CHAPTER I

INTRODUCTION

I. Rationale of the Design Project

In the Philippines, fossil fuels (coal, oil and natural gas) and renewable energy (geothermal, hydropower, wind, biomass and solar) are the sources of power being gene rated and sold to the electric companies by generation companies.According to Department of Energy (DOE), as of December 31, 2016, the total installed capacity generated by power plants in the Philippines is 21,423 MW. 7,419 MW of it is generated by coal-fired power plants, 3,616 MW comes from oil-based power plants and 3,431 MW comes from natural gas power plants. Geothermal, hydroelectric, wind, biomass and solar power plants account for 1,916 MW, 3,618 MW, 427 MW, 233 MW and 765 MW, respectively.

National Grid Corporation of the Philippines (NGCP) currently manages and operates the power transmission system in the Philippines. Electrical grids are classified into two – namely, on-grid and off-grid. On-grid refers to the three major main grids in the country – each one for Luzon, Visayas and Mindanao. As for the off-grid, these are the areas not connected to the main grid.As of August 2015, a total of 31,038 MVA substation capacities and 20,073 circuit-km are accounted in NGCP's asset. According to DOE's list of existing power plants as of December, 31, 2016, Luzon currently has an installed capacity of 14,977 MW, Visayas has 3,284 MW and 3,162 MW for Mindanao. Its dependable capacity are 13,600 MW for Luzon, 2,813 MW for Visayas and 2,684 MW for Mindanao.

Power distribution system in the Philippines is operated by distribution utilities which includes electric cooperatives, privately-owned, government-owned and local government unit utilities. Currently, Manila Electric Corporation (MERALCO) is the largest electric distribution company in the Philippines. Based on its annual report in 2015, it is servicing a total of 5,784,000 customers consuming 37,124,000 GWh of electricity sales.

Power utilization in the Philippines is based on its electricity consumption. Electricity consumption includes electricity sales (residential, commercial, industrial and others) plus the own-use consumption of power plant and systems loss. Based on the Power Situation Highlights for January – June 2016 released by Electric Power Industry Management Bureau (EPIMB), Philippines consumes a total of 38,009,696 MWh – 76% for electricity sales, 13% for own-use and 11% for system loss. As for the electricity sales, 10,325,888 MWh (27%) is consumed by the residential sector while 8,551,502 (23%) for commercial, 8,418,568 (22%) for industrial sectors and 1,681,287 for any other sector.

Considering the information above and the fact that Philippines is a fast-developing country, emerging needs when it comes to energy sector shall be highly prioritized. For that reason, so as to come up with improvements in this field,the researchers are to design a coal-fired power plant located in Brgy. Mayao Castillo, Lucena City, Quezon.

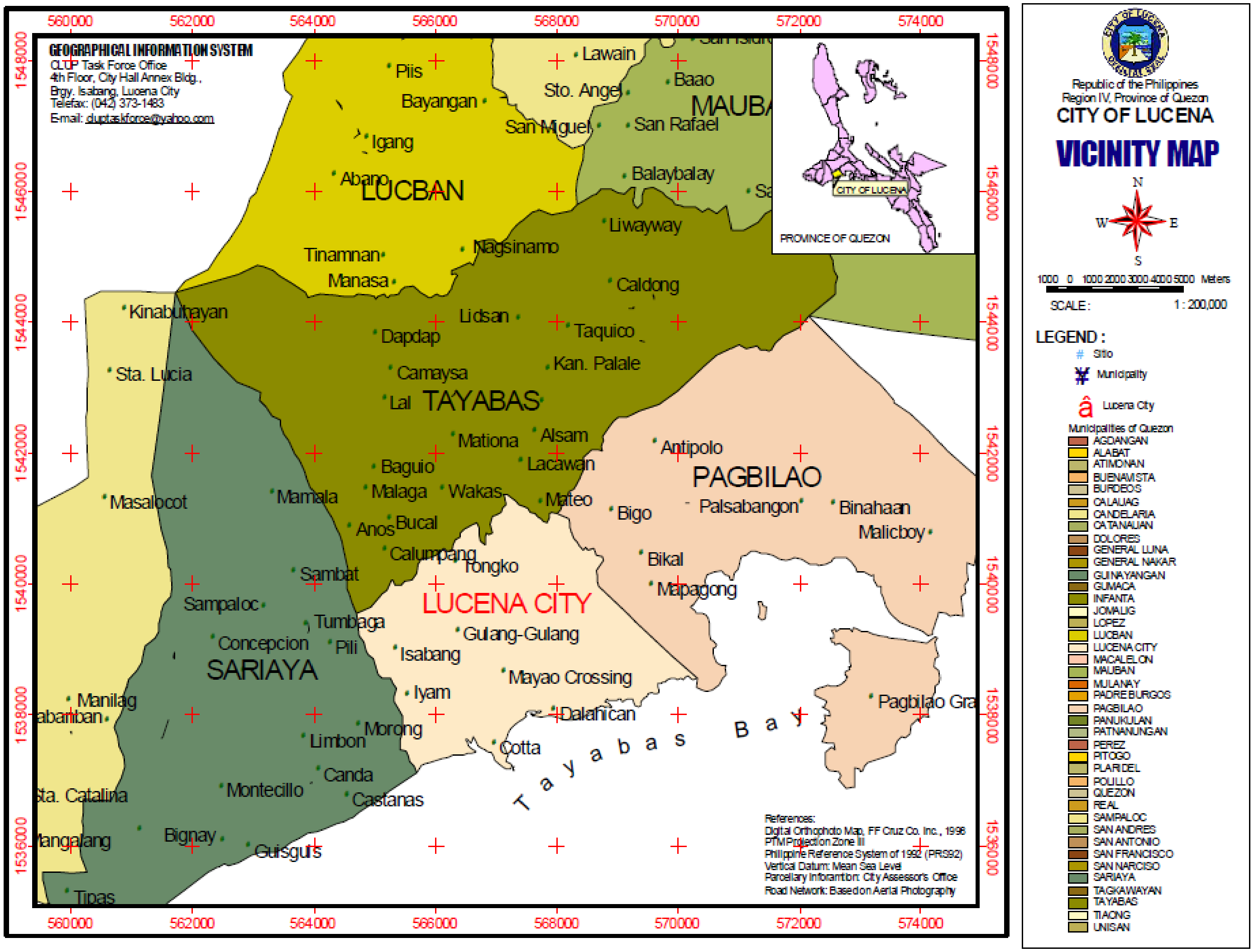

Figure 1. Vicinity Map of Quezon Province

II. Site Location

Lucena City, the capital of Quezon Province, is approximately 137 km, SEof the Manila via the Maharlika Highway. Its geographical coordinates is located at 13°56’ N latitude and 121°37 E longitude. Lucena is bounded on the north and northeast by the Municipality of Pagbilao, on the south and southeast by the Tayabas Bay, on thesouthwest by the Municipality of Sariaya, and onthe northwestby the City of Tayabas. Figure 1 shows the vicinity map of Quezon Province.

Initially, availability of land, water and fuel resources are the factors considered for the selection of site location for a coal-fired power plant.

The land area of Lucena City is 8,402.66 ha – 2,087.11 ha (25%) is for urban use while 6315.55 ha (75%) is for agricultural use. It is composed of 33 barangays, 11 of which are classified as urban; 6 as suburban, 11 as rural and 5 as coastal barangays. The 5 coastal barangays are:

1. Brgy. Barra (99.51 ha)
2. Brgy. Dalahican (330.53 ha)
3. Brgy. Mayao Castillo (764.15 ha)
4. Brgy. Ransohan (64.35 ha)
5. Brgy. Talao-talao (199.26 ha)

Figure 2 shows the barangay boundary map of Lucena City.

Each of the barangays in Lucena City are classified according to their use as shown in Figure 3. The coastal barangays are classified as follows:

1. Brgy. Barra (cocal area)
2. Brgy. Dalahican (cocal, fish pond, occupied residential area)
3. Brgy. Mayao Castillo (irrigated and unirrigated rice land)
4. Brgy. Ransohan (cocal area)
5. Brgy. Talao-talao (cocal, fish pond, occupied residential area)

As for the fuel resources, which is the coal, BatanCoal Resources Corporation (BCRC) in Liguan, Rapu-Rapu Island, Albay and Filsystems, Inc. in Bulalacao, Oriental Mindoro are the nearest coal operatorsin Lucena City, presently under its development and production operations. The mode of transportation of the coal resources can be by road tankers or ships.

Considering the information above, the researchers selected Brgy. Mayao Castillo as the best suitable site location for a coal-fired power plant. In addition, electricity is currently provided by MERALCO, having 8 substations and distribution lines connected in Lucena City. As of December 2014, MERALCO has an electric sale of about 16M from 50,289 accounts/servicesin Lucena City only. Taking advantage of this situation can be a contributing factor for the selection of this site.

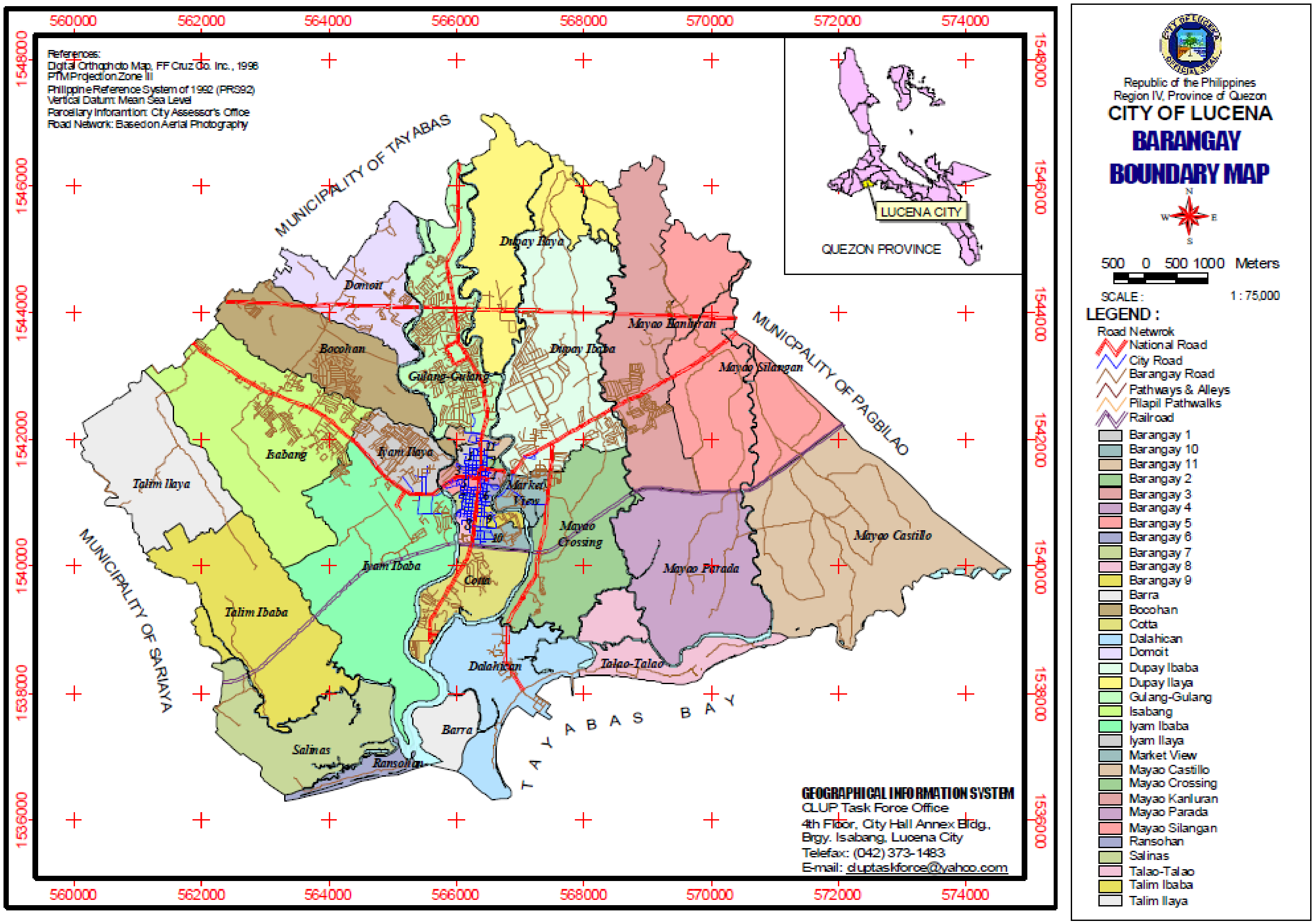

Figure 2. Barangay Boundary Map

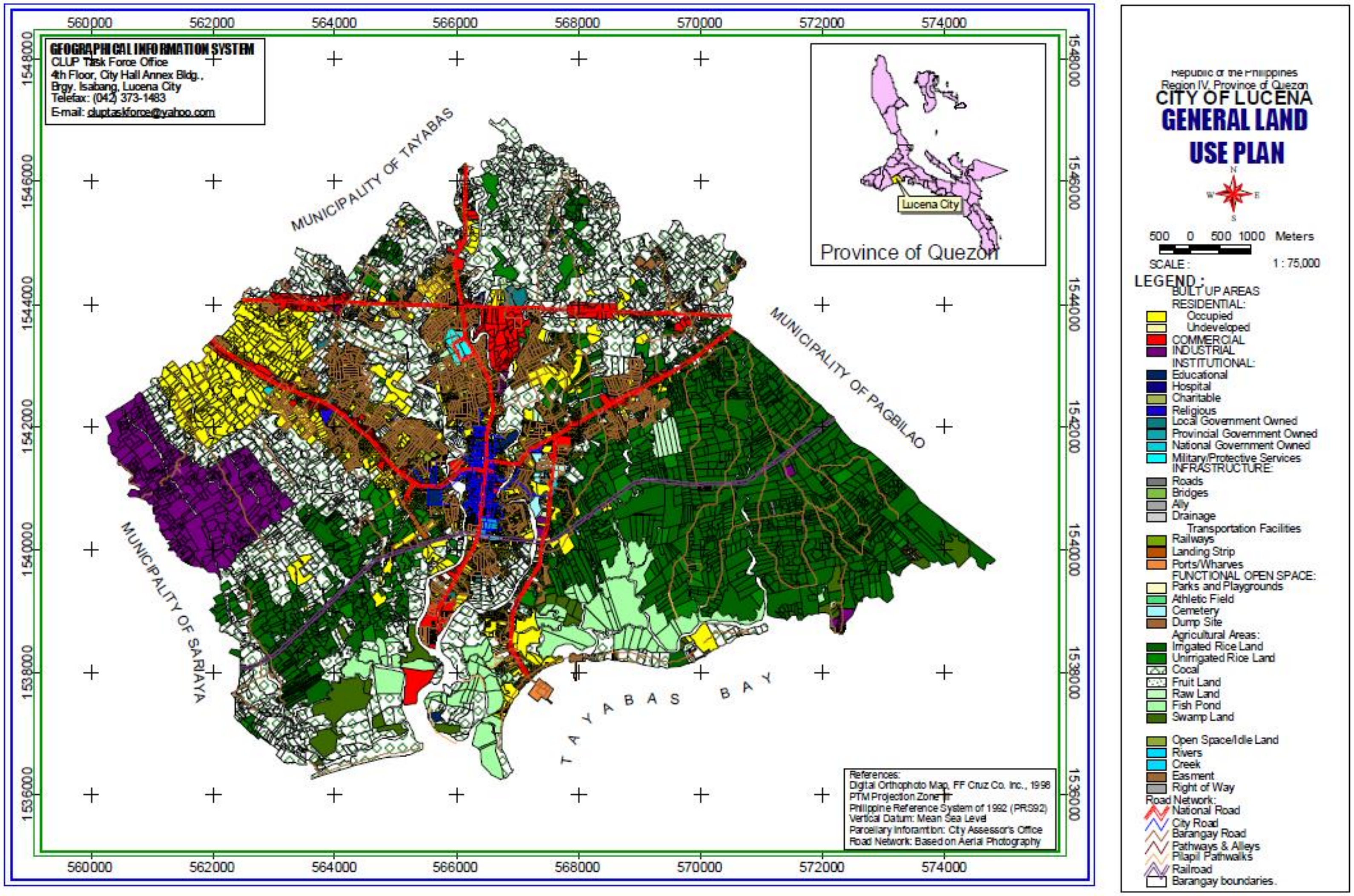

Figure 3. Barangay Boundary Map

III. Load Demand Survey for the Target Customers

Load demands from different electric cooperatives (BATELEC I, BATELEC II, QUEZELCO I and QUEZELCO II) and local government-owned utility (IEEC) that services several cities and municipalities were collected as reference for the chosen target customers. The actual load demands of the selected distribution utilities, from 2009 to 2016,are shown in the table below.

Table 1

Actual Load Demands (MW), 2009-2016

Year	Distribution Utilities				
	BATELEC I	BATELEC II	IEEC	QUEZELCO I	QUEZELCO II
2009	44.0	117.0	3.4	24.0	3.7
2010	45.3	113.6	3.3	24.0	3.7
2011	46.8	117.1	3.4	24.4	3.8
2012	48.4	119.1	3.4	25.1	3.9
2013	50.5	123.0	3.5	26.5	4.1
2014	52.8	125.4	3.5	27.1	4.3
2015	55.2	129.0	3.5	28.5	4.5
2016	57.3	130.8	3.5	30.3	4.7

Source: DOE

As for the target customers, municipalities and cities serviced by BATELEC I (Municipalities of Agoncillo, Balayan, Calaca, Calatagan, Lemery, Lian, Nasugbu, San Luis, San Nicolas, Sta. Teresita, Taal and Tuy), BATELEC II (Cities of Lipa and Tanauan and Municipalities of San Jose, Alitagtag, Cuenca, Mataas na Kahoy, Padre Garcia, Taysan, Lobo, Mabini, Tingloy, Malvar, Talisay, Laurel, Balete, Rosario and San Juan) and IEEC (Municipality of Ibaan) in Batangas province are included as shown in the Figure 4.

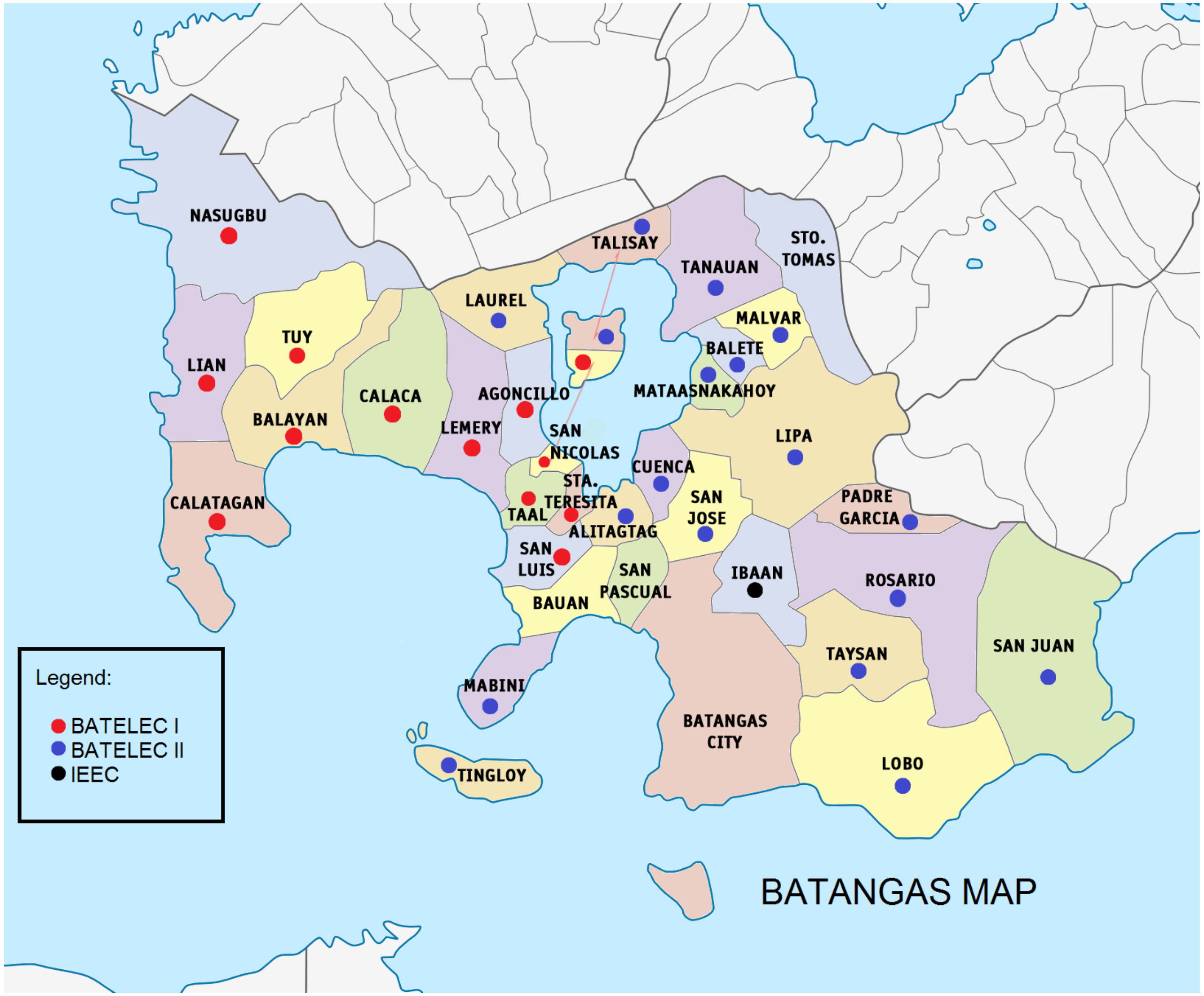

Figure 4. Target Customers in Batangas Province

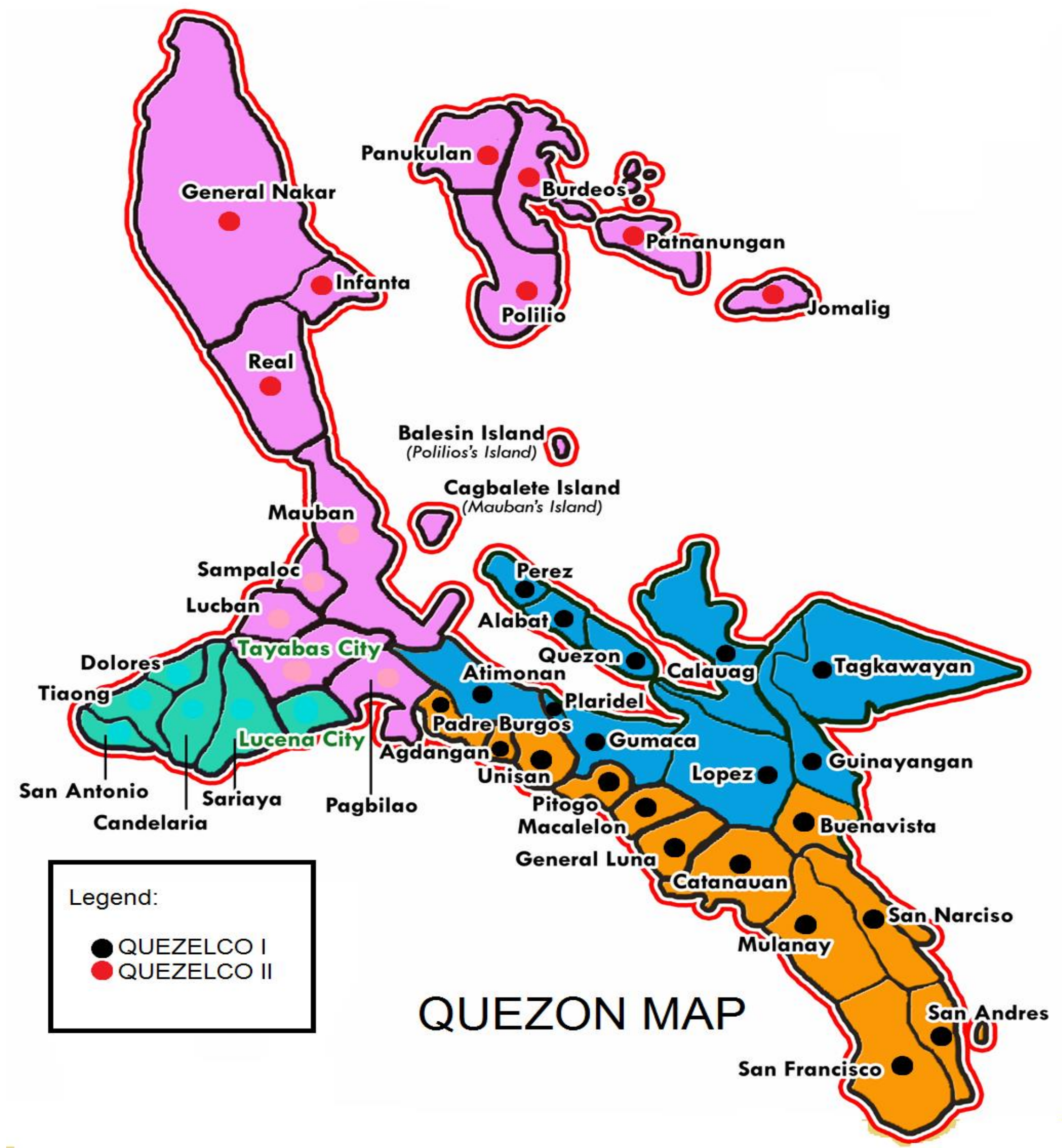

Figure 5. Target Customers in Quezon Province

In addition, as shown in Figure 5, for Quezon province, QUEZELCO I (Municipalities of Pitogo, Macalelon, Gen. Luna, Catanauan, Mulanay, San Narciso, San Francisco, Buenavista, San Andres, Unisan, Agdangan, Padre Burgos, Atimonan, Gumaca, Lopez, Plaridel, Alabat, Quezon, Perez, Calauag, Guinayangan, Tagkawayan and Del Gallego) and QUEZELCO II (Municipalities of Infanta, Real, Gen. Nakar, Polillo, Burdeos, Panukulan, Patnanungan and Jomalig) are included.

Load projection for 10 years, from 2017 to 2026, as shown below, was calculated using the moving-average forecasting technique.

Table 2

Load Projection (MW), 2017-2026

Year	Distribution Utilities				
	BATELEC I	**BATELEC II**	**IEEC**	**QUEZELCO I**	**QUEZELCO II**
2009	44.0	117.0	3.4	24.0	3.7
2010	45.3	113.6	3.3	24.0	3.7
2011	46.8	117.1	3.4	24.4	3.8
2012	48.4	119.1	3.4	25.1	3.9
2013	50.5	123.0	3.5	26.5	4.1
2014	52.8	125.4	3.5	27.1	4.3
2015	55.2	129.0	3.5	28.5	4.5
2016	57.3	130.8	3.5	30.3	4.7
2017	50.0	121.9	3.4	26.2	4.1
2018	50.8	122.5	3.4	26.5	4.1
2019	51.5	123.6	3.5	26.8	4.2
2020	52.1	124.4	3.5	27.1	4.2
2021	52.5	125.1	3.5	27.4	4.3
2022	52.8	125.3	3.5	27.5	4.3
2023	52.8	125.3	3.5	27.6	4.3
2024	52.5	124.9	3.5	27.4	4.3
2025	51.9	124.1	3.5	27.1	4.2
2026	**52.1**	**124.4**	**3.5**	**27.2**	**4.2**
AVERAGE DEMAND (MW), 2026 = 211.4					

IV. Calculation of the Plant Capacity

The data gathered used in the 10-year projection of the load demand shown in Table 2, the following calculations will be used to determine the plant capacity.

A. Maximum Demand

Determining the maximum demand will be the first step for the calculation of the plant capacity using the equation below.

$$\text{Maximum Demand (MW)} = \frac{\text{Average Load (MW)}}{\text{Load Factor (\%)}}$$

The average load (MW) will be used in the calculation is from the 10th year of the load projection, which is 2026. As for the load factor, different distribution utilities uses their own load factor based on the demands in their service.

Table 3 shows the tabulated data and calculated results for the maximum demand of the target distribution utilities customer.

Table 3

Maximum Demand (MW), 2026

	BATELEC I	BATELEC II	IEEC	QUEZELCO I	QUEZELCO II
Load Factor	April 2014 73.3%	March 2016 66.63%	August 2013 87.85%	June 2014 71.14%	July 2014 40.78%
Average Load Demand, 2026 (MW)	52.1	124.4	3.5	27.2	4.2
Max. Demand, 2026 (MW)	71.1	186.7	4.0	38.2	10.3
					MAXIMUMDEMAND (MW) = 310.3

B. Plant Capacity

To determine the total plant capacity of the plant, reserved capacity and system's losses should be taken into consideration.

Assuming a reserved capacity of 20% and a maximum value of 10% for the system's losses, the calculation is shown below.

$$\text{Plant Capacity} = (\text{Maximum Demand})(1 + \%R + \%SL)$$

$$\text{Plant Capacity} = (310.3\ \text{MW})(1 + 20\% + 10\%)$$

$$\text{Plant Capacity} = 403.39\ \text{MW} \approx 405\ \text{MW}$$

The design of coal-fired power plant will have a capacity of 405 MW and will be located in Brgy. Mayao Castillo, Lucena City, Quezon.

CHAPTER II

DESIGN OBJECTIVES

The main thrust of this project is to design a coal-fired steam power plant that will have a capacity of at least 400 MW which will be located in Lucena city, Quezon, Philippines. Specifically, it aims to:

1. Present three possible design options of a coal fired power plant having its specifications of the system and having an analysis of the performance of the plant considering:
    1.1. Energy Balance
    1.2. Thermal Efficiency
    1.3. Work Output
2. Determine the technical specifications, having in reference to the required standards (namely PSME, ASTM or ASME) to be used in the design and the design tradeoffs. These design tradeoffs will evaluate the three design options from multiple realistic constraints. The best design option will be selected through design philosophies with either Worst Case Design or Pareto Optimum.
3. Show an economic analysis of each design option that presents calculations on the following economic parameters:
    3.1. Present Net Worth Value
    3.2. Payback Period
    3.3. Rate of Return/Rate of Investment

4. Prepare an environmental impact assessment to determine its social-economical benefits for each design option. Health and safety requirements shall be considered in the overall phases of the design project.
5. Establish a detailed project construction execution plan of the design option that will be selected from the parameters given.

CHAPTER III

TECHNICAL ASPECTS

Considerations of three different design trade-offs are to be evaluated as an initial step in the determination of the best design option. This includes the selection of equipment

Design Option No. 1

Considering the situation in a simple rankine cycle, moisture content increases during the late stages of the expansion process. Moisture is harmful to the blades of the turbine. It causes erosion and caviation of the turbine blades.

How can we take advantage of the increased efficiencies at higher boiler pressures without facing the problem of excessive moisture at the final stages of the turbine? Expansion of the steam in the turbine in two stages and reheating it in between minimizes the moisture content and at the same time increases the efficiency of the cycle.

And in this design option, a reheat rankine cycle is considered. Schematic layout and T-s diagram of the cycle is shown in the figures on the next pages.

1. Specifications of the Selected Equipment

Equipment for a reheat rankine cycle are selected to determine the initial parameters to be used in the calculation of the plant performance. Technical specifications of each equipment are shown below.

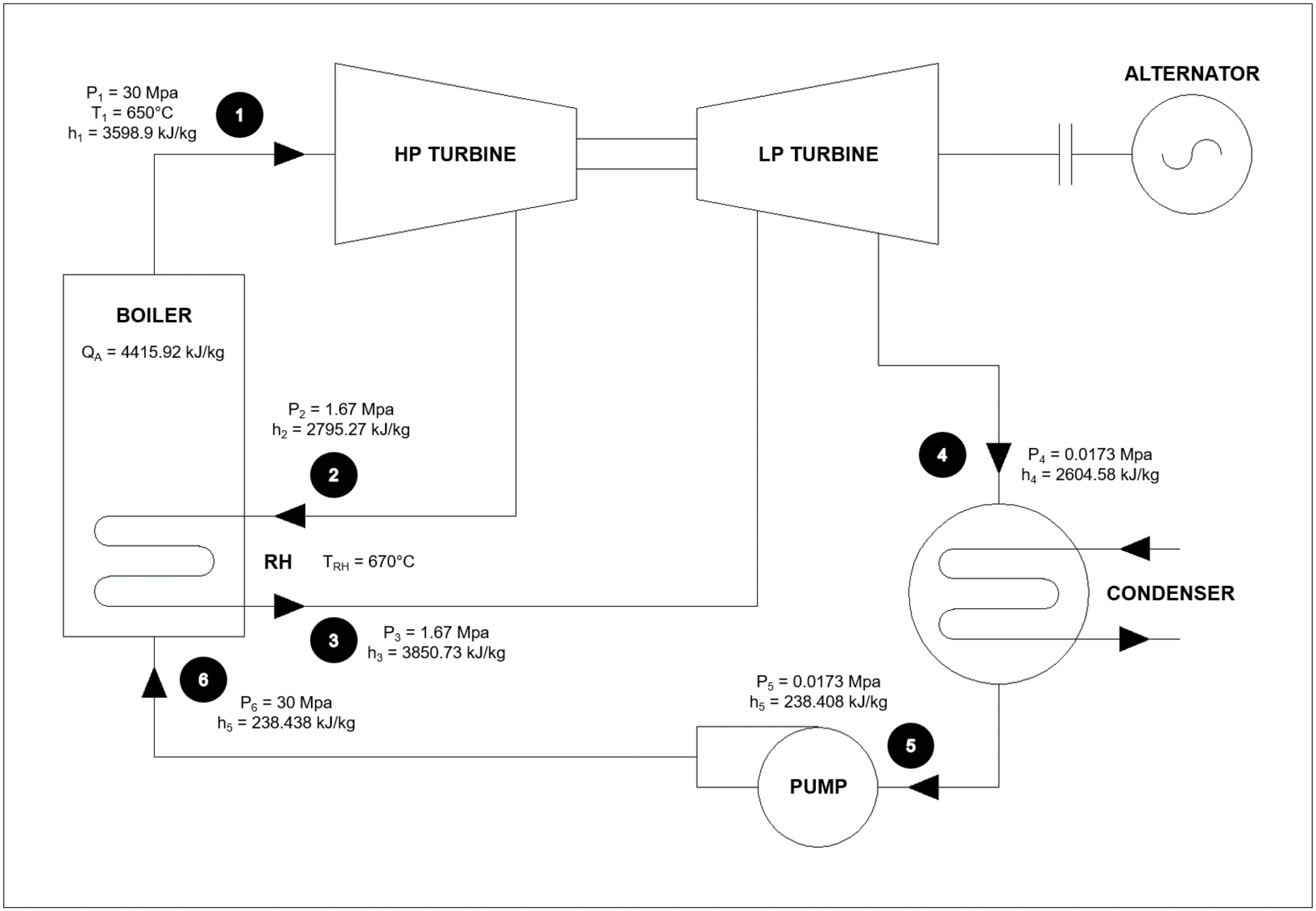

Figure 6. Schematic Layout of Design Option No. 1

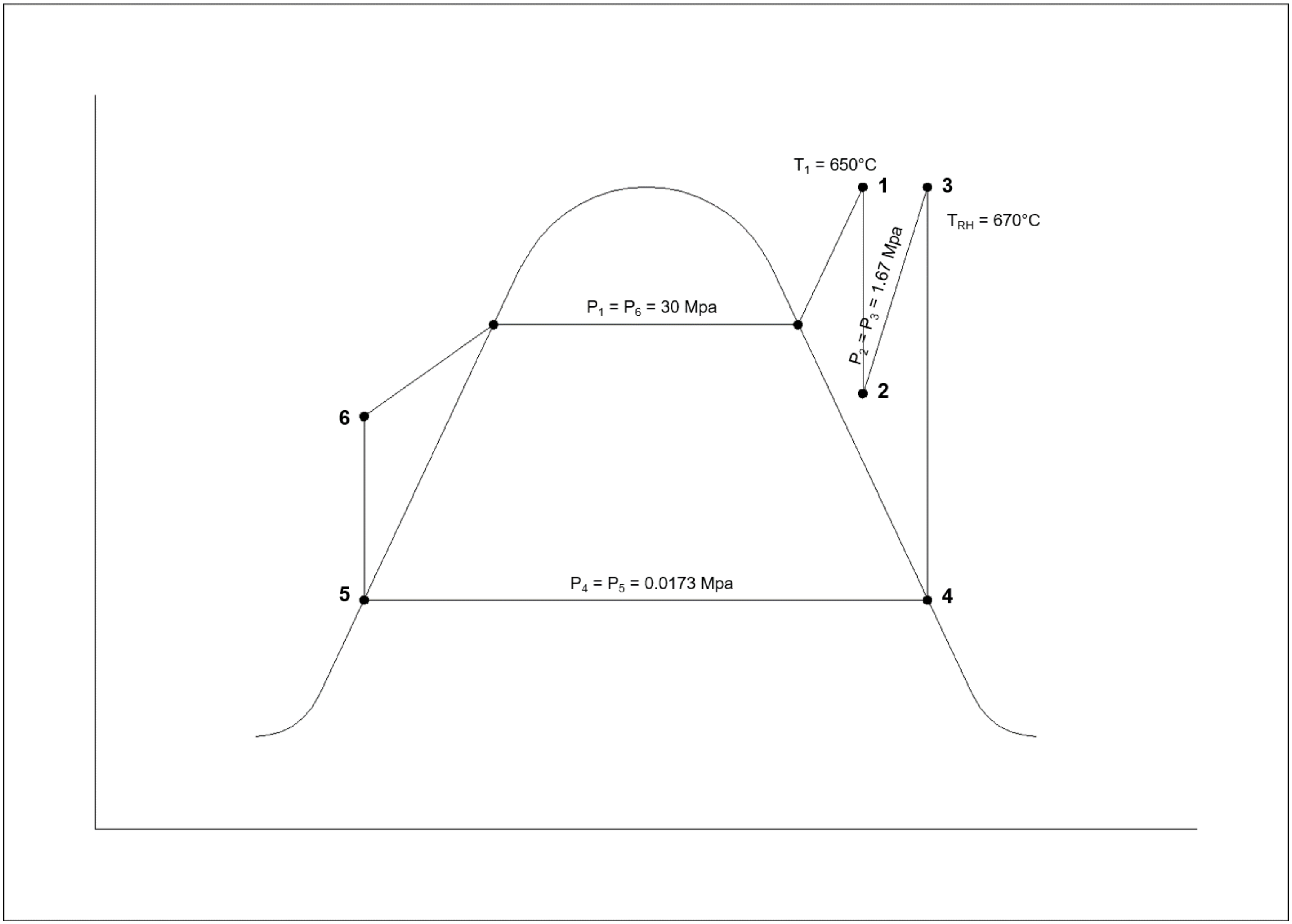

Figure 7. T-s Diagram of Design Option No. 1

TURBINE

Brand/Model: GE/STF-D1050 SRH

Main Steam: 330 bar (4786 psi), 650°C (1200°F)

Reheat Temperature: 670°C (1238°F)

GENERATOR

Brand/Model: GE/TOPAIR

Efficiency: Up to 98.9%

Considering the selected equipment, the following operating conditions are to be used. Followed by this, is the calculation of the operating conditions of the other equipment. After the calculation, equipment that will best suit the calculated operating conditions will be selected.

Steam Pressure: P_1 = 330 bar = 33 MPa

Steam Temperature: T_1 = 650°C

Reheat Temperature: T_{RH} = 670°C

At point 1:

$h_1 = h$ @ T_1 = 650°C, P_1 = 33 MPa

$\mathbf{h_1 = 3575.5\ kJ/kg}$

$s_1 = s$ @ T_1 = 650°C, P_1 = 33 MPa

$\mathbf{s_1 = 6.3417\ kJ/kg.K}$

At points 1-2:

$\mathbf{s_1 = s_2 = 6.3417 kJ/kg.K}$

$s_2 = s_g$ @ P_2 = ? = 6.3417kJ/kg.K

From Steam Table, Table 2, at s_2 = 6.3417kJ/kg.K:

s	h	P
6.3502 kJ/kg.K	2799.0kJ/kg	1.95 MPa
6.3417kJ/kg.K	h_2	P_2
6.3409 kJ/kg.K	2799.5 kJ/kg	2 MPa

By interpolation,

h_2 = 2799.456989 kJ/kg

P_2 = 1.995698925 MPa = 2 MPa

At point 3:

$P_2 = P_3$ = 2 MPa

From Steam Table, Table 3, at $T_{RH} = T_3$= 670°C, P_3 = 2 MPa:

	1.95 MPa	2 MPa	2.05 Mpa
660°C	3826.2kJ/kg		3825.5kJ/kg
670°C	x	h_3	y
680°C	3871.8kJ/kg		3871.2kJ/kg

By interpolation,

x = 3849kJ/kg

y = 3848.35kJ/kg

Then,

h_3 = 3848.675 kJ/kg

From Steam Table, Table 3, at T_{RH}= T_3 = 670°C, P_3 = 2 MPa:

	1.95 MPa	2 MPa	2.05 Mpa
660°C	7.8646kJ/kg.K		7.8410kJ/kg.K
670°C	x	s_3	y
680°C	7.9130kJ/kg.K		7.8895kJ/kg.K

By interpolation,

x = 7.8888 kJ/kg.K

y = 7.86525kJ/kg.K

Then,

s_3 = 7.877025 kJ/kg.K

At point 4:

s_3 = s_4 = 7.877025 kJ/kg.K

s_4 = s_g @ P4 = ? = 7.877025kJ/kg.K

s	h	P
7.8916 kJ/kg.K	2611.6 kJ/kg	0.021 MPa
7.877025kJ/kg.K	h_4	P_4
7.8756kJ/kg.K	2613.3kJ/kg	0.022 MPa

h_4 = 2613.148594 kJ/kg

P_4 = 0.0219109375 MPa = 0.022MPa

At point 5:

$\mathbf{P_4 = P_{condenser} = P_5 = 0.022MPa}$

$h_5 = h_f$ @ $P_5 = 0.022$ MPa

$\mathbf{h_5 = 260.08\ kJ/kg}$

$v_5 = v_f$ @ $P_5 = 0.022$ MPa = ?

$\mathbf{v_5 = 1.0178x10^{-3}\ m^3/kg}$

At point 6:

$W_{pump} = v_5(P_1 – P_{condenser})$

$W_{pump} = (1.0178x10^{-3}m^3/kg)(33\ MPa – 0.022\ MPa)$

$\mathbf{W_{pump} = 0.0000335650084kJ/kg}$

Also,

$W_{pump} = h_6 – h_5$

$0.0000335650084\ kJ/kg = h_6 – 260.08\ kJ/kg$

$\mathbf{h_6 = 260.0800336\ kJ/kg}$

Computing for the actual enthalpies (h_2', h_4'),

Typical isentropic efficiencies of a turbine ranges from 70% to 90%. For this calculation, use n_i = 90%.

$n_i = (h_1 – h_2')/(h_1 – h_2)$

$90\% = (3575.5\ kJ/kg – h_2')/(3575.5\ kJ/kg – 2799.456989\ kJ/kg)$

$\mathbf{h_2' = 2877.061208\ kJ/kg}$

$n_i = (h_3 - h_4')/(h_3 - h_4)$

$90\% = (3848.675\ kJ/kg - h_4')/(\ 3848.675\ kJ/kg - 2613.148594\ kJ/kg)$

$\mathbf{h_4' = 2736.701235\ kJ/kg}$

Computing for the net work (W_{net}),

$W_{net} = W_t - W_{pump}$

where,

$W_t = (h_1 - h_2') + (h_3 - h_4')$

$W_t = (3575.5 - 2877.061208) kJ/kg + (3848.675 - 2736.701235) kJ/kg$

$\mathbf{W_t = 1810.412557\ kJ/kg}$

Then,

$W_{net} = W_t - W_{pump}$

$W_{net} = 1810.412557\ kJ/kg - \mathbf{0.0000335650084} kJ/kg$

$\mathbf{W_{net} = 1810.412523\ kJ/kg}$

Computing for heat added(Q_A),

$Q_A = (h_1 - h_6) + (h_3 - h_2')$

$Q_A = (3575.5 - 260.113565)\ kJ/kg + (3848.675 - 2877.061208) kJ/kg$

$\mathbf{Q_A = 4287.000227\ kJ/kg}$

Computing for thermal efficiency (n_{th}),

$n_{th} = W_{net}/Q_A$

n_{th} = (1810.412523 kJ/kg)/(4287.000227 kJ/kg)

n_{th} = 0.4222950539(100%)

n_{th} = 42.23028756%

Computing for the total mass the steam entering the turbine (m_t),

Based on Efficiency Assessment of Steam Turbine, values for mechanical efficiency are in the range of 98.63% and 99.06%, use n_m = 99.06%.

Considering GE's TOPAIR, use n_g = 98.9%.

Considering the proposed plant capacity of 405 MW,

$P_{out} = (m_t)(W_{net})(n_m n_g)$

405 MW = (m_t)(1810.412523 kJ/kg)(99.06%)(98.9%)

m_t = 228.3404554 kg/s = 822 MT/hr

Design Option No. 2

In a rankine cycle, the first part of the heat-additionprocess in the boiler takes place at relatively low temperatures.This lowers the average heat addition temperature and thus the cycle efficiency.

To remedy this shortcoming, we look for ways to raise the temperature of the liquid leaving the pump (called the feedwater) before it enters the boiler. One such possibility is to transfer heat to the feedwater from the expanding steam in a counterflow heat exchanger built into the turbine, that is, to use regeneration. This solution is also impractical because it is difficult to design such a heat exchanger and because it would increase the moisture content of the steam at the final stages of the turbine.

A practical regeneration process in steam power plants is accomplished byextracting, or “bleeding,” steam from the turbine at various points. This steam, which could have produced more work by expanding further in the turbine, is used to heat the feedwater instead. The device where the feedwater is heated by regeneration is called a regenerator, or a feedwater heater (FWH).

A feedwater heater is basically a heat exchanger where heat is transferred from the steam to the feedwater either by mixing the two fluid streams (open feedwater heaters) or without mixing them (closed feedwater heaters).

And in this design option, a double-stage regenerative rankine cycle, using open feedwater heaters, is considered. Schematic layout and T-s diagram of the cycle is shown in the figures on the next pages.

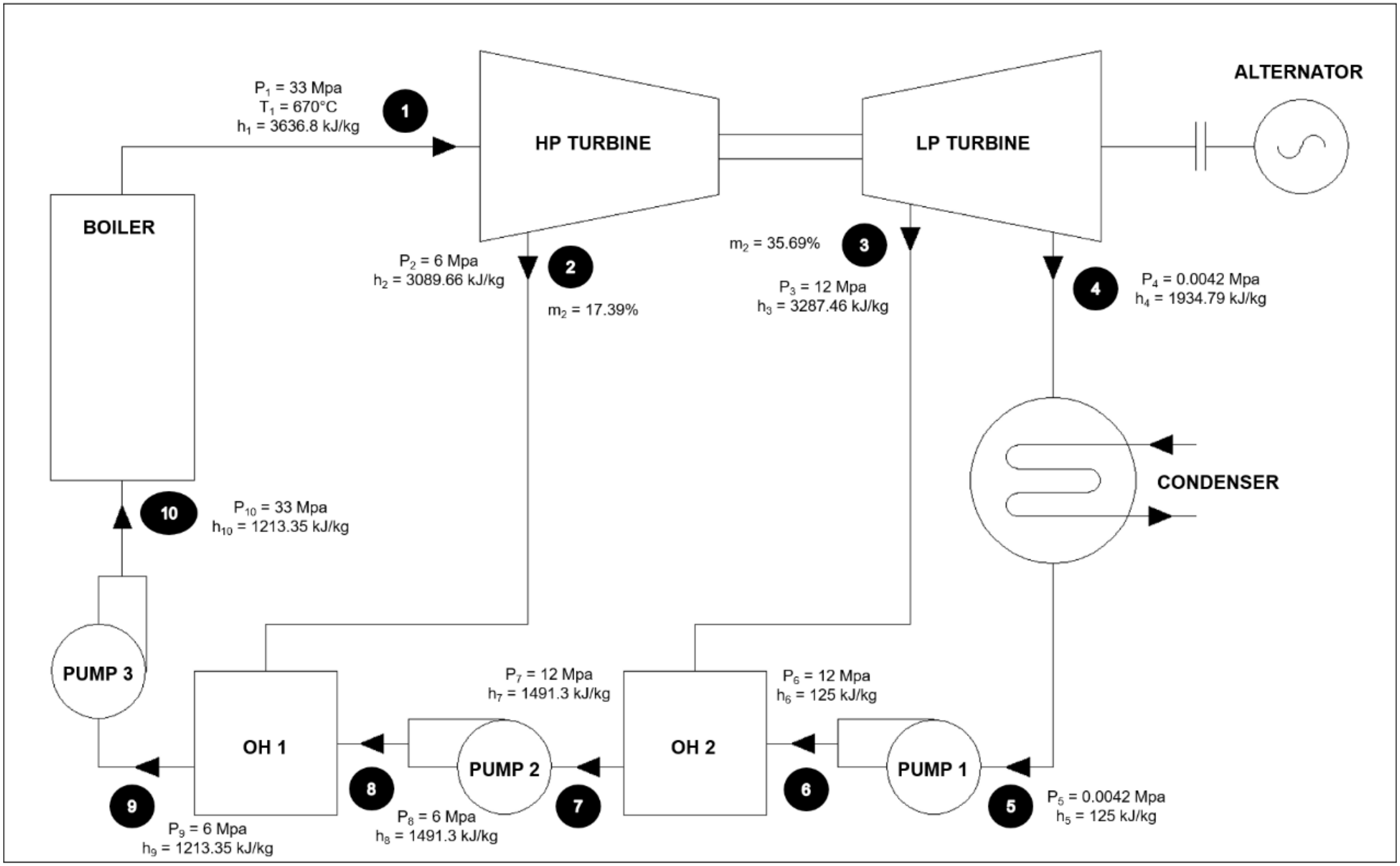

Figure 8. Schematic Layout of Design Option No. 2

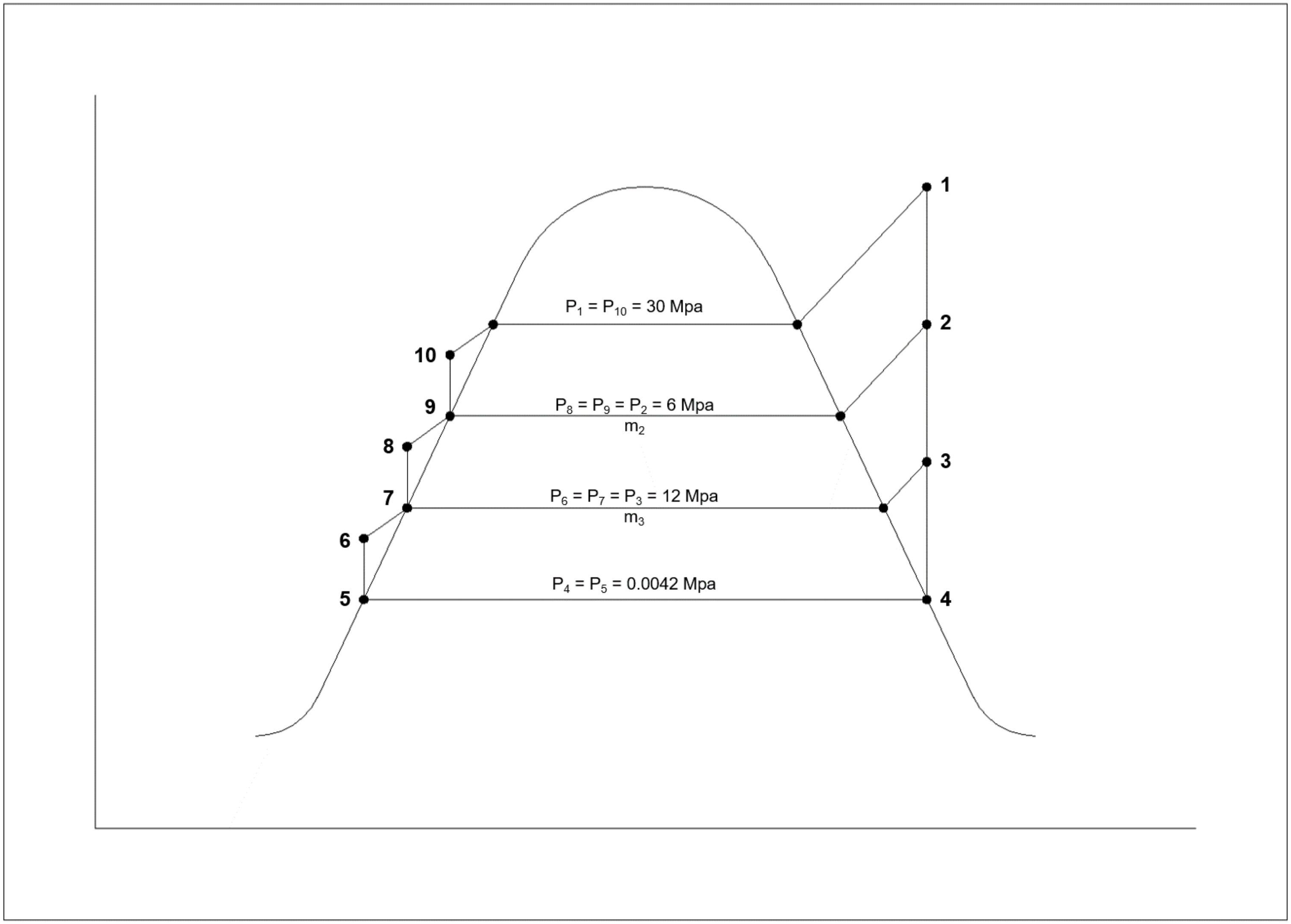

Figure 9. T-s Diagram of Design Option No. 2

1. Specifications of the Selected Equipment

Equipment for a regenerative rankine cycle are selected to determine the initial parameters to be used in the calculation of the plant performance. Technical specifications of each equipment are shown below.

TURBINE

Brand/Model: GE/STF-D1050

Main Steam: 330 bar (4786 psi), 650°C (1200°F)

GENERATOR

Brand/Model: GE/TOPAIR

Efficiency: Up to 98.9%

OPEN FEED WATER HEATERS

Brand/Model: CHEM Process Systems/LP and HP Feedwater Heaters

Pressure Ratings: LPFH: 400 to 1500 psi

HPFH: 1500 to 4800 psi

CONDENSER

Brand/Model: GE/Church Window and Daisy

Pressure Ratings: 40 mbar

Considering the selected equipment, the following operating conditions are to be used. Followed by this, is the calculation of the operating conditions of the other equipment. After the calculation, equipment that will best suit the calculated operating conditions will be selected.

Steam Operating Pressure: P_1 = 330 bar = 33 MPa

Steam Operating Temperature: T_1 = 650°C

LPFH Operating Pressure: P_{LPFH} = 400 psi = 2.7579 = 2.8 MPa

HPFH Operating Pressure: P_{HPFH} = 1500 psi = 10.34214 = 10.4 MPa

Condensing Pressure: 42 mbar

At point 1:

h_1 = h @ T_1 = 650°C, P_1 = 33 MPa

h_1 = 3575.5 kJ/kg

s_1 = s @ T_1 = 650°C, P_1 = 33 MPa

s_1 = 6.3417 kJ/kg.K

At point2:

$s_1 = s_2 = s_3 = s_4$ =6.3417kJ/kg.K

From Steam Table, Table 3, at $P_{HPFH} = P_2$ = 10.4 MPa

s	h
6.3147 kJ/kg.K	3177.9kJ/kg
6.3417kJ/kg.K	h_2
6.3550 kJ/kg.K	3206.5 kJ/kg

By interpolation,

h_2 = 3197.06129 kJ/kg

At point 3:

From Steam Table, Table 3, at $P_{LPFH} = P_3$ = 2.8 MPa

s	h
6.3343 kJ/kg.K	2865.7kJ/kg
6.3417kJ/kg.K	h_3
6.3887 kJ/kg.K	2894.4 kJ/kg

By interpolation,

h_3 = 2869.604044 kJ/kg

At point 4:

$s_4 = s_f + xs_{fg}$

where,

s_f @ 0.0042 Mpa = 0.4343 kJ/kg.K

s_{fg} @ 0.0042 Mpa = 8.0229 kJ/kg.K

Then,

6.4073 kJ/kg.K = 0.4343 kJ/kg.K + x(8.0229kJ/kg.K)

x = 0.7444938863

$h_4=h_f + xh_{fg}$

where,

h_f @ 0.0042Mpa = 125 kJ/kg

h_{fg} @ 0.0042 Mpa= 2430.9 kJ/kg

Then,

h_4 = 125kJ/kg + 0.7444938863(2430.9kJ/kg)

h_4 = 1934.790188 kJ/kg

At point 5:

P_4= $P_{condenser}$ = P_5= 0.0042MPa

h_5 = h_f@ P_5 = 0.0042 Mpa

h_5 = 125 kJ/kg

v_5 = v_f @ P_5 = 0.0042 MPa

v_5 = 1.0043x10^{-3} m^3/kg

At point 5-6:

W_{pump} = v_5(P_3 – $P_{condenser}$)

W_{pump} = (1.0043x10^{-3}m^3/kg)(2.8 MPa – 0.0042 MPa)

W_{pump} = 0.00000280782194 kJ/kg

Also,

W_{pump}= h_6 – h_5

0.00000280782194 kJ/kg = h_6 – 125 kJ/kg

h_6 = 125.0000028 kJ/kg

At point 7:

P_{LPFH} = P_3= P_7 = 2.8 MPa

$h_7 = h_f @ P_7 = 2.8$ Mpa

$\mathbf{h_7 = 990.59\ kJ/kg}$

$v_7 = v_f @ P_7 = 2.8MPa$

$\mathbf{v_7 = 1.2090x10^{-3}\ m^3/kg}$

At point 7-8:

$W_{pump} = v_7(P_2 - P_3)$

$W_{pump} = (1.2090x10^{-3}m^3/kg)(10.4\ MPa - 2.8\ MPa)$

$\mathbf{W_{pump} = 0.0000091884\ kJ/kg}$

Also,

$W_{pump} = h_8 - h_7$

$0.00000931884\ kJ/kg = h_8 - 990.59\ kJ/kg$

$\mathbf{h_8 = 990.5900092\ kJ/kg}$

At point 9:

$\mathbf{P_{HPFH} = P_2 = P_9 = 10.4\ MPa}$

$h_9 = h_f @ P_9 = 10.4$ Mpa

$\mathbf{h_9 = 1424.76\ kJ/kg}$

$v_9 = v_f @ P_9 = 10.4MPa$

$\mathbf{v_9 = 1.4667x10^{-3}\ m^3/kg}$

At point 7-8:

$W_{pump} = v_9(P_1 – P_2)$

$W_{pump} = (1.4667x10^{-3}m^3/kg)(33\ MPa – 10.4\ MPa)$

$\mathbf{W_{pump} = 0.00003314742\ kJ/kg}$

Also,

$W_{pump}= h_{10} – h_9$

$0.00003314742\ kJ/kg = h_{10} – 1424.76\ kJ/kg$

$\mathbf{h_{10} = 1424.760033\ kJ/kg}$

Computing for the total pump work (W_p),

$W_p = W_{pump,5\text{-}6} + W_{pump,7\text{-}8} + W_{pump,9\text{-}10}$

$W_p = (0.00000280782194 + 0.0000091884 +0.00003314742)\ kJ/kg$

$\mathbf{W_p = 0.00004514364194\ kJ/kg}$

Computing for the actual enthalpies (h_4'),

Typical isentropic efficiencies of a turbine ranges from 70% to 90%. For this calculation, use n_i = 90%.

$n_i = (h_1 – h_4')/(h_1 – h_4)$

$90\% = (3575.5\ kJ/kg – h_4')/(3575.5\ kJ/kg – 2613.148594\ kJ/kg)$

$\mathbf{h_4' = 2709.383735\ kJ/kg}$

Computing for the net work (W_{net}),

$W_{net} = W_t – W_{pump}$

where,

$W_t = (h_1 – h_4')$

W_t =(3575.5 – 2709.383735)kJ/kg

W_t = 866.1162654 kJ/kg

Then,

$W_{net} = W_t – W_{pump}$

W_{net} = 866.1162654 kJ/kg **–** 0.000045143641 94 kJ/kg

W_{net} = 866.1162203 kJ/kg

Computing for heat added(Q_A),

$Q_A = (h_1 – h_{10})$

Q_A = (3575.5 – 1424.760033) kJ/kg

Q_A = 2150.739967 kJ/kg

Computing for thermal efficiency (n_{th}),

$n_{th} = W_{net}/Q_A$

n_{th} = (886.1162203 kJ/kg)/(2150.739967 kJ/kg)

n_{th} = 0.402706154(100%)

n_{th} = 40.2706154%

Computing for the total mass the steam entering the turbine (m_t),

Based on Efficiency Assessment of Steam Turbine, values for mechanical efficiency are in the range of 98.63% and 99.06%, use n_m = 99.06%.

Considering GE's TOPAIR, use n_g = 98.9%.

Considering the proposed plant capacity of 405 MW,

$P_{out} = (m_t)(W_{net})(n_m n_g)$

405 MW = (m_t)(866.1162203 kJ/kg)(99.06%)(98.9%)

m_t = 477.2920889 kg/s = 1718.25152 MT/hr

Design Option No. 3

In this design option, a reheat-regenerative rankine cycle, using open feedwater heaters, is considered. Schematic layout and T-s diagram of the cycle is shown in the figures on the next pages.

Reheat-regenerative steam power cycle increases its efficiency by increasing the average temperature of heat reception. In spite of such an increase in efficiency, reheating increases the irreversibility of feed water heaters by using superheated steam of a greater temperature difference in the regenerative cycle. This invention introduces some modifications to the regular reheat regenerative steam power cycle that reduces the irreversibility of the regenerative process. The invention applies reversible reheating in addition to the regular reheating and uses smaller temperature differences across feed water heaters than the regular cycle.

A comparison study between the regular reheat regenerative cycle and the invented cycle is done. The results indicate that a gain in efficiency of up to 2.5% is obtained when applying invented cycle at the same conditions of pressure, temperatures, number of reheating stages, and feed water heaters. In addition, the invented cycle has some practical advantages associated with up to 50% reduction in the mass flow rate that is regularly reheated for the same output power. Such advantages such as less pressure drop and heat transfer loss. Such advantages allow us to use a greater number of reheating stages of the invented cycle for the same pressure drop and heat transfer losses of the reheater pipes of the regular cycle. Another practical advantage of the invented cycle over the regular cycle is higher heat transfer coefficients for the heat exchangers of the feed water heaters because they are mainly operated in the two-phase region. Such practical advantage results in smaller sizes for the heat exchangers of the invented cycle compared with the ones for the regular cycle.

1. Specifications of the Selected Equipment

Equipment for a reheat-regenerative rankine cycle are selected to determine the initial parameters to be used in the calculation of the plant performance. Technical specifications of each equipment are shown below.

TURBINE

Brand/Model: GE/STF-D1050

Main Steam: 330 bar (4786 psi), 650°C (1200°F)

Reheat Temperature: 670°C (1238°F)

GENERATOR

Brand/Model: GE/TOPAIR

Efficiency: Up to 98.9%

OPEN FEED WATER HEATERS

Brand/Model: CHEM Process Systems/LP and HP Feedwater Heaters

Pressure Ratings: LPFH: 400 to 1500 psi

CONDENSER

Brand/Model: GE/Church Window and Daisy

Pressure Ratings: 40 mbar

Considering the selected equipment, the following operating conditions are to be used. Followed by this, is the calculation of the operating conditions of the other equipment. After the calculation, equipment that will best suit the calculated operating conditions will be selected.

Steam Operating Pressure: P_1 = 330 bar = 33 MPa

Steam Operating Temperature: T_1 = 650°C

Reheat Temperature: T_{RH} = 670°C

LPFH Operating Pressure: P_{LPFH} = 400 psi = 2.7579 = 2.8 MPa

Condensing Pressure: 42 mbar

At point 1:

h_1 = h @ T_1 = 650°C, P_1 = 33 MPa

h_1 = 3575.5 kJ/kg

s_1 = s @ T_1 = 650°C, P_1 = 33 MPa

s_1 = 6.3417 kJ/kg.K

At points 1-2:

$s_1 = s_2$ = 6.3417kJ/kg.K

$s_2 = s_g$ @ P_2 = ? = 6.3417kJ/kg.K

From Steam Table, Table 2, at s_2 = 6.3417kJ/kg.K:

s	h	P
6.3502 kJ/kg.K	2799.0kJ/kg	1.95 MPa
6.3417kJ/kg.K	h_2	P_2
6.3409 kJ/kg.K	2799.5 kJ/kg	2 MPa

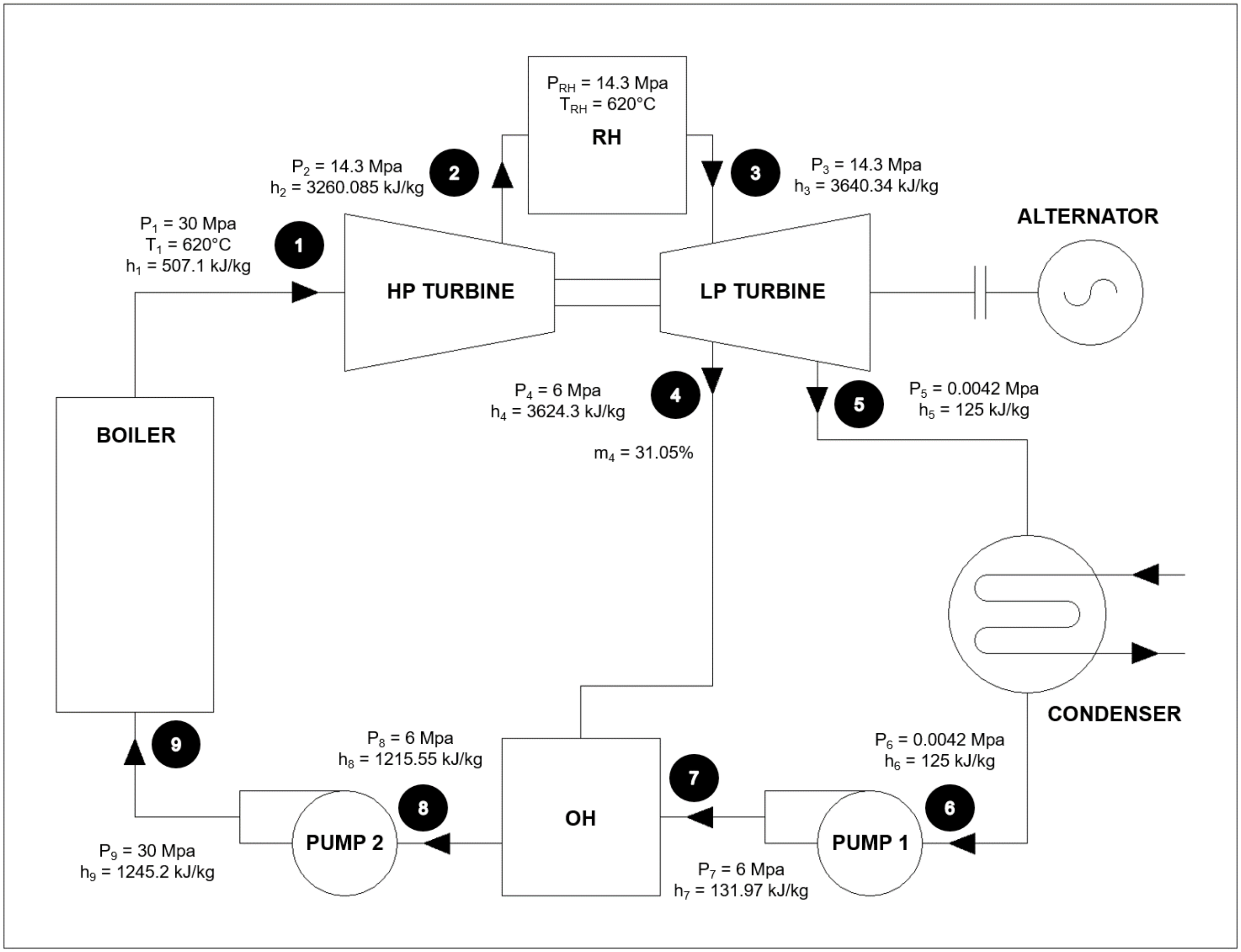

Figure 10. Schematic Layout of Design Option No. 3

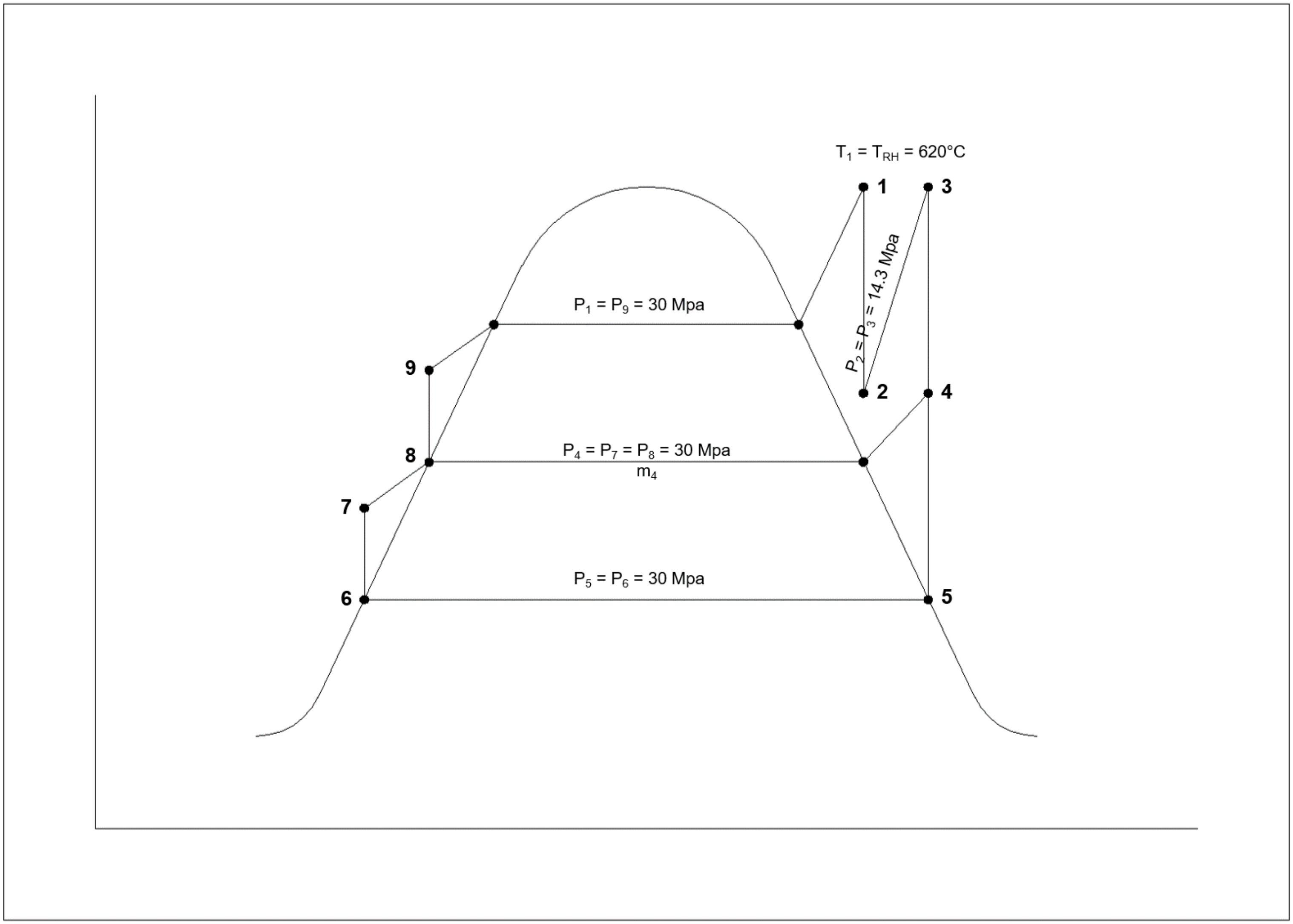

Figure 11. T-s Diagram of Design Option No. 3

By interpolation,

h_2 = 2799.456989 kJ/kg

P_2 = 1.995698925 MPa = 2 MPa

At point 3:

$P_2 = P_3$= 2 MPa

h_3 = h @ T_{RH} = 670°C, P_3 = 2 MPa

h_3 = 3848.7 kJ/kg

$s_3 = s_4 = s_5$ = s @ T_{RH} = 670°C, P_3 = 2 MPa

At point 4:

$s_3 = s_4 = s_5$ = 7.8769 kJ/kg.K

From Steam Table, Table 3, at $P_{LPFH} = P_4$ = 2.8 MPa

s	h
7.8370 kJ/kg.K	3959.2kJ/kg
7.8769kJ/kg.K	h_2
7.8834 kJ/kg.K	4005.8 kJ/kg

By interpolation,

h_4 = 3999.271983 kJ/kg

At points 5-6:

$s_5 = s_f + xs_{fg}$

where,

s_f @ 0.0042 Mpa = 0.4343 kJ/kg.K

s_{fg} @ 0.0042 Mpa = 8.0229 kJ/kg.K

Then,

7.8769 kJ/kg.K = 0.4343 kJ/kg.K + x(8.0229kJ/kg.K)

x = 0.9276695459

$h_5 = h_f + xh_{fg}$

where,

h_f @ 0.0042Mpa = 125 kJ/kg

h_{fg} @ 0.0042 Mpa= 2430.9 kJ/kg

Then,

h_5 = 125kJ/kg + 0.9276695459(2430.9kJ/kg)

h_5 = 2380.071899 kJ/kg

At point 6:

$P_5 = P_{condenser} = P_6$ = 0.0042MPa

$h_6 = h_f$@ P_5 = 0.0042 Mpa

h_6 = 125 kJ/kg

$v_6 = v_f$ @ P_5 = 0.0042 MPa

$\mathbf{v_6 = 1.0043x10^{-3}\ m^3/kg}$

At point 6-7:

$W_{pump} = v_6(P_4 – P_{condenser})$

$W_{pump} = (1.0043x10^{-3}m^3/kg)(2.8\ MPa – 0.0042\ MPa)$

$\mathbf{W_{pump} = 0.00280782194\ kJ/kg}$

Also,

$W_{pump}= h_7 – h_6$

$0.00280782194\ kJ/kg = h_7 – 125\ kJ/kg$

$\mathbf{h_7 = 125.0028078\ kJ/kg}$

At point 8:

$\mathbf{P_{LPFH} = P_4= P_8 = 2.8\ MPa}$

$h_8 = h_f @\ P_8 = 2.8$ Mpa

$\mathbf{h_8 = 990.59\ kJ/kg}$

$v_8 = v_f\ @\ P_7 = 2.8MPa$

$\mathbf{v_8 = 1.2090x10^{-3}\ m^3/kg}$

At point 8-9:

$W_{pump} = v_8(P_2 – P_4)$

$W_{pump} = (1.2090x10^{-3}m^3/kg)(2.8\ MPa – 2\ MPa)$

$\mathbf{W_{pump} = 0.0009672\ kJ/kg}$

Also,

$W_{pump} = h_9 - h_8$

$0.0009672\ kJ/kg = h_9 - 990.59\ kJ/kg$

$\mathbf{h_9 = 990.5909672\ kJ/kg}$

Computing for the total pump work (W_p),

$W_p = W_{pump,6\text{-}7} + W_{pump,8\text{-}9}$

$W_p = (0.00280782194 + 0.0009672)\ kJ/kg$

$\mathbf{W_p = 0.00377502194\ kJ/kg}$

Computing for the actual enthalpies (h_4'),

Typical isentropic efficiencies of a turbine ranges from 70% to 90%. For this calculation, use n_i = 90%.

$n_i = (h_1 - h_2')/(h_1 - h_2)$

$90\% = (3575.5\ kJ/kg - h_4')/(3575.5\ kJ/kg - 2799.456989\ kJ/kg)$

$\mathbf{h_2' = 2877.06129\ kJ/kg}$

$n_i = (h_3 - h_5')/(h_3 - h_5)$

$90\% = (3848.7\ kJ/kg - h_5')/(3848.7\ kJ/kg - 2380.071899\ kJ/kg)$

$\mathbf{h_5' = 2526.934709\ kJ/kg}$

Computing for the net work (W_{net}),

` $W_{net} = W_t – W_{pump}$

`   where,

$W_t = (h_1 – h_2') + (h_3 – h_5')$

W_t = [(3575.5 – 2877.06129) + (3848.7 –2526.934709)] kJ/kg

W_t = 2020.204001 kJ/kg

Then,

$W_{net} = W_t – W_{pump}$

W_{net} = 2020.204001 kJ/kg + 0.0009643921781 kJ/kg

W_{net} = 2020.204965 kJ/kg

Computing for heat added(Q_A),

$Q_A = (h_1 – h_9) + (h_3 – h_2')$

Q_A = [(3575.5 – 990.5890328) + (3848.7 – 2877.06129)] kJ/kg

Q_A = 3556.549677 kJ/kg

Computing for thermal efficiency (n_{th}),

$n_{th} = W_{net}/Q_A$

n_{th} = (2020.204965 kJ/kg)/(3556.549677kJ/kg)

n_{th} = 0.4680238288(100%)

n_{th} = 46.80238288%

Computing for the total mass the steam entering the turbine (m_t),

Based on Efficiency Assessment of Steam Turbine, values for mechanical efficiency are in the range of 98.63% and 99.06%, use n_m = 99.06%.

Considering GE's TOPAIR, use n_g = 98.9%.

Considering the proposed plant capacity of 405 MW,

$P_{out} = (m_t)(W_{net})(n_m n_g)$

405 MW = (m_t)(2020.204965 kJ/kg)(99.06%)(98.9%)

m_t = 204.6279596 kg/s = 736.6606546 MT/hr

Ultimate and Proximate Analysis of coal fuel to be used in the proposed 405 MW steam power plant:

For Bituminous Coal:

Ultimate Analysis:

C = 42.11

H = 2.76

O = 9.89

N = 1.22

S = 0.41

A = 38.65

Proximate Analysis:

Moisture = 5.98

Volatile Matter = 20.70

Fixed Carbon = 34.69

HHV = 4000 Kcal/kg = 16743.2 KJ/kg

Assumptions:

For a 1 kg basis:

Assume ambient temperature, Ta = 27ºC (temperature of air entering)

Tf = 30ºC (temperature of fuel entering)

According to Tools and Basic Information for Engineering and Design of Technical Applications, if the temperature difference between the flue gas leaving a boiler and the ambient supply temperature is assumed 300ºC then the carbon measured in the flue gas is 10% and 5% carbon oxidized to carbon monoxide. Then, Tfg = 243ºC, 10% of carbon in refuse , 5% carbon oxidized to carbon monoxide, 1.9% HHV for radiation and convection losses, according to Clever Brooks Facts about steam generators. According to engineering toolbox, to have an efficient boiler operation Pulverized coal-fired boilers may run with 25 percent excess air, Excess air = 25%

Solve for theoretical air – fuel ratio,

A/F_{theo} = 11.5C + 34.5 (H – O/8) + 4.5S

A/F_{theo} = 11.5(0.4211) + 34.5 (0.0276 – 0.0989/8) + 4.5(0.0041)

A/F_{theo} = 5.38679375 kg_a/kg_f

Solve for actual theoretical air – fuel ratio,

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

$A/F_{actual} = 5.38679375\ (1 + 0.25)$

$A/F_{actual} = 6.733492188\ kg_a/kg_f$

On a basis of 1 kg of fuel using the ultimate analysis of coal, the combustion products are,

$CO_2 = (44/12)\ [1 – (CO + CO_2)]\ C$

$CO_2 = (44/12)\ [1 – (0.1 – 0.05)]\ (0.4211)$

$CO_2 = 1.466831667\ kg_{CO2}/kg_{fuel}$

$CO = (28/12)(CO)(C)$

$CO = (28/12)(0.05)(0.4211)$

$CO = 0.04912833333\ kg_{CO}/kg_{fuel}$

$O_2 = 0.232\ e\ (A/F_{theo}) + (16/12)\ (CO)(C)$

$O_2 = 0.232(0.25)\ (5.38679375) + (16/12)\ (0.05)(0.4211)$

$O_2 = 0.3405073708\ kg_{O2}/kg_{fuel}$

$N_2 = 0.768\ (1 + e)\ (A/F_{theo}) + N_2$

$N_2 = 0.768\ (1 + 0.25)\ (5.38679375) + 0.0122$

$N_2 = 5.183522\ kg_{N2}/kg_{fuel}$

$W_v = 0.622\ P_v / (101.325 - P_v)$; $P_v = P_{sat}$ @ 27°C = 3.569 KPa

$W_v = 0.622\ (3.569\ KPa) / (101.325 – 3.569KPa)$

$W_v = 0.0227\ kg_v/kg_a$

$H_2O = 9H_2 + Moisture + W_v$

$H_2O = 9(0.0276) + 0.0598 + 0.0227$

$H_2O = 0.3309\ kg_{H2O}/kg_{fuel}$

Solve for total moles of gas,

$m_T = (CO_2/44) + (CO/28) + (O_2/32) + (N_2/28)$

$m_T = (1.466831667/44) + (0.04912833333/28) + (0.3405073708/32) +$

$(5.183522/28)$

$m_T = 0.2308575522\ mol_{gas}/kg_{fuel}$

For mass proportion of combustion products,

$CO_2 = (CO_2/44)/\ m_T$

$CO_2 = (1.466831667/44)/\ 0.2308575522$

$CO_2 = 0.1444054267$

$CO = (CO/28)/\ m_T$

$CO = (0.04912833333\ /28)/\ 0.2308575522$

$CO = 7.600285615x10^{-3}$

$O_2 = (O_2/32)/ m_T$

$O_2 = (0.3405073708 /32)/ 0.2308575522$

$O_2 = 0.04609273223$

$N_2 = (N_2/44)/ m_T$

$N_2 = (5.183522 /44)/ 0.2308575522$

$N_2 = 0.5103030724$

$C_{refuse} = 0.1C$

$C_{refuse} = 0.1\ (0.4211)$

$C_{refuse} = 0.04211$

$Weight_{refuse} = C_{refuse} + ash_{refuse}$

$Weight_{refuse} = 0.04211 + 0.3865$

$Weight_{refuse} = 0.42861\ kg_{refuse}/kg_{fuel}$

Solve for heat loss carried by dry flue gas, Q_2,

$Q_2 = m_{dg}(Cp_{dg})(t_{fg}-t_a)$

$m_{dg} = [(4CO_2 + O_2 + 700)/3(CO_2+CO)]\ (C_{ab}/100)$

$m_{dg} = [(4(0.1444054267) + 0.04609273223 +$

$700)/3(0.1444054267+7.600285615x10^{-3})] \quad (0.4211-0.04211) /100]$

$m_{dg} = 5.822793926\ kg_{dg}/kg_{fuel}$

Q_2 = 5.822793926 (1.0046)(243-27)

Q_2 = 1263.509016 KJ/kg

Solve for heat loss due to moisture evaporation in air supplied, Q_3,

$Q_3 = m_{vapor}$ (Cp_{vapour}) (t_{fg}-t_a)

Where: Cp = 1.9258 KJ/kg

$m_v = H_v$ (m_a); H_v = 0.0227 kg_{vapour}/kg_{air}

m_a = [$28N_2/12(CO_2$ + CO)(0.769)](C_{ab})

m_a = [(28 x 0.5103030724)/12(0.1444054267 + 7.600285615x10^{-3})(0.769)](
0.4211-0.04211)

m_a = 3.114489552 kg_{air}/kg_{fuel}

Q_3 = 0.0227(3.114489552)(1.9258)(243-27)

Q_3 = 29.40882473 KJ/kg

Solve for heat loss due to unburned combustible in the ash pit, Q_4,

Q_4 = 33830 ($Weight_{refuse}$)(C_{refuse})

Q_4 = 33830 (0.42861)(0.04211)

Q_4 = 610.589791 KJ/kg

Solve for heat loss due to incomplete combustion of fuel, Q_5,

Q_5 = [(CO)/ (CO_2+CO)] (C_{ab}/100)(23630)

Q_5 = [(7.600285615x10^{-3})/ (0.1444054267+7.600285615x10^{-3})]

(0.4211-0.04211/100)(23630)

Q_5 = 4.47776685 KJ/kg

Solve for the heat loss due to the evaporated moisture in the oxygen

$Q_6 = 9H_2\,(h'' - h_f')$

Where,

$$h'' = 2584.7 + 1.9258\left(T_{fg} - 45.81\right) = 2584.7\ + 1.9258\ (243 - 45.81)$$

$$h'' = 2964.448502\ \frac{kJ}{kg}$$

$$h_f = \mathrm{h}\ @\ T_{fg} = h\ @\ 30\ ºC = 125.66\ \frac{kJ}{kg}$$

thus,

$$\mathrm{Q}_6 = 9(0.0276\ )(2964.448502 - 125.66)$$

$$\mathrm{Q}_6 = 705.1550639\ \frac{kJ}{kg}$$

Solving for heat loss due to evaporated moisture in coal, Q_7

$$\mathrm{Q}_7 = \mathrm{Moisture}(h'' - h_f{}')$$

$$\mathrm{Q}_7 = (0.0598)(2964.448502 - 125.66)$$

$$\mathrm{Q}_7 = 169.7595524\ \frac{kJ}{kg}$$

Solving for heat loss due to radiation and convection, Q_8

$$\mathrm{Q}_8 = 0.019HHV$$

$$\mathrm{Q}_8 = 0.019(16743.2\frac{\mathrm{kJ}}{\mathrm{kg}})$$

$$\mathrm{Q}_8 = 318.1208\frac{\mathrm{kJ}}{\mathrm{kg}}$$

Solving for heat absorbed by steam generator, Q_1

$$HHV = Q_1 + Q_2 + Q_3 + Q_4 + Q_5 + Q_6 + Q_7 + Q_8$$

$$Q_1 = HHV - Q_2 - Q_3 - Q_4 - Q_5 - Q_6 - Q_7 - Q_8$$

$$Q_1 = 16743.2\,\frac{\mathrm{kJ}}{\mathrm{kg}} - 3101.020815\,\frac{\mathrm{kJ}}{\mathrm{kg}}$$

$$Q_1 = 13642.17919\,\frac{\mathrm{kJ}}{\mathrm{kg}}$$

For Design 1

Mass flow rate of fuel for each unit

$$Q_1 = \frac{m_T(h_1 - h_6)}{m_f}$$

$$m_f = \frac{m_T(h_1 - h_6)}{Q_1}$$

$$m_f = \frac{228.3404554\ \frac{\mathrm{kg}}{\mathrm{s}}(3575.5\ - 260.113565)\frac{\mathrm{kJ}}{\mathrm{kg}}}{13642.17919\,\frac{\mathrm{kJ}}{\mathrm{kg}}}$$

$$\boldsymbol{m_f = 55.4923695\,\frac{\mathbf{kg}}{\mathbf{s}}}$$

Heat Rate in each Steam Generator

$$Heat\ Rate = \frac{m_f HHV}{Plant\ Capacity}$$

$$Heat\ Rate 5 \frac{55.4923695\,\frac{\mathrm{kg}}{\mathrm{s}}(16743.2\,\frac{\mathrm{kJ}}{\mathrm{kg}})}{405\ kW}\, x\ 3600\ s$$

$$Heat\ Rate = 8{,}258{,}843.031\,\frac{\mathrm{kJ}}{\mathrm{MW-hr}}\ or\ 7{,}828{,}287.233\,\frac{\mathrm{BTU}}{\mathrm{MW-hr}}$$

Surface Condenser Design Calculations

$$Q_R = m_T (h_4 - h_5)$$

$$Q_R = 228.3404554 \frac{\mathrm{kg}}{\mathrm{s}} (2613.148594 \frac{kJ}{kg} - 260.08 \frac{KJ}{kg})$$

$$\boldsymbol{Q_R = 537,300.7543\ \mathrm{kW}}$$

Stack Design Calculations

Design Data and Assumptions:

Temperature of flue gas leaving, t_{fg} = 243 °C

Temperature of air entering, t_a = 27 °C

Static draft head, h_t = 1 in of H_2O = 2.54 cm

Solve for density of air entering, ρ_a

PV=mRT

$$\frac{V}{m} = \frac{P_a}{R_a T_a}$$

$$= \frac{101.325\ kPa}{\left(0.287 \frac{KJ}{kg-K}\right)(27 + 273)K}$$

$$\rho_a = 1.176829268 \frac{kg}{m^3}$$

For density of flue gas, ρ_{fg}

Actual $R_g = 273.5 \frac{J}{kg-K}$

$$\frac{V}{m} = \frac{P_g}{R_g T_g}$$

$$= \frac{101.325\ kPa}{\left(0.2735 \frac{KJ}{kg-K}\right)(243 + 273)K}$$

ρ_{fg}= 0.7179754262 $\frac{kg}{m^3}$

Solve for height of the stack/chimney,

$$h_t = \frac{\rho_a - \rho_g}{\rho_w} \times H$$

$$2.54\ cm = \frac{(1.176829268 - 0.7179754262\,)\frac{kg}{m^3}}{1000\ kg/m^3} \times H$$

$$H = 5535.531728\ cm$$

$$H = 55.35531728\ m$$

Solve for the theoretical velocity of flue gas, V_t

$$V_t = \sqrt{2gh \times \left(\frac{\rho_a - \rho_g}{\rho_g}\right)}$$

$$= \sqrt{2\left(9.81\,\frac{m}{s^2}\right)(55.35531728\ m)\left(\frac{1.176829268kg/m^3 - 0.7179754262\ kg/m^3}{0.7179754262kg/m^3}\right)}$$

$V_t = 26.34581087\ m/s$

Assuming 50% of the theoretical velocity the actual velocity of the flue gas would be, V_a:

$V_a = 0.50\ (V_t) = \ 0.50\ (26.34581087\ m/s)$ = 13.17290544 m/s

Assuming 50% of the theoretical velocity the actual velocity of the flue gas would be, V_a:

$V_a = 0.50\ (V_t) = \ 0.50\ (26.34581087\ m/s)$ = 13.17290544 m/s

Solving for the volume flow rate of flue gas, V_{fg}*:*

$W_{fg} = m_{dg} + W\ = 9.339516663 + 0.0558 =$ 9.395316663

$m_{fg} = m_f(W_{fg}) = 55.4923695\,\frac{kg}{s}$ (9.395316663)= 521.3683838 kg/s

$V_{fg} = m_{fg}/(\rho_{fg})$ = 521.368383 kg/s / $0.7179754262\ kg/m^3$ = 726.1646636 $\frac{m^3}{s}$

Solving for the diameter of the stack,

Area = V_{fg}/V_a = 726.1646636 m^3/s / 13.17290544 m/s

$$\frac{\pi\, D^2}{4} = 55.12562638\, m^2$$

D = 8.377835486 m

For Design 2

Mass flow rate of fuel for each unit

$$Q_1 = \frac{m_T(h_1 - h_{10})}{m_f}$$

$$m_f = \frac{m_T(h_1 - h_{10})}{Q_1}$$

$$m_f = \frac{477.2920889\ \frac{\mathrm{kg}}{\mathrm{s}}(3575.5\ - 1424.760033)\,\frac{\mathrm{kJ}}{\mathrm{kg}}}{13642.17919\,\frac{\mathrm{kJ}}{\mathrm{kg}}}$$

$$\boldsymbol{m_f} = \mathbf{75.24686175\,\frac{kg}{s}}$$

Heat Rate in each Steam Generator

$$Heat\ Rate = \frac{m_f HHV}{Plant\ Capacity}$$

$$Heat\ Rate = \frac{75.24686175\,\frac{\mathrm{kg}}{\mathrm{s}}(16743.2\,\frac{\mathrm{kJ}}{\mathrm{kg}})}{405\ kW}\, x\ 3600\ s$$

$$Heat\ Rate = 11{,}198{,}873.38\,\frac{\mathrm{kJ}}{\mathrm{MW-hr}}\ or\ 11{,}143{,}157.6\,\frac{\mathrm{BTU}}{\mathrm{MW-hr}}$$

Surface Condenser Design Calculations

$$Q_R = m_T\,(h_4 - h_5)$$

$$Q_R = 228.3404554\,\frac{\mathrm{kg}}{\mathrm{s}}(1934.790188\,\frac{kJ}{kg} - 125\,\frac{KJ}{kg})$$

$$\boldsymbol{Q_R = 413,248.3157\ \mathrm{kW}}$$

Stack Design Calculations

Design Data and Assumptions:

Temperature of flue gas leaving, t_{fg} = 243 °C

Temperature of air entering, t_a = 27 °C

Static draft head, h_t = 1 in of H_2O = 2.54 cm

Solve for density of air entering, ρ_a

PV=mRT

$$\frac{V}{m} = \frac{P_a}{R_a T_a}$$

$$= \frac{101.325\ kPa}{\left(0.287\,\frac{KJ}{kg-K}\right)(27+273)K}$$

$$\rho_a = 1.176829268\,\frac{kg}{m^3}$$

For density of flue gas, ρ_{fg}

Actual $R_g = 273.5\,\frac{J}{kg-K}$

$$\frac{V}{m} = \frac{P_g}{R_g T_g}$$

$$= \frac{101.325\ kPa}{\left(0.2735\,\frac{KJ}{kg-K}\right)(243+273)K}$$

$$\rho_{fg} = 0.7179754262\ \frac{kg}{m^3}$$

Solve for height of the stack/chimney,

$$h_t = \frac{\rho_a - \rho_g}{\rho_w} \times H$$

$$2.54\ cm = \frac{(1.176829268 - 0.7179754262)\frac{kg}{m^3}}{1000\ kg/m^3} \times H$$

$$H = 5535.531728\ cm$$

$$H = 55.35531728\ m$$

Solve for the theoretical velocity of flue gas, V_t

$$V_t = \sqrt{2gh \times \left(\frac{\rho_a - \rho_g}{\rho_g}\right)}$$

$$= \sqrt{2\left(9.81\,\frac{m}{s^2}\right)(55.35531728\ m)\left(\frac{1.176829268 kg/m^3 - 0.7179754262\ kg/m^3}{0.7179754262 kg/m^3}\right)}$$

$V_t = 26.34581087\ m/s$

Assuming 50% of the theoretical velocity the actual velocity of the flue gas would be, V_a:

$V_a = 0.50\ (V_t) = 0.50\ (26.34581087\ m/s)$ = 13.17290544 m/s

Assuming 50% of the theoretical velocity the actual velocity of the flue gas would be, V_a:

$V_a = 0.50\ (V_t) = 0.50\ (26.34581087\ m/s)$ = 13.17290544 m/s

Solving for the volume flow rate of flue gas, V_{fg}:

$W_{fg} = m_{dg} + W = 9.339516663 + 0.0558 = 9.395316663$

$m_{fg} = m_f(W_{fg}) = 75.24686175 \frac{kg}{s}$ (9.395316663)= 706.968094 kg/s

$V_{fg} = m_{fg}/(\rho_{fg})$ = 706.968094 kg/s / $0.7179754262\ kg/m^3$ = 984.6689291 $\frac{m^3}{s}$

Solving for the diameter of the stack,

Area = V_{fg}/V_a = 984.6689291 m^3/s / 13.17290544 m/s

$$\frac{\pi D^2}{4} = 74.74956331\ m^2$$

D = 9.755721396 m

For Design 3

Mass flow rate of fuel for each unit

$$Q_1 = \frac{m_T(h_1 - h_6)}{m_f}$$

$$m_f = \frac{m_T(h_1 - h_9)}{Q_1}$$

$$m_f = \frac{204.6279596\ \frac{\mathrm{kg}}{\mathrm{s}}(3575.5\ - 990.5909672)\frac{\mathrm{kJ}}{\mathrm{kg}}}{13642.17919\frac{\mathrm{kJ}}{\mathrm{kg}}}$$

$$\boldsymbol{m_f = 38.77273959\frac{\mathbf{kg}}{\mathbf{s}}}$$

Heat Rate in each Steam Generator

$$Heat\ Rate = \frac{m_f HHV}{Plant\ Capacity}$$

$$Heat\ Rate = \frac{38.77273959\frac{\mathrm{kg}}{\mathrm{s}}(16743.2\frac{\mathrm{kJ}}{\mathrm{kg}})}{405\ kW} x\ 3600\ s$$

$$Heat\ Rate = 5{,}770{,}486.52\,\frac{\text{kJ}}{\text{MW}-\text{hr}}\ or\ 5{,}469{,}655.469\,\frac{\text{BTU}}{\text{MW}-\text{hr}}$$

Surface Condenser Design Calculations

$$Q_R = \ m_T\,(h_5 - h_6)$$

$$Q_R = \ 204.6279596\,\frac{\text{kg}}{\text{s}}(2380.071899\,\frac{kJ}{kg} - 125\ \frac{KJ}{kg})$$

$$\boldsymbol{Q_R = \ 461{,}450.7614\ \text{kW}}$$

Stack Design Calculations

Design Data and Assumptions:

Temperature of flue gas leaving, t_{fg} = 243 °C

Temperature of air entering, t_a = 27 °C

Static draft head, h_t = 1 in of H_2O = 2.54 cm

Solve for density of air entering, ρ_a

PV=mRT

$$\frac{V}{m} = \frac{P_a}{R_a T_a}$$

$$= \frac{101.325\ kPa}{\left(0.287\,\frac{KJ}{kg-K}\right)(27+273)K}$$

$$\rho_a = 1.176829268\,\frac{kg}{m^3}$$

For density of flue gas, ρ_{fg}

Actual $R_g = 273.5\,\frac{J}{kg-K}$

$$\frac{V}{m} = \frac{P_g}{R_g T_g}$$

$$= \frac{101.325\ kPa}{\left(0.2735 \frac{KJ}{kg-K}\right)(243 + 273)K}$$

$$\rho_{fg} = 0.7179754262\ \frac{kg}{m^3}$$

Solve for height of the stack/chimney,

$$h_t = \frac{\rho_a - \rho_g}{\rho_w} \times H$$

$$2.54\ cm = \frac{(1.176829268 - 0.7179754262\ )\frac{kg}{m^3}}{1000\ kg/m^3} \times H$$

$$H = 5535.531728\ cm$$

$$H = 55.35531728\ m$$

Solve for the theoretical velocity of flue gas, V_t

$$V_t = \sqrt{2gh \times \left(\frac{\rho_a - \rho_g}{\rho_g}\right)}$$

$$= \sqrt{2\left(9.81\frac{m}{s^2}\right)(55.35531728\ m)\left(\frac{1.176829268 kg/m^3 - 0.7179754262\ kg/m^3}{0.7179754262 kg/m^3}\right)}$$

$V_t = 26.34581087\ m/s$

Assuming 50% of the theoretical velocity the actual velocity of the flue gas would be, V_a:

$V_a = 0.50\ (V_t) =\ 0.50\ (26.34581087\ m/s)$ = 13.17290544 m/s

Assuming 50% of the theoretical velocity the actual velocity of the flue gas would be, V_a:

$V_a = 0.50\ (V_t) =\ 0.50\ (26.34581087\ m/s)$ = 13.17290544 m/s

Solving for the volume flow rate of flue gas, V_{fg}*:*

$W_{fg} = m_{dg} + W = 9.339516663 + 0.0558 =$ 9.395316663

$m_{fg} = m_f\left(W_{fg}\right) = 38.77273959\,\frac{kg}{s}$ (9.395316663)= 364.2821663 kg/s

$V_{fg} = m_{fg}/\left(\rho_{fg}\right)$ = 507.3741427 kg/s / $0.7179754262\ kg/m^3$ = 507.3741427 $\frac{m^3}{s}$

Solving for the diameter of the stack,

Area = V_{fg}/V_a = 507.3741427 m^3/s / 13.17290544 m/s

$$\frac{\pi\ D^2}{4} = 38.51649471\ m^2$$

D = 7.002908266 m

Chapter IV
Economic Analysis

This chapter presents the economics of each design options of the coal fired power plant. This will cover the capital expenditures, operating expenditures, and the overall project cost.

I. Capital Expenditures

These expenditures are money which is invested on physical assets that are necessary for the setup of the power plant. It will include the real estate or land costs, equipment costs, building costs that are established, electrical costs, and miscellaneous.

A. Land costs

The present cost of land per square meter is Php 700.00. The total land area that the designed power plant will occupy is 100,000 sqm or 10 hectare.

Land Cost = 100000 sqm (Php 700.00 / sqm)

Land Cost = Php 70,000,000

B. Equipment Costs

Most of the money that is invested on capital expenditures goes to the equipment that will be used on the power plant. The tables below will present the prices of equipment that will be needed on each design option of the coal fired power plant.

Considering circumstances of unforeseen complications on equipment, 20% of the total cost will be added as a contingency plan to cope up with the matter. With currency in US Dollars, the rate of exchange of 1 US dollar to Philippine Peso is Php 49.84.

Table 4

Equipment Price List for Design Option 1

Item Name	No. of Units	Price per Unit ($)	Total Cost ($)
Steam Turbine	1	280,000,000	280,000,000
Steam Turbine Generator	1	80,000,000	80,000,000
Boiler	1	100,000,000	100,000,000
Condenser	1	1,000,000	1,000,000
Pump	1	9000	9000
Surface Condenser	1	1,200,000	1,200,000
Electrostatic Precipitator	1	150,000	150,000
Induced Draft Fan	1	4,000	4,000
Forced Draft Fan	2	4,000	8,000
		Total	$554,845,200
			Php27,653,484,770

Table 5

Equipment Price List for Design Option 2

Item Name	No. of Units	Price per Unit ($)	Total Cost ($)
Steam Turbine	1	280,000,000	280,000,000
Steam Turbine Generator	1	80,000,000	80,000,000
Boiler	1	100,000,000	100,000,000
Condenser	1	1,000,000	1,000,000
Pump	3	8,500	25,500
Surface Condenser	1	1,000,000	1,000,000
Electrostatic Precipitator	1	150,000	150,000
Induced Draft Fan	1	4,500	4,500
Forced Draft Fan	2	4,000	8,000
Feedwater Heater (HP)	1	9,700	9,700
Feedwater Heater (LP)	1	6,000	6,000
		Total	**$553,413,840**
			Php27,582,145,790

Table 6
Equipment Price List for Design Option 3

Item Name	No. of Units	Price per Unit ($)	Total Cost ($)
Steam Turbine	1	280,000,000	280,000,000
Steam Turbine Generator	1	80,000,000	80,000,000
Boiler	1	100,000,000	100,000,000
Condenser	1	1,000,000	1,000,000
Electrostatic Precipitator	1	150,000	150,000
Pump	2	9,000	18,000
Reheater	1	20,000	20,000
Feedwater Heater (LP)	1	6,000	6,000
Induced Draft Fan	1	4,500	4,500
Forced Draft Fan	2	4,000	8,000
		Total	**$553,447,800**
			Php27,583,838,350

C. Building Costs

From “Power Plant Theory and Theory” by Potter, building costs accumulate 33% of the overall equipment costs.

For Design Option 1:

Building Costs = Equipment cost x 33%

Building Costs = Php 27,653,484,770 x 33%

Building Costs = Php 9,125,649,974

For Design Option 2:

Building Costs = Equipment cost x 33%

Building Costs = Php 27,582,145,790 x 33%

Building Costs = Php 9,102,108,111

For Design Option 3:

Building Costs = Equipment cost x 33%

Building Costs = Php 27,583,838,350 x 33%

Building Costs = Php 9,102,666,656

D. Electrical Costs

From “Power Plant Theory and Theory” by Potter, electrical costs accumulate 20% of the overall equipment costs.

For Design Option 1:

Electrical Costs = Equipment cost x 20%

Electrical Costs = Php 27,653,484,770 x 20%

Electrical Costs = Php 5,530,696,954

For Design Option 2:

Electrical Costs = Equipment cost x 20%

Electrical Costs = Php 27,582,145,790 x 20%

Electrical Costs = Php 5,516,429,158

For Design Option 3:

Electrical Costs = Equipment cost x 20%

Electrical Costs = Php 27,583,838,350 x 20%

Electrical Costs = Php 5,516,767,670

E. Miscellaneous Costs

This will include the engineering and professional fees required in order to establish the power plant. This is assumed as 10% of the overall equipment costs.

For Design Option 1:

Miscellaneous Costs = Equipment cost x 10%

Miscellaneous Costs = Php 27,653,484,770 x 10%

Miscellaneous Costs = Php 2,765,348,477

For Design Option 2:

Miscellaneous Costs = Equipment cost x 10%

Miscellaneous Costs = Php 27,582,145,790 x 10%

Miscellaneous Costs = Php 2,758,214,579

For Design Option 3:

Miscellaneous Costs = Equipment cost x 10%

Miscellaneous Costs = Php 27,583,838,350 x 10%

Miscellaneous Costs = Php 2,758,383,835

Table 7

Summary of the Capital Expenditures

Expenditures	**Design Option 1**	**Design Option 2**	**Design Option 3**
Equipment Cost(Php)	27,653,484,770	27,582,145,790	27,583,838,350
Land Cost (Php)	7,000,000	7,000,000	7,000,000
Building Cost (Php)	9,125,649,974	9,102,108,111	9,102,666,656
Electrical Cost (Php)	5,530,696,954	5,516,429,158	5,516,767,697
Miscelaneous Costs (Php)	2,765,348,477	2,758,214,579	2,758,383,835
Total(Php)	**45,145,180,180**	**45,028,897,640**	**45,031,656,540**

II. Operating Expenditures

According to Skrotzki and Vopat of "Power Plant Station and Economy", the annual operating expenditures are in the form of percentage analysis presented below:

Fuel Cost	
Labor	running cost – 20%
Maintenance and Repair	running cost – 20%
Supplies	running cost – 10%
Supervision	running cost – 20%

Operating Taxes running cost – 5%

A. Fuel Cost

For Design Option 1:

Solving for fuel cost:

Heat rate = 8,258,843.031 kJ / MW - hr

Coal Price = \$ 51.57 per ton = Php 2.5702488/kg

HHV = 16,743.2 kJ/kg

Fuel cost = $((P2.5702488)(405MW)(8760hrs)(8258843.031))/HHV$

Fuel Cost = Php 4,497,954,329

For Design Option 2:

Solving for fuel cost:

Heat rate = 11,198,873.38 kJ / MW - hr

Coal Price = \$ 51.57 per ton = Php 2.5702488/kg

HHV = 16,743.2 kJ/kg

Fuel cost = $((P2.5702488)(405MW)(8760hrs)(11198873.38))/HHV$

Fuel Cost = Php 6,099,161,929

For Design Option 3:

Solving for fuel cost:

Heat rate = 5,770,486.52 kJ / MW - hr

Coal Price = \$ 51.57 per ton = Php 2.5702488/kg

HHV = 16,743.2 kJ/kg

Fuel cost = $((P2.5702488)(405MW)(8760hrs)(5770486.52))/HHV$

Fuel Cost = Php 3,142,738,604

B. Labor Cost

For Design Option 1:

Labor Cost = Php 4,497,954,329 x 20%

Labor Cost = Php 899,590,865.5

For Design Option 2:

Labor Cost = Php 6,099,161,929 x 20%

Labor Cost = Php 1,219,832,386

For Design Option 3:

Labor Cost = Php 3,142,738,604 x 20%

Labor Cost = Php 628,547,720.8

C. Maintenance and Repair

For Design Option 1:

Cost = Php 4,497,954,329 x 20%

Cost = Php 899,590,865.5

For Design Option 2:

Cost = Php 6,099,161,929 x 20%

Cost = Php 1,219,832,386

For Design Option 3:

Cost = Php 3,142,738,604 x 20%

Cost = Php 628,547,720.8

D. Supplies Cost

For Design Option 1:

Cost = Php 4,497,954,329 x 10%

Cost = Php 449,795,432.9

For Design Option 2:

Cost = Php 6,099,161,929 x 10%

Cost = Php 609,916,192.9

For Design Option 3:

Cost = Php 3,142,738,604 x 10%

Cost = Php 314,273,860.4

E. Supervision Cost

For Design Option 1:

Supervision Cost = Php 4,497,954,329 x 20%

Supervision Cost = Php 899,590,865.5

For Design Option 2:

Supervision Cost = Php 6,099,161,929 x 20%

Supervision Cost = Php 1,219,832,386

For Design Option 3:

Supervision Cost = Php3,142,738,604 x 20%

Supervision Cost = Php 628,547,720.8

F. Operating Taxes

For Design Option 1:

Operating Taxes = Php 4,497,954,329x 5%

Operating Taxes = Php 224,897,716.5

For Design Option 1:

Operating Taxes = Php 6,099,161,929x 5%

Operating Taxes = Php 304,958,096.5

For Design Option 1:

Operating Taxes = Php 3,142,738,604x 5%

Operating Taxes = Php 157,136,930.2

Table 8

Summary of Operating Expenditures

Expenditures(Php)	**Design Option 1**	**Design Option 2**	**Design Option 3**
Fuel Cost	4,497,954,329	6,099,161,929	3,142,738,604
Labor Cost	899,590,865.5	1,219,832,386	628,547,720.8
Maintenance and Repair Cost	899,590,865.5	1,219,832,386	628,547,720.8
Supplies Cost	449,795,432.9	609,916,192.9	314,273,860.4
Supervision Cost	899,590,865.5	1,219,832,386	628,547,720.8
Operating Taxes	224,897,716.5	304,958,096.5	157,136,930.2
Total (Php)	**7,871,420,075**	**10,673,533,380**	**5,499,792,557**

III. Net Present Value

To get the net present worth value for each design options for the power plant considering that *Net Present Value = Cash Inflows – Cash Outflows* considering a range of 5 to 6.5% rate of investment for plants as stated from "Power Plant Engineering" by Morse, we first make use of the maximum range then the minimum range for sensitivity analysis.

For Cash Inflows:

Cash Inflows = Revenue @ year 10 + Salvage Value

Where them revenue is the power generation multiplied to the actual plant output considering plant consumptions of 7.5% of the overall output of the plant. Generation rate in the present year is Php 3.923/kW-hr. The Salvage value accumulates 5% of the total capital expenditures.

For Cash Outflows:

Cash Outflow = Capital Expenditures + Operating cost @ year 10

For Design Option 1:

Annual Revenue = Php 3.923/kW-hr x (374,625 kW x 0.925)(8760hrs/yr)

Annual Revenue = Php 12,874,167,950

$$\text{Revenue @ year 10} = \text{Php } 12{,}874{,}167{,}950 \times \frac{1-1.065^{-10}}{0.065}$$

Revenue @ year 10 = Php 92,550,207,620

Salvage Value = Php 45,145,180,180 x 0.05

Salvage Value = Php 2,257,259,009

Salvage Value @ year 10 = Php 2,257,259,009 x $(1 + 0.065)^{-10}$

Salvage Value @ year 10 = Php 1,202,500,643

Operating cost @ year 10 = Php 4,497,954,329 x $\frac{1-1.065^{-10}}{0.065}$

Operating cost @ year 10 = Php 32,335,030,020

Cash Inflow = Php 92,550,207,620 + Php 1,202,500,643

Cash Inflow = Php 93,752,708,260

Cash Outflow = Php 45 145 180 180+ Php 32,335,030,020

Cash Outflow = Php 77,480,210,200

Present Net Worth = Php 16,272,498,060

For Design Option 2:

Annual Revenue = Php 3.923/kW-hr x (374,625 kW x 0.925)(8760hrs/yr)

Annual Revenue = Php 12,874,167,950

Revenue @ year 10 = Php 12,874,167,950 x $\frac{1-1.065^{-10}}{0.065}$

Revenue @ year 10 = Php 92,550,207,620

Salvage Value = Php 45, 028, 897, 640 x 0.05

Salvage Value = Php 2,251,444,882

Salvage Value @ year 10 = Php 2,251,444,882 x $(1 + 0.065)^{-10}$

Salvage Value @ year 10 = Php 1,199,403,306

Operating cost @ year 10 = Php 6, 099, 161, 929 x $\frac{1-1.065^{-10}}{0.065}$

Operating cost @ year 10 = Php 43,845,839,610

Cash Inflow = Php 92,550,207,620+ Php 1,199,403,306

Cash Inflow = Php 92,550,207,620

Cash Outflow = Php 45, 028, 897, 640 + Php 43,845,839,610

Cash Outflow = Php 88,874,737,250

Present Net Worth = Php 36,754,703,700

For Design Option 3:

Annual Revenue = Php 3.923/kW-hr x (374,625 kW x 0.925)(8760hrs/yr)

Annual Revenue = Php 12,874,167,950

Revenue @ year 10 = Php 12,874,167,950 x $\frac{1-1.065^{-10}}{0.065}$

Revenue @ year 10 = Php 92,550,207,620

Salvage Value = Php 45, 031, 656, 540x 0.05

Salvage Value = Php 2,251,582,827

Salvage Value @ year 10 = Php 2,251,582,827 x $(1 + 0.065)^{-10}$

Salvage Value @ year 10 = Php 1,199,476,793

Operating cost @ year 10 = Php 3,142,738,604x $\frac{1-1.065^{-10}}{0.065}$

Operating cost @ year 10 = Php 22,592,614,260

Cash Inflow = Php 92,550,207,620+ Php 1,199,476,793

Cash Inflow = Php 93,749,684,410

Cash Outflow = Php 45 031 656 540+ Php 22,592,614,260

Cash Outflow = Php 67,624,270,800

Present Net Worth = Php 26,125,413,610

IV. Payback Period

The payback period is the length of time required for an investment to recover its initial outlay in terms of profits or savings. The working equation goes as:

$$\text{Payback Period} = \frac{\text{Capital Expenditure-Salvage Value}}{\text{Cash In flow per Period}}$$

For Design Option 1:

$$\text{Payback Period} = \frac{\text{Php } 45{,}145{,}180{,}180 - \text{Php } 45{,}145{,}180{,}180\ (0.05)}{\text{Php } 45{,}145{,}180{,}180 - \text{Php } 4{,}497{,}954{,}329}$$

Payback Period = 1.055125418

For Design Option 2:

$$\text{Payback Period} = \frac{\text{Php } 45{,}028{,}897{,}640 - \text{Php } 45{,}028{,}897{,}640(0.05)}{\text{Php } 45{,}028{,}897{,}640 - \text{Php } 6{,}099{,}161{,}929}$$

Payback Period = 1.09837482

For Design Option 3:

$$\text{Payback Period} = \frac{\text{Php } 45{,}031{,}656{,}540 - \text{Php } 45{,}031{,}656{,}540(0{,}05)}{\text{Php } 45{,}031{,}656{,}540 - \text{Php } 3{,}142{,}738{,}604}$$

Payback Period = 1.021274261

V. Rate of Return/Rate of Investment

Rate of return is the profit of an investment at a given time period being expressed as the proportion of its original investment. The working equation will be the inverse of the payback period multiplied to 100 %

$RR = PP^{-1} \times 100\%$

For Design Option 1:

RR = (**1.055125418**) $^{-1}$ x 100%

RR = 94.77546299%

For Design Option 2:

RR = (**1.09837482**) $^{-1}$ x 100%

RR = 91.04360204%

For Design Option 3:

RR = (**1.021274261**) $^{-1}$ x 100%

RR = 97.91689051%

VI. Sensitivity Analysis

Assuming the rate is at its minimum, the net present value for the given design options will be as follows:

For Design Option 1:

$$\text{Revenue @ year 10} = \text{Php } 12{,}874{,}167{,}950 \times \frac{1-1.05^{-10}}{0.05}$$

Revenue @ year 10 = Php 99,410,912,340

Salvage Value @ year 10 = Php 2,257,259,009 x $(1 + 0.05)^{-10}$

Salvage Value @ year 10 = Php 1,385,761,222

$$\text{Operating cost @ year 10} = \text{Php } 4{,}497{,}954{,}329 \times \frac{1-1.05^{-10}}{0.05}$$

Operating cost @ year 10 = 34,732,011,050

Cash Inflow = Php 99,410,912,340 + Php 1,385,761,222

Cash Inflow = Php 100,796,673,600

Cash Outflow = Php 45 145 180 180 + Php 34,732,011,050

Cash Outflow = Php 79,877,191,230

Present Net Worth = Php 20,919,482,370

For Design Option 2:

Revenue @ year 10 = Php 12,874,167,950x $\frac{1-1.05^{-10}}{0.05}$

Revenue @ year 10 = Php 99,410,912,340

Salvage Value @ year 10 = Php 2,251,444,882 x $(1 + 0.05)^{-10}$

Salvage Value @ year 10 = Php 1,382,191,853

Operating cost @ year 10 = Php 6,099,161,929 x $\frac{1-1.05^{-10}}{0.05}$

Operating cost @ year 10 = Php 47,096,111,710

Cash Inflow = Php 99,410,912,340 + 1382191853

Cash Inflow = Php 100,793,104,200

Cash Outflow = Php 45 028 897 640 + Php 47,096,111,710

Cash Outflow = Php 92,125,009,350

Present Net Worth = Php 8,668,094,850

For Design Option 3:

Revenue @ year 10 = Php 12,874,167,950 x $\frac{1-1.05^{-10}}{0.05}$

Revenue @ year 10 = Php 99,410,912,340

Salvage Value @ year 10 = Php 2,251,582,827x $(1 + 0.05)^{-10}$

Salvage Value @ year 10 = Php 1,382,276,539

Operating cost @ year 10 = Php 3,142,738,604 x $\frac{1-1.05^{-10}}{0.05}$

Operating cost @ year 10 = Php 24,267,394,450

Cash Inflow = Php 99,410,912,340 +1,382,276,539

Cash Inflow = Php 100,793,188,900

Cash Outflow = Php 45 031 656 540 + Php 24,267,394,450

Cash Outflow = Php 69,299,050,990

Present Net Worth = Php 31,494,137,910

Chapter V

Environmental Management

This chapter will focus on the preparation of the environmental impact assessment which will discuss the socio-economic benefits of the project for each plant options designed.

Socio Economic Benefits

Assessments are done on this matter is to determine the possible outcomes of establishing coal-fired steam power plants in to society in order to attain the government and social acceptability for development. Factors considered for its socio – economic standards include its reliability, affordability, and its present known technologies to support its system.

Reliable in an aspect that having the coal's ability to cope up with the power requirement during peak power demands on a base load or as peak load that can support the grid system to avoid sudden blackouts or power shortages.

Having its fuel, coal being very affordable than any other fuels for energy production due to the resources being abundant, making energy productions cheaper. Alongside the fact that the fuel is cheap, the extraction of coal from coal mine deposits does not require much expenditures on that matter. Consequently, its price remains low compared to other fuel and energy sources.

The production and use of coal as a fuel are well understood, and the technology required in producing it is constantly advancing. Moreover, coal-mining techniques are continuously enhanced to ensure that there is a constant supply of coal for the production of power and energy.

Social and Ethical Considerations

Social acceptance is of a crucial factor for coal-fired steam power plants due to the high pollution factor that contributes to climate change, specifically the smoke it emits that contains carbon dioxide, nitrous oxide, sulfur oxides, fly ashes and particulate matter that can be of major alongside it that it can be harmful to the health of individuals.

Coal creates a lot of problems for the environment. The main one has to do with air pollution (carbon emissions). When burned coal emits high levels of carbon dioxide to the atmosphere, which is the main greenhouse gas that causes global warming. It also emits other pollutants to the air when burned which include mercury, selenium, and arsenic. As far as waste management goes, coal creates a lot of solid waste product such as fly ash, bottom ash, and flue-gas desulfurization sludge. This waste contains mercury, uranium, thorium, arsenic, and other metals that are all harmful for the environment. Coal also pollutes the water. This occurs mostly during the various extraction processes. The process that gets the most exposure, especially around the Appalachian region, is a form of surface mining called mountaintop removal. This process involves extracting entire coal seams from a mountain, hill, or ridge by removing the land or overburden above the seam (which pollutes the water and depletes woodland resources). These are just a few examples of the negative environmental impacts of coal ("Environmental Impacts of Coal").

There are also many social challenges facing the coal industry, but we are just going to focus on the negative health effects and employee safety. Coal can cause a lot of health problems. These problems include respiratory issues (bronchitis, asthma attacks, etc.), black lung, congestive heart failure, and some forms of cancer. Mostly people acquire these sicknesses through the extraction, preparation, combustion, waste storage, and transport of coal, but the general public can also be affected. Employee safety is another social concern that surrounds the coal industry. This type of industry involves the use of heavy equipment, which creates several safety hazards. Fire, explosion, the release of gas and structural failure are some of the other safety risks associated with coal (Fears). Overall, this is a very dangerous job requiring workers to always be alert and aware of their work environment at all times.

Health and Safety Requirements

In any occupation, a level of risk can always be expected while on the job. Some occupations are obviously more dangerous than others, and for many years, the power industry had a reputation of being one of the most hazardous workplace environments. The industry has worked hard to eliminate this reputation, and today it is a much safer work environment than in the past. According to OSHA, there has been a consistent downward trend in the number of annual fatalities and recordable injuries. OSHA reports that for electric power generation and distribution, natural gas distribution, and water sewage and other distribution companies, the number of annual fatalities has decreased from 73 in 2006 to 26 in 2009. The total rate of injury and illness cases has also declined during that same time period from 4.1 cases per 100 workers to 3.3. Power companies typically have two sets of safety exposures: those that exist in the plant and those that exist in the field. Field workers are widely recognized as having the more hazardous occupation, but plant employees also sometimes work under dangerous conditions. Three hazards account for a large majority of the injuries: direct contact with electricity, fires and explosions of boiler equipment, and contact with hazardous chemicals.

The top performers in the power industry realize that implementing a safety program that becomes imbedded in the culture of the organization will not only benefit its workers, but also will help them become more competitive in the marketplace. These organizations realize that the monetary cost associated with implementing an effective safety program is far less than the indirect costs associated with a high frequency of injuries. The industry leaders in safety have identified the most common hazards, developed safety programs, successfully assessed these programs, and understand the correlation between employee safety and profitability.

Waste Management

- **Solid Wastes**

  The sources and amounts of solid waste produced by a coal-fueled steam power plant are dependent mainly on the fuel type, fuel burn rate, and degree of pollutant removal from the boiler exhaust. Other factors, such as fuel burning equipment, may also affect the solid waste production rate. Solid wastes produced at a plant burning fossil fuel include fly ash, bottom ash, pulverizer rejects (if pulverized coal is burned), and flue gas desulfurization scrubber solids (if an FGD device is employed).

Fly ash removed from exhaust gases makes up 60–85% of the coal ash residue in pulverized-coal boilers and 20% in stoker boilers. Bottom ash includes slag and particles that are coarser and heavier than fly ash. Due to the presence of sorbent material, FBC wastes have a higher content of calcium and sulfate and a lower content of silica and alumina than conventional coal combustion wastes. Low-volume solid wastes from coal-fired thermal power plants and other plants include coal mill rejects/pyrites, cooling tower sludge, wastewater treatment sludge, and water treatment sludge. Oil combustion wastes include fly ash and bottom ash and are normally only generated in significant quantities when residual fuel oil is burned in oil-fired steam electric boilers. Other technologies (e.g., combustion turbines and diesel engines) and fuels (e.g., distillate oil) generate little or no solid wastes. Overall, oil combustion wastes are generated in much smaller quantities than the large-volume CCW discussed above. Gas-fired thermal power plants generate essentially no solid waste because of the negligible ash content, regardless of the combustion technology. Metals are constituents of concern in both CCW and low-volume solid wastes. For example after the combustion of the coal in the boiler, 20% of the ash is collected at the bottom of the boiler called bottom ash and 80% is carried along with flue gases called fly ash. Bottom ash is mixed with water and made into sludge form and sent through pumps into the ash ponds. The Electro Static Precipitator is used to collect the ash particles in the flue gases. The era after the introduction of the Electro Static Precipitator has partly protected the environment from harmful gases and hazardous chemicals. Generally dust is collected from the waste in two processes that is mechanically and electrically.

Mechanically is by using filters and electrically is by using Electro Static Precipitators. The ESP is efficient in precipitation of particles from sub microns to large sizes of particles and hence they are preferred to mechanical precipitators. The efficiency of modern ESP‟s is of the order 99.9%.The Electro Static Precipitators have high collecting efficiency, low sensitivity to high temperatures, low pressure drop, limited process controls and an easy and reduced maintenance make the electro static precipitators one of the most reliable and appreciated units available at the moment in the market. Electrostatic precipitators can be used for collecting virtually all kinds of dust coming from coal and oil fired power stations, blast furnaces and industrial furnaces, iron and steel processes, cement factories, municipal solid wastes incinerators , paper mills, wood factories, textile industries, food and pharmaceuticals industries.

- **Air wastes**

  The primary emissions to air from the combustion of fossil fuels or biomass are sulfur dioxide (SO2), nitrogen oxides (NOX), particulate matter (PM), carbon monoxide (CO), and greenhouse gases, such as carbon dioxide (CO2). Depending on the fuel type and quality, mainly waste fuels or solid fuels, other substances such as heavy metals (i.e., mercury, arsenic, cadmium, vanadium, nickel, etc), halide compounds (including hydrogen fluoride), unburned hydrocarbons and other volatile organic compounds (VOCs) may be emitted in smaller quantities, but may have a significant influence on the environment due to their toxicity and/or persistence. Sulfur dioxide and nitrogen oxide are also implicated in long-range and trans-boundary acid deposition.

- **Water Wastes**

  Reliable and safe operation of a coal-fired power plant is strongly linked to freshwater resources. Despite the worldwide pressure to retire existing coal-fired power plants and deny permits for new such power plants, as the demand for the electricity is increasing continuously, humankind will not renounce too soon to the fired-coal power plants. But, thermoelectric generation requires a sustainable and large freshwater source, mostly used to cool and condense the steam after it exists the turbine. Further on, thermoelectric blocks operation causes the industrial pollutant wastewater that is discharged in river's waters.

Installation for water pretreatment is necessary for suspension reduction in the raw water, using several decanters operating on basis of coagulation and flocculation processes. Inside the decanters is also performed a decarbonation process, by the treatment with Ca(OH)2 in order to obtain the precipitation of Ca and Mg soluble salts. Decanted water is stored in tanks, and through a pump system is provided further on towards the demineralized water and softened water installations.

- **Land Area**

Coal – Fired Power plants can be built in a small area of land near a sufficient and available water source such as the sea, unlike geothermal or hydroelectric power plants which accumulate a lot of land mass. Having a long pipe lines for geothermal plants has an effect on the residential that occupy a certain area. Same applies for hydroelectric plants which will require relocation for residents near the area of the plant for the construction of pathways for reservoirs.

Atmospheric Analysis Standards

Emission

The amount and nature of air emissions depends on factors such as the fuel (e.g., coal, fuel oil, natural gas, or biomass), the type and design of the combustion unit (e.g., reciprocating engines, combustion turbines, or boilers), operating practices, emission control measures (e.g., primary combustion control, secondary flue gas treatment), and the overall system efficiency. For example, gas-fired plants generally produce negligible quantities of particulate matter and sulfur oxides, and levels of nitrogen oxides are about 60% of those from plants using coal (without emission reduction measures). Natural gas-fired plants also release lower quantities of carbon dioxide, a greenhouse gas. Some measures, such as choice of fuel and use of measures to increase energy conversion efficiency, will reduce emissions of multiple air pollutants, including CO2, per unit of energy generation. Optimizing energy utilization efficiency of the generation process depends on a variety of factors, including the nature and quality of fuel, the type of combustion system, the operating temperature of the combustion turbines, the operating pressure and temperature of steam turbines, the local climate conditions, the type of cooling system used, etc. Recommended measures to prevent, minimize, and control air emissions include:

- Use of the cleanest fuel economically available (natural gas is preferable to oil, which is preferable to coal) if that is consistent with the overall energy and environmental policy of the country or the region where the plant is proposed. For most large power plants, fuel choice is often part of the national energy policy, and fuels, combustion technology and pollution control technology, which are all interrelated, should be evaluated very carefully upstream of the project to optimize the project's environmental performance;
- When burning coal, giving preference to high-heat-content, low-ash, and low-sulfur coal;
- Considering beneficiation to reduce ash content, especially for high ash coal.
- Selection of the best power generation technology for the fuel chosen to balance the environmental and economic benefits. The choice of technology and pollution control systems will be based on the site-specific environmental assessment(some examples include the use of higher energy-efficient systems, such as combined cycle gas turbine system for natural gas and oil-fired units, and supercritical, ultra-supercritical or integrated coal gasification combined cycle(IGCC) technology for coal-fired units);
- Designing stack heights according to Good International Industry Practice (GIIP) to avoid excessive ground level concentrations and minimize impacts, including acid deposition.

- Considering use of combined heat and power (CHP, or cogeneration) facilities. By making use of otherwise wasted heat, CHP facilities can achieve thermal efficiencies o f70 –90 percent, compared with 32 – 45 percent for conventional thermal power plant.

ASTM International Environmental Standards

ASTM's environmental assessment and risk management standards provide the proper procedures for carrying out specific evaluation procedures for identifying and predicting the possible biophysical, social, and other relevant impacts that certain products and projects may have on the natural environment, as well as on the health and safety of the immediate users of such. These environmental assessment and risk management standards are valuable to environmental scientists and engineers, impact assessment institutions, and real estate firms in implementing the appropriate environmental impact designs to ensure overall prevention of the associated contamination risks.

Table 9

Pollutant Emission of a Coal-Fired Power Plant

Fuel (kgperMW-hr)	Nitrogen Oxides	Sulfur Dioxide	Carbon Dioxide	Particulate Matter
Coal	4.31	10.39	2191	2.23
Coal, life cycle emissions	7.38	14.8	-------	20.3

Source: ASTM EnvironmentalStandards,2011

The Philippines Clean Air Actof1999 (RepublicActNo.8749) outlines the government‘s measures to reduce air pollution and incorporate environmental protection into its development plans. It relies heavily on the polluter pays principle and other market-based instruments to promote self-regulation among the population. Its emission standards for all motor vehicles and issues pollutantlimitationsforindustrylikecoal-firedthermalpowerplants.Emission limit values are laid down by The Department of Environment and Natural Resources, Philippines as implementing Rules and Regulations for Philippines.

Table 10

National Emission Standards for Particulate Matter for Stationary

	Emission source		
	Fuel burning equipment		Other Stationary Sources
	Urban and industrial area	Other area	
Emission Limit, (mg/m3)	150	200	200

Source: DENR Administrative Order No. 2000 - 81, 7 Nov 2000

Table 11

National Emission Standards for Sulphur Oxides for Stationary Sources

	Existing source		New source	
	Fuel burning equipment	Other source	Fuel burning equipment	Other source
Emission Limit, (mg/m3)	1500 as SO_2	1000 as SO_2	700 as SO_2	200 as SO_2

Source: DENR Administrative Order No. 2000 - 81, 7 Nov 2000

Table 12

National Emission Standards for Nitrogen Oxides for Stationary

	Fuel Burning Steam Geanerator		Other sources	
	Existing source	Newsource	Existing source	Newsource
EmissionLimit, (mg/m^3)	1500 as NO_2	1000 as NO_2	1000 as NO_2	500as SO_2

Source: DENR Administrative Order No. 2000 - 81, 7 Nov 2000

Environmental Toxicology Standards

Water Treament Standards

Design Option 1

Using the data obtained from Technical calculations,

Heat Rate=8258843.031KJ/MW-hr (*DesignOptionNo.1*)

Thermal Efficiency= 42.23028756% (*DesignOptionNo.1*)

Using able10, use emission factors under bituminous coals

Emissions/MW-hr= (emission factor)(Heat Rate) (Plant Efficiency)

$$\frac{\boldsymbol{SOx\ emissions}}{\boldsymbol{MWh}} = 3.5\,x\,\frac{10^{-7}Kg}{KJ} \times 8258843.031\,\frac{KJ}{MWh} \times 0.4223028756$$

$$\frac{\boldsymbol{SOx\ emissions}}{\boldsymbol{MWh}} = \mathbf{1.220706606}\frac{\boldsymbol{kg}}{\boldsymbol{MWh}}$$

$$\frac{\boldsymbol{NOx\ emissions}}{\boldsymbol{MWh}} = \ 3.0\ x\frac{1^{-7}Kg}{KJ} \times 8258843.031\frac{KJ}{MWh} \times 0.4223028756$$

$$\frac{\boldsymbol{NOx\ emissions}}{\boldsymbol{MWh}} = \mathbf{1.046319948}\frac{\boldsymbol{kg}}{\boldsymbol{MWh}}$$

$$\frac{\boldsymbol{COx\ emissions}}{\boldsymbol{MWh}} = 1.14 \times 10^{-4}kg/KJ \times 8258843.031\frac{KJ}{MWh} \times 0.4223028756$$

$$\frac{\boldsymbol{COx\ emissions}}{\boldsymbol{MWh}} = \mathbf{397.6015804}\frac{kg}{MWh}$$

From Stationary Sources, addition of limestone as scrubber will control SO_2 from 75-80%.

Design Option 2

Using the data obtained from Technical calculations,

Heat Rate= 11198873.38 KJ/MW-hr (*DesignOptionNo.2*)

Thermal Efficiency= 40.2706154% (*DesignOptionNo.2*)

UsingTable10, use emission factors under bituminous coals

Emissions/MW-hr= (emission factor)(Heat Rate) (Plant Efficiency)

$$\frac{\boldsymbol{SOx\ emissions}}{\boldsymbol{MWh}} = 3.5\ x\frac{10^{-7}Kg}{KJ} \times 11198873.38\frac{KJ}{MWh} \times 0.402706154$$

$$\frac{\boldsymbol{SOx\ emissions}}{\boldsymbol{MWh}} = \mathbf{1.57844933}\frac{kg}{MWh}$$

$$\frac{\boldsymbol{NOx\ emissions}}{\boldsymbol{MWh}} = \ 3.0\ x\frac{10^{-7}Kg}{KJ} \times 11198873.38\frac{KJ}{MWh} \times 0.402706154$$

$$\frac{\boldsymbol{NOx\ emissions}}{\boldsymbol{MWh}} = 1.352956568\frac{\boldsymbol{kg}}{\boldsymbol{MWh}}$$

$$\frac{\boldsymbol{COx\ emissions}}{\boldsymbol{MWh}} = 1.14 \times \frac{10^{-4} kg}{KJ} \times 11198873.38 \frac{KJ}{MWh} \times 0.402706154$$

$$\frac{\boldsymbol{COx\ emissions}}{\boldsymbol{MWh}} = \mathbf{514.123496} \frac{\boldsymbol{kg}}{\boldsymbol{MWh}}$$

From Table1.1-1 of Control Techniques For Sulfur Dioxide Emissions

From Stationary Sources, addition of limestone as scrubber will control SO_2 from 80–95%.

Design Option 3

Using the data obtained from Technical calculations,

Heat Rate= 5770486.52 KJ/MW-hr (*DesignOptionNo.3*) Thermal

Efficiency= 46.80238288% (*DesignOptionNo.3*)

UsingTable10, use emission factors under bituminous coals

Emissions/MW-hr= (emission factor)(Heat Rate) (Plant Efficiency)

$$\frac{\boldsymbol{SOx\ emissions}}{\boldsymbol{MWh}} = 3.5\ x \frac{10^{-7} Kg}{KJ} \times 5770486.52 \frac{KJ}{MWh} \times 0.4680238288$$

$$\frac{\boldsymbol{SOx\ emissions}}{\boldsymbol{MWh}} = \mathbf{0.9452538183} \frac{\boldsymbol{kg}}{\boldsymbol{MWh}}$$

$$\frac{\boldsymbol{NOx\ emissions}}{\boldsymbol{MWh}} = 3.0\ x \frac{10^{-7} Kg}{KJ} \times 5770486.52 \frac{KJ}{MWh} \times 0.4680238288$$

$$\frac{\boldsymbol{NOx\ emissions}}{\boldsymbol{MWh}} = \mathbf{0.8102175585} \frac{\boldsymbol{kg}}{\boldsymbol{MWh}}$$

$$\frac{\boldsymbol{COx\ emissions}}{\boldsymbol{MWh}} = 1.14 \times \frac{10^{-4} kg}{KJ} \times 5770486.52 \frac{KJ}{MWh} \times 0.4680238288$$

$$\frac{\boldsymbol{COx\ emissions}}{\boldsymbol{MWh}} = \mathbf{307.8826722} \frac{kg}{MWh}$$

Design Option 1

First design utilizes pulverized coal as it enters the boiler. Its fly-ash emission from the boiler amounts to 75-85% of the ash in the fuel. Some ashes are collected at the bottom of the boiler, while those fly-ashes are collected by an electrostatic precipitator in order to minimize its emission. The electrostatic precipitators are installed before the induced draft fan.

Additional equipment for this design is the use of air preheater. An air preheater (APH) is a term used to describe a device designed to heat air before another process with the primary objective of increasing the thermal efficiency of the process.

Design Option 2

In design option 2, the coal-fired thermal power plant is the same as to that of design option 1, installing all the auxiliary equipment mentioned in the first design. The only difference is that the equipment in this design will be doubled compared to the second option. One electrostatic precipitator collects the excess fly ashes to control particulate matter for each boiler which controls its fly-ash emission and particulate matter. It also uses magnetic separator, which are installed in the coal conveying system for coal preparation before entering the pulverizer. Air preheater are also installed for both units in order to utilize the heat from the exiting flue gases.

Design Option 3

Design option 3 uses pulverized coal and its fly-ash emission from the boiler amounts to 80 to 90% of the ash in the fuel. To take control of this fly-ash emission, the installation of electrostatic precipitator this collects the excess fly ashes to control particulate matter. Typically, these collecting devices are installed before the induced draft fan. But these fly-ash causes erosion of the fan blades and housing.

Additional equipment for this design is the use of magnetic separator. Like other types of coal equipment, certain preparation of the coal is necessary before

feeding it to pulverizer. Magnetic separator are usually installed in the coal conveying system to remove the larger pieces of tramp iron, cloth, wood, straw and other unnecessary objects so that they will not be collected in the mill and create fire hazard.

Chapter VI

DESIGN TRADE-OFFS

The chapter will cover the evaluation of the three design options that was presented in the previous chapters. From the different multiple realistic constraints given, three were chosen namely technical, which is the efficiency of each plant, economical, and environmental regarding the smoke emissions. This will be considered in order to select the best possible design option through the use of a design philosophy, Pareto Optimum.

Table 13

Realistic Constraints Considered in the Design Trade – Offs

Realistic Constraints	Design Option 1	Design Option 2	Design Option 3
I. Technical			
A. Thermal Efficiency	42.23028756%	40.2706154	46.80238288
II. Economical			
A. Net Present Worth	Php16,272,498,060	Php36,754,703,700	Php26,125,413,610
III. Environmental			
A. SO_x emission	1.220706606 kJ/Mw-hr	1.57844933 kJ/Mw-hr	0.9452538183 kJ/Mw-hr
B. NO_x emission	1.046319948 kJ/Mw-hr	1.352956568 kJ/Mw-hr	0.8102175585 kJ/Mw-hr

C. CO_2 emission	397.6015804 kJ/Mw-hr	514.123496 kJ/Mw-hr	307.8826722 kJ/Mw-hr

Technical Aspect

- **Thermal Efficiency**

A table is shown below for the interpolation of the efficiencies of the three design options that were made. From the solved efficiencies, ranges were optimized to 40% to 50% scaled 1 to 10 where 1 is of lowest value (40%) and the 10 is of the highest value (50%)

Table 14

Interpolation of Values for Thermal Efficiency

	Efficiency	Numerical Value
	40	1
Design Option 1	42.23028756	3.007
Design Option 2	40.2706154	1.24355386
Design Option 3	46.80238288	7.122144592
	50	10

Economical Aspects

- **Net Present Value**

A table is shown below for the interpolation of the net present value of the three design options that were made. Ranges were optimized to 10T to 40T scaled 1 to 10 where 1 is of lowest value (10T) and the 10 is of the highest value (40T)

Table 15

Interpolation of Values for Thermal Efficiency

	Net Present Value	Numerical Value
	10T	1
Design Option 1	16T	2.8
Design Option 2	36T	8.8
Design Option 3	26T	5.8
	40T	10

Environmental Aspects

The Environmental aspects were evaluated with the use of pollution emission standard limits that were given on the previous chapter, wherein this will rate the SO_x, NO_x and the Carbon Dioxide emissions that were generated by each design options which are expressed in lb/MW-hr.

- SO_x emission

Table13 shows the interpolation of the values for SO_x emission per MW-hr. Limits are set according to the standard emission data from ASTM Environmental Standards shown in Tables of the previous chapter. The scaled value of SO_x emissions solved by giving a value of 10 to 0 emission and 1 to 10.39.

Table 16

Interpolation of Values for Thermal Efficiency

	SO_x Emission	Numerical Value
	10.39	1
Design Option 1	1.220706606	8.942602555
Design Option 2	1.57844933	8.632719541
Design Option 3	0.9452538183	9.181205135
	0	10

- NO_x emission

Table13 shows the interpolation of the values for NO_x emission per MW-hr. Limits are set according to the standard emission data from ASTM Environmental Standards shown in Tables of the previous chapter. The scaled value of NO_x emissions solved by giving a value of 10 to 0 emission and 1 to 4.31

Table 17

Interpolation of Values for Thermal Efficiency

	Efficiency	Numerical Value
	4.31	1
Design Option 1	1.046319948	7.815109157
Design Option 2	1.352956568	7.17480067
Design Option 3	0.8102175585	8.308130388
	0	10

- CO_2 emission

Table13 shows the interpolation of the values for CO_2 emission per MW-hr. Limits are set according to the standard emission data from ASTM Environmental Standards shown in Tables of the previous chapter. The scaled value of CO_2 emissions solved by giving a value of 10 to 0 emission and 1 to 1000

Table 18

Interpolation of Values for Thermal Efficiency

	Efficiency	Numerical Value
	1000	1
Design Option 1	397.6015804	6.421585776
Design Option 2	514.123496	5.372888536
Design Option 3	307.8826722	7.22905595

	0	10

Pareto Optimum

These design analysis will allow the designers to assign the degree of importance on the constraints that were used in order to evaluate the three design options. In assigning the degree of importance for each of the realistic constraint must sum up to 10. The table below will present the values for each constraint alongside the degree of importance.

Table 19

Pareto Optimum Chart

Multiple Realistic Constraints	Design Option No.1	Design Option No.2	Design Option No.3	Degreeof Importance
TechnicalAspect				
Thermal Efficiency	**3.007**	**1.244**	**7.122**	**5**
EconomicAnalysis				
NetPresentValue	**2.8**	**8.8**	**5.8**	**1**
Environmental Impact				
SO_xemission	**8.943**	**8.632**	**9.181**	**½**
NO_xemission	**7.815**	**7.174**	**8.308**	**½**
CO_2emission	**6.422**	**5.373**	**7.229**	**3**

For Design OptionNo.1

= 3.007(5) + 2.8(1) + 8.943(0.5) + 7.815(0.5) + 6.422(3)

DO 1= 45.48

For Design OptionNo.2

= 1.244(5) + 8.8(1) + 8.632(0.5) + 7.174(0.5) + 5.373(3)

DO 2= 39.042

For Design OptionNo.3

= 7.122(5) + 5.8(1) + 9.181(0.5) + 8.308(0.5) + 7.229(3)

DO 3 = 71.8415

Based on the evaluation using Pareto optimum, it recommends using design option 3 as the best design to be proposed for constructing a coal fired power plant.

Chapter VII

Project Construction Execution Plan

The chapter will discuss the construction management and strategy, quality control and assurance, work scheduling and overall management and commissioning of the project on the selected design proposal of a coal fired power plant based on Pareto optimum.

I. Construction Management and Strategy

The designers' first priority before constructing a power plant is to conduct appropriate researching and surveying of the desired location. There are many factors to be considered namely water access, roads, surface condition and fuel source. Water and road access is vital for the plant's maintenance and also to transport necessary equipments and fuel with ease. Surface condition should also be considered to ensure the strength of foundation of the plant. Fuel source should also be close to the location of the plant for less cost of transportation.

The necessary data and information that was gathered about the location, procurement, design, construction and commissioning will be assessed by the contractor, engineering and construction groups. The use of space should be maximized and also comply with regulatory restrictions. A regular visitation of construction manager is required to evaluate the development of the construction. Safety is also on the top priority during construction.

Next is the construction of plant's foundation. It will be done using heavy equipments like excavators, back hoe and cranes. As for the installation of electrical workings, it will be headed by the electricians. Construction crew will lead the building of roads and transmission lines.

The last phase in the power plant construction will be the linking of the plant to the power grid for it to be possible to begin generation of electricity and the plant's operation.

II. Quality Control and Assurance

Quality control and assurance is a division that will be assigning the personnel who would manage and supervise the activities in line with controlling and monitoring and assessment of quality standards.

The job of the quality control and assurance department is to plan programs and activities for quality output and standards. The progress will be then evaluated through monitoring.

In case of difficulties during generation, the department join with specialist or professional to resolve the trouble as fast as possible.

The monitoring should be weekly and monthly to maintain target efficiency. This monitoring can be a pressure and leakage testing, vibration testing, non-destructive testing and visual inspection.

A. Engineering Construction Technology

Boiler and steam turbine needs pipes and valves for conveying of steam. Given that the safety is at most priority, these piping and valves have their own appropriate design to ensure the quality and safety during operations. Construction of piping, cable trays, supports, equipment and local instrumentation panels on the land or ground will promote safety and work efficiency.

B. Preventive Maintenance Technology

To prevent chance of failing, a piece of equipment should be cleaned, checked up and maintained. Preventive maintenance keeps the equipments in condition to work to promote safety in the plant.

The maintenance can be either time or usage trigger. Time based maintenance is based on a calendar schedule while usage based maintenance is scheduled on a certain mileage of an equipment.

C. Plant Design System

During the firing of fuels, receiving, storing and handling of coal must have a certain design and installation system. It also the same system is used for handling limestone for boiler reagent. Handling and processing of fuel should be considered because firing of fuel produces ash byproducts.

Comprehensive assessment of condition of current systems and components will be conducted duting the conceptual design stage of the project. Existing systems and components can be reused, replaced or upgraded. The design report should contain the records of the detailed system descriptions.

D. Air Quality Control System

As the world's need for accessible power grows, coal power plants will continue to be a vital method to meet this demand. However, to limit emissions, it is essential that coal-fired power plants provide maximum efficiency and rely on leading air quality and pollution control technologies. An air quality control system aims to do that.

With nearly 900 billion tons of reserves, coal power remains an integral part of the energy mix that includes renewables as well as gas power generation. Today, 40% of the world's electricity comes from coal power and we predict that amount will decrease only slightly, to 30%, over the next decade.

With this 30% predicted usage, emissions from coal power plants will continue to be a major area of focus. The construction of plant should focused on reducing environmental impact, and across all global sources of power generation that countries need to fuel economic development.

E. Turbine Generator and Balance of Plant Systems

The existing components and piping system in a plant was studied to verify if it is suitable in terms of operating and design conditions. The efficiency of the plant can be maintained by upgrading or replacing these components and systems.

The plant systems' old control systems need to be monitored and controlled. The turbine interfaces, boiler protection and balance in the system will be monitored and controlled by the new distributed control system.

The consideration of boiler logic design provisions and B&V, together with turbine water induction prevention provision will be important. A program will be made to execute the logic design for the boiler and BOP systems. The miscellaneous improvements in the plant should contain the screw-type air compressors, additional air dryers and titanium plate-type heat exchangers installations

F. Valve Line-Up Requirements

In testing the boiler efficiency test, the boiler must usually in the coordinated control mode during the test except of drain and vent systems, blow down systems and soot blower system.

Each testing period, a walk down must be done before starting the test. The purpose of this is to verify the closed position of the feedwater system valves and main steam valves.

G. Emission Monitoring System

With issues over the environment and carbon dioxide (CO2) so prolific in both the public and political eye, in addition to concerns over the more ‘conventional’ pollutants of nitrogen oxides (NOx) and sulphuer oxides (SOx), reducing emissions has become an enormous proposition for the power generation industry. Coal and oil fired power generating plants face one of the most difficult set of circumstances relating to the need to meet increasingly strict regulatory requirements.

Environment Protection Agency (EPA) Standards will be considerd for the environment’s protection. The wastes of the plant will be have a certain requirement before it released to the environment, this requirement will be set by the management in accordance with the DENR standards.

The water temperature should be cooled before releasing to the Tayabas bay. The smoke stack should have a certain height to protect the neighboring community from exhaust gas.

There are many common sources of pollution from a power plant like gaseous products from the boiler, dust from coal pipe, fly ash from the chimney or stack, thermal pollution in the rivers due to passage of water circulating in the condenser, contaminated chemicals from liquid effluents and noise from the boiler. To reduce the pollution to the environment, there should be necessary requirements or standards to make sure that the quality and health policy is observed.

H. Risk Management System

The concern of risk management has continuously increased in construction projects. Projects have a high level of risk and complexity, which results in greater possibilities of cost overruns and schedule conflicts when compared with local projects. Therefore, the goal of risk management is to improve project performance by systematically identifying and assessing project risks, developing strategies to reduce or avoid risks and to maximize opportunities.

III. Work Scheduling and Overall Management

Table 15 shows the project schedule for the development of the proposed power plant. It is made to show how the construction of the selected best design option of the power plant is scheduled and managed.

Table 20

Project schedule for the development of the proposed power plant

Task	2017				2018				2019				2020				2021				2022				2023			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Project Management Plan																												
Overall Permitting Activities																												
Detailed Engineering Design																												
Design Review																												
Construction																												
Construction Review																												
Initial Synchronizatio n																												
Fuel and Power Plant Testing																												

IV. Commissioning of the Project

All the equipments should be checked correctly before operation to ensure the safety of the plant. The assessment of the equipment condition shoulde be recorded to monitor its proficiency and safety.

A. Administrative Manual

The administrative manual describes the essential administrative and management requirements to implement the project on time, within budget, and in accordance with policies and procedures.

B. Progress Monitoring Procedures

Progress monitoring procedures will be used to evaluate the regularly scheduled meeting to improve the plan and even give solutions or alterations if necessary.

C. Technical Manual

Technical manual contains instructions for installation, operation, use, maintenance, parts list, support, and training requirements for the effective deployment of an equipment, machine, process, or system.

D. Checkout Procedures

Check out procedures includes the startup and checkout procedures of each engineering system. These procedures were set by professionals to cope up within an engineering system level

E. Turnover Packages

Turnover packages describe the startup segment of the project which begins when the facility, or a portion of the facility, is mechanically and operationally ready to begin startup checkout activities. The startup segment ends when all testing phases have been completed and the portion of the facility, or engineering system, is turned over to plant operations for control.

F. Startup Schedule

A detailed schedule to effectively monitor all startup activities beginning with the initial system turnover from construction to final system turnover to plant operations would be necessary. The startup schedule is formulated to support the major project milestones and to ensure that the components and equipment for each milestone have been thoroughly tested and checked out.

G. Commencement of Acceptance Tests

Acceptance test phase of the project will begin after each engineering system undergoes the following procedures namely startup, checkout and testing activities, mechanical/electrical completion of turnover from construction to startup and operational system tests and ultimate turnover from startup to plant operations.

CHAPTER VIII

SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the summary of the design, conclusions and recommendations.

Summary of the Design

After the evaluation of the gathered data and information, the following are the summary of the design:

1. The proposed location of the 405 MW steam power plant is located in Lucena City, Quezon wherein a large area from the vicinity will be covered by the plant including the province of and municipalities of Quezon.
2. Design Option 3 was considered as the best design option based on Pareto Optimum.
3. The capital expenditure of the best design derived from economic analysis is Php 45,031,656,540 with total operational expenditure of Php 5,499,792,557.
4. The best design option has an over-all efficiency of 46.80238288%.
5. Considering the cash-in flows and out flows and the time value of money the proposed coal fired steam power plant has a payback period of approximately 1.5 years.

Conclusions

Based on the mentioned finding of the design above, the following conclusions were brought up:

1. The design and evaluation of each equipment and facilities were appropriate.
2. The feasibility of the proposed coal-fired power plant seems to be possible considering the aspects of design and viable plant factors.
3. Through the use of related references and the use of internet, technical information has been gathered. It provides the equipment catalog that presents the specifications and prices.
4. The obtain values are within the range of the available power plant components.

Recommendations

Further study and evaluation is needed in order to ensure the full advantage of the proposed 405 MW coal-fired power plant. The designers would like to recommend the following:

1. Further research of developed and advanced design to improve the operation of the existing power plant.
2. Additional consultation from concerned person to gather further information to improve the design and feasibility of the actual construction.
3. Awareness of new power plant technologies should be kept in mind to further increase the efficiency.

4. Further understanding of new techniques and principles in line with power plant design would be necessary to produce best plant layout for the existing design.