1. Introduction

This is a summary report of the Feasibility Study of the 180 MW power plant, which was carried out from February 2000 to November 2001.

NEWJEC Inc., Osaka, Japan, carried out this feasibility study in association with GCP International, Inc., USA. In addition, as the subcontractors of NEWJEC, SIAM TONE co., Ltd., Thailand and TEAM Consulting Engineer Management Co., Ltd., Thailand carried out the detailed site investigation.

1.1. Background of the Study

In Cambodia, various industries and infrastructures, as well as power system, were damaged in years of civil war. Recently, Cambodia has just started their restoration including power generation plant and transmission/distribution system. At present, Cambodian power systems are isolated. And power generation facilities rely on the small diesel power plants and those capacity is not enough to supply the required power demand. In addition, the average power tariff in 2000 is about 14.6 ¢/kWh which is quite high comparing to the neighboring countries. Therefore, the Government of Cambodia has been aspiring to construct a new and economically superior large capacity power plant

Based on this situation, the Government of Cambodia requested the Japanese Government to conduct the Feasibility Study on Sihanoukville Combined Cycle Power Development Project. In response of this request, the Japanese Government decided to conduct this feasibility study through the studies by Projection Formation Team and Preliminary Study Mission.

1.2. Objective of the Study

Objective of the Study is to conduct the Feasibility Study on the Sihanoukville Combined Cycle Power Development Project. Further to be carried out is to provide the technical transfer on the power development study to the counterpart engineers of MIME and EDC during a period of the Study.

The type of power plant is proposed to be Gas Turbine Combined Cycle with 90 MW × 2 at present, however, the appropriateness of the installed capacity shall be reviewed in the course of the Study. The optimum power generation system will be selected by comparing the combined cycle with various types of thermal power plants such as steam plant and diesel plant.

2. Power Development Plan

2.1. Power Demand Forecast

2.1.1. Census and Economic Related Index

(1) Population and Population Distribution Data

Full scale population census in Cambodia over the country has not been carried out until very recently from 1962. As explained above, there is less statistical data on the population. However, the Cambodian Government is forecasting that the population will steadily be growing as follows.

	Population (million person)	Population Increase
Year 2000	11.7	3.0 %
Year 2005	13.5	2.8 %
Year 2010	15.4	2.6 %
Year 2015	17.8	2.4 %

(2) Economic Index

GDP in Cambodia has been steadily increasing at the rate more than 7% from 1992 to 1996. However, the GDP increase in 1997 and 1998 stayed at the low level because of the political change. As the political situation now becomes stable, it is expected that the GDP will steadily increase again at the rate of 4 to 6 %.

2.1.2. Power Demand Forecast

(1) Actual Records of the Power Demand in Cambodia

Peak power demand in Cambodia reached 387 GWh in energy generation, and 97 MW in generation output availability, respectively in 1999. The power demand has been steadily increasing after 1995. Increase of power demand is influenced, on macro basis, by the increase of population, GDP, etc. Therefore, it is considered that power demand will increase steadily.

(2) Power Demand Forecast of the Cambodia Power Sector Strategy

According to the Cambodia Power Sector Strategy, it is forecasted that the peak demand will increase to 746 MW and the generated power will increase to 2,634 GWh in 2016. The average annual growth rates of those are 12% and 9.4%, respectively. This demand forecast is based on the Power Transmission Master Plan & Rural Electrification Strategy by the World Bank.

The demand forecast was carried out, in the following manner;

(a) Determination of the representative areas,
(b) Demand forecast of each representative area,
(c) Demand forecast of the other areas using the data of the representative area which has similar economic features,
(d) Summation of each area demand.

(3) Revision of the Previous Forecast

Power demand forecast in Cambodia is based on the IBRD Report. According to the comparison between IBRD demand forecast and the actual record, the actual record is slightly lower than the IBRD forecast. Therefore, the demand forecast should be revised.
Power demand forecast was revised by means of macro method, according to the data obtained during JICA mission's study, including the actual record in 2000.

As a result, according to the comparison of power demand forecasts made by IBRD and revised by JICA Study Team, the revised forecasts are lower than the IBRD's forecasts.

(4) Effects by Economic Development Plan

At present, Cambodia government has several economic development plans, such as, Industrial zone and free-export-processing zone in Sihanoukville, industrialization plan of areas along with National Road Rout 4 (Phnom Penh - Sihanoukville), free-export-processing zones at the border areas with Thailand, etc. However, every plan is only preliminary planning stage and there is no specific plan.

At any rate, likely industries in Cambodia are light industries like a garment and heavy or chemical industries, which consume much electricity, could not be expect in near future. Therefore, the effect by economic development plans to the power demand was not considered in the study.

(5) Demand Forecast taking account of Grid Connection

It is necessary to develop the demand forecast taking account of the connection of each area load to the main grid, for the study of power development program. Therefore, the load distribution is based on the IBRD Report.

In addition to Base Case (mentioned above), Low Case is also considered taking into account uncertainty of economic growth, which is based on a demand growth rate of 10% less than that of Base Case.

2.2. <u>Optimum Power Development Program</u>

2.2.1. Power Development Program

(1) Projects of Power Development

According to MIME/EDC, Cambodian Power Development Program as of the beginning of 2000 was as follows:

- 2001 : IPP2 Combined Cycle Power Project (60 MW)
- 2002 : Kirirom and Prek Thnot Hydropower Projects (29 MW)
- 2003 : Power import from Vietnam and Thailand
- 2003 - 5: Temporary power purchase from New IPP (15 MW until 2005)
- 2004 / 5: Sihanoukville Combined Cycle Power Project (90 MW × 2)
- 2008 : Kamchay Hydropower Project (47 - 127 MW)
- 2011 : Battambang Hydropower Project (60 MW)
- 2012 : Stung Atay Hydropower Project (110 MW)
- 2014 : New Combined Cycle Power Project (90 MW)
- 2016 : Russei Chrum Hydropower Project (125 MW)

The above development plan has been already modified as follows:

- The construction of IPP2 is suspended.
- Kirirom and Prek Thnot Hydropower (29 MW) is changed to;
  2003 : Kirirom Hydropower (12 MW)
- Operation time of Temporary IPP (15 MW) is changed to “from 2000 to 2003”.

(2) Sihanoukville Combined Cycle Power Project

In the above program, the Sihanoukville Project Stage 1 (90 MW) and Stage 2 (90 MW) are planned to be commissioned in 2004 and 2005, respectively. However, taking account of the practical construction schedule, the commissioning year of the Stage 1 is 2006 at the earliest.

(3) Power Import

Power import from Vietnam is planned to be commissioned in 2003, however the transmission project by IBRD is already delayed, so it may possibly be in 2004. Available import power is designed to be limited to 80 MW until 2005 and 200 MW after 2005.

2.2.2. Study on the Least Cost Power Development Program

(1) Data of Power Plants

Data of existing power plants and planned plants for the study on power development program are shown in Table 2.2-1 and Table 2.2-2. In these tables, standard data was substituted for unavailable data.

Table 2.2-1 Existing and Committed Major Plants

Plant Name	Capacity (MW)	SMD (days/yr)	FOR (%)	Plant Life (years)	Fixed O/M Cost ($/kW-yr)	Variable O/M Cost ($/MWh)	Fuel Type	Heat Rate (MMBTU/ MWh)	Fuel Cost ($/ MMBTU)	Installed Year
IPP1	35	28	6	20	21	3	HFO	9.0	3.99	1997
Temporary IPP	15	28	6	20	21	3	Diesel	9.0	6.02	2000-3
C2 (1)	18	28	6	20	21	3	HFO (3)	11.9	3.99	1999 (Rehabili.)
C3 (2)	14.2	28	6	20	21	3	Diesel	11.9	6.02	1996
C5	10	28	6	20	21	3	Diesel	11.9	6.02	1995
C6	18	28	6	20	21	3	HFO (3)	11.9	3.99	1996

SMD : Scheduled maintenance day (Source : EDC, Consultant's data-base)
FOR : Forced outage rate

Note : (1) Demolished in 2004, (2) Demolished in 2004 and 2006, (3) Sifted to HFO in 2000

Table 2.2-2 Planned Alternative Plant Specifications and Restrictions

Plant Name	Capacity (MW)	Annual Hydro Energy (GWh) per Unit	Total Installed Cost ($/kW)	SMD (days/ yr)	FOR (%)	Plant Life (years)	Fixed O/M Cost ($/kW -yr)	Variable O/M Cost ($/MWh)	Fuel Type	Heat Rate (MMBTU /MWh)	Fuel Cost ($/ MMBTU)	Maximum Units Allowed in Study	Maximum Units Allowed per year	First Year Available
Sihanoukville	90	-	870	49	8	20	20	2.5	natural gas	6.83	4.0	2	2	2006
Kirirom	12	53	2,027	6	1	40	10	0.25	hydro	-	-	1	1	2003
Kamchay	127	558	1,961	6	1	40	10	0.25	hydro	-	-	1	1	2008
Stung Atay	110	588	1,422	6	1	40	10	0.25	hydro	-	-	1	1	2011
St. Russei Chrum	125	668	2,197	6	1	40	10	0.25	hydro	-	-	1	1	2012
Battambang 1 & 2	60	307	1,900	6	1	40	10	0.25	hydro	-	-	1	1	2016

SMD : Scheduled maintenance day (Source : EDC, Consultant's data-base)
FOR : Forced outage rate

(2) Results of the Study

For the study, the following criteria were adopted.

- Reserve margin : 15% minimum
- Loss of load hours : 24 hours maximum

The results of the study on the least cost power development program is shown in Fig.2.2-1. According to the study result, the Sihanoukville Project (Stage 1 of 90

MW and Stage 2 of 90 MW) should be commissioned in 2006 and 2008 for Base Case, and 2006 and 2009 for Low Case, respectively. However, the commissioning time of 2006 for Stage 1 is not determined by a required generation capacity, but by the earliest possible completion time of Stage 1. The Sihanoukville Project is required to be commissioned earlier than the follow-on import from Vietnam, because this project has an advantage over the import power from Vietnam. Therefore, this project should be carried out early.

While, a short construction interval of two years in Base Case would require further detailed study in consideration of a possible financial arrangement, issues raised by overlapped construction works, etc.

- Remarks -

Feasibility studies of Kamchay hydropower projects have not yet been completed, therefore, the JICA Study Team could not obtain accurate data about hydropower projects by the time the Final Report was prepared. After completion of the feasibility studies of hydropower projects power development plan shall be reviewed.

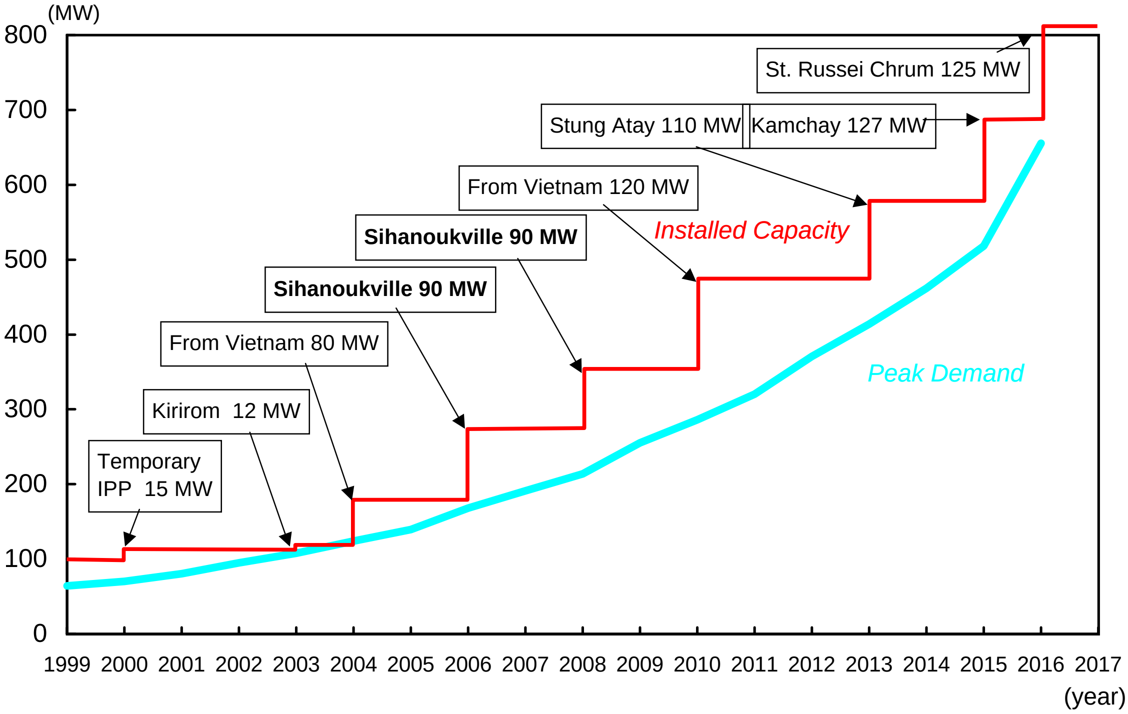


Fig.2.2-1 (1) Proposed Power Generation Expansion Plan (Base Case)

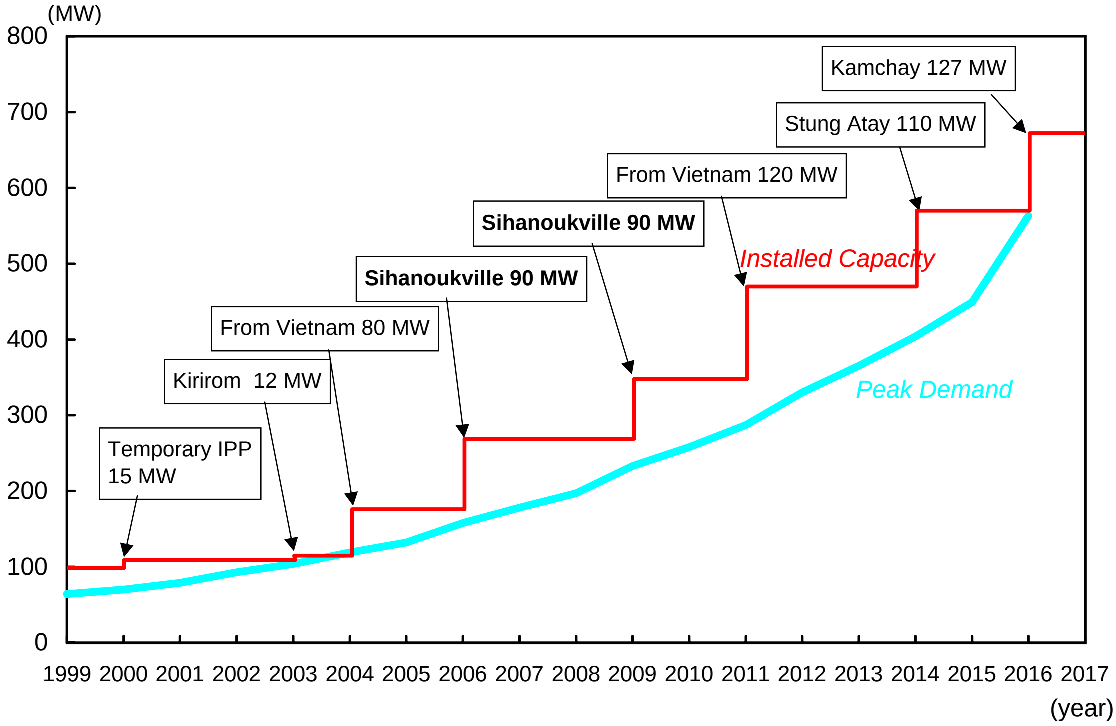


Fig.2.2-1 (2) Proposed Power Generation Expansion Plan (Low Case)

2.3. Power System Planning

Power transmission system in Cambodia is still undeveloped on the whole, excluding the 115 kV transmission system around Phnom Penh City. At present, almost all areas relies on the power supply by the scattered small power plants independently. To supply the stable power from newly constructed power plants to consumers effectively, it is indispensable to develop the power transmission system in Cambodia.

According to the power system expansion plan of EDC, the double circuits, 220 kV transmission lines between Sihanoukville and the load center, Phnom Penh City will be constructed. The Sihanoukville Combined Cycle Power Plant will be connected to this transmission system. For justification of this transmission system, the system analysis such as load flow analysis, fault analysis, stability analysis, etc. were carried out. The data include some standard data as substitutes for unavailable data.

The studied transmission expansion plan until 2010, which was informed by EDC, is shown in Fig.2.3-1.

For the analysis, the criteria will be applied as shown in Table 2.3-1

Table 2.3-1 Criteria of Cambodian Power System

Operation limit of equipment	Current flow of each equipment should not exceed each rated capacity
System stability	In case that 3-phase fault is occurred in power system, the system should recover the stable condition within around 10 seconds after fault clearing. The fault clearance times are estimated to be 0.1 seconds for 220 kV line and 0.14 seconds for 115 kV line.
System frequency	Not to exceed 50 ±0.5 Hz under normal condition, and 47 Hz to 52 Hz under fault condition.
Voltage deviation	Not to exceed ±5% under normal condition, and -10% to + 5% under fault condition.
Short circuit current level	Allowable interrupting circuit current of circuit breaker is set at 31.5 kA as design value.

2.3.1. Load Flow Analysis

Load flow analysis was carried out for the power system in 2006 and 2010.

As the results of load flow analysis for the power system in 2006 and 2010, each load flow meets the above criteria under normal and fault condition. However, voltage decrease at 115 kV substations become severe in 2010 under fault condition. Therefore, 40 MVA shunt capacitance is necessary to be installed at some substations.

2.3.2. Stability Analysis

Stability analysis for the power system in 2006 and 2010 was carried out. The following condition was assumed.
- 3 phase fault near Sihanoukville Plant, open the faulted circuit without reclosing

As the results of stability analysis for the power system in 2006 and 2010, each power swing converges within 10 seconds.

2.3.3. Fault Analysis

As the results of fault analysis for the short circuit current at each station in 2006 and 2010, each short circuit current is lower than the design level 31.5 kA.

2.3.4. System Frequency Analysis

Power system frequency should be kept within the criteria, even if one generator unit is disconnected. In other words, generation unit capacity should be limited, taking account of frequency decrease due to the generation unit trip. As mentioned above, generation unit capacity should be limited to about 15% of total generation power.
But then, the total generation power of the power system will be large, year by year. Therefore, a smaller unit capacity is not recommendable, in terms of plant efficiency.

Around 30 MW unit capacity is recommendable, on condition that the load shedding due to generation unit trip is acceptable to some extent (less than 10 MW).

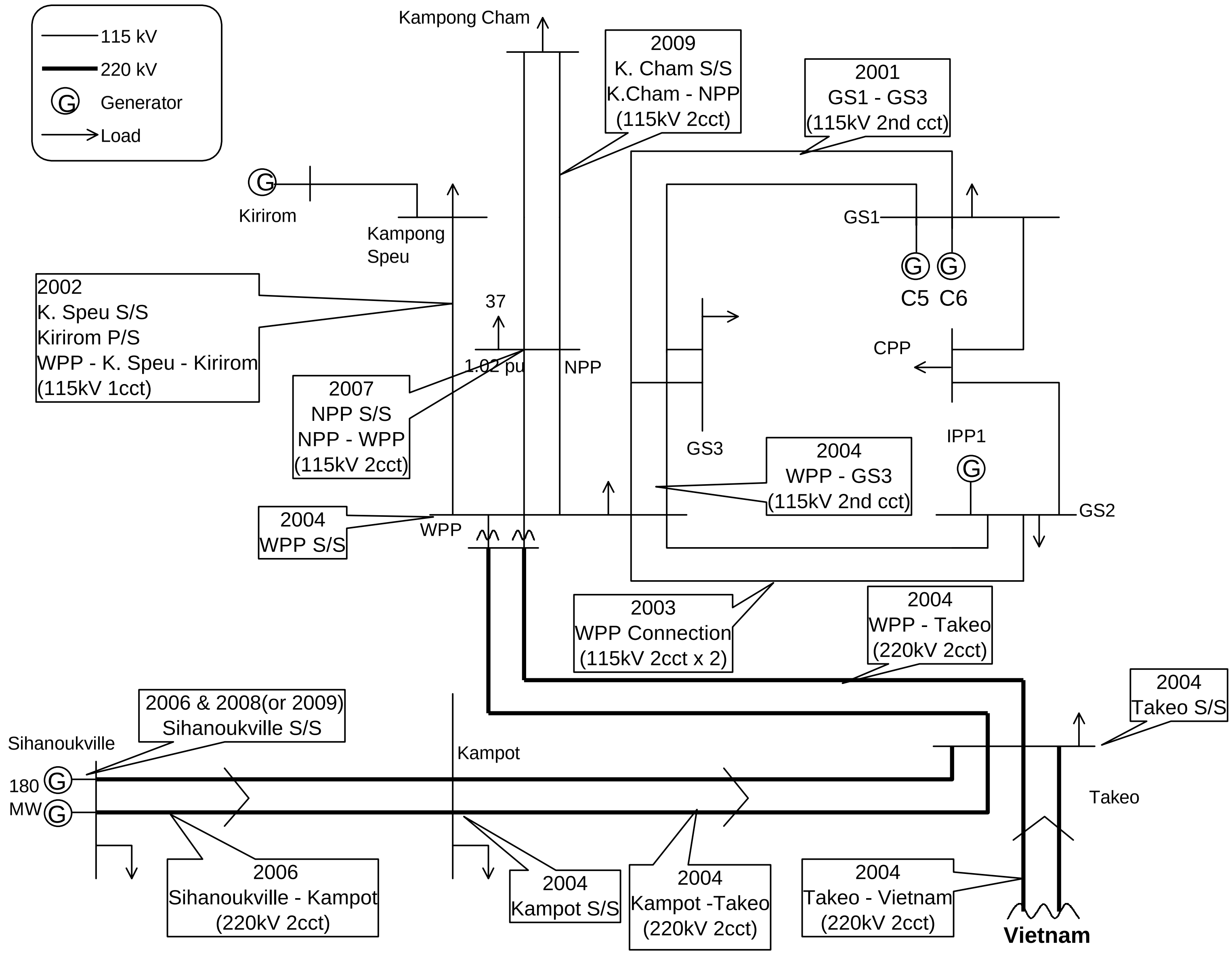


Fig.2.3-1 Transmissin Expansion Plan (until 2010)

2.4. Information about Related Transmission/Substation Project

This Feasibility Study was commenced on the condition that the transmission line between Phnom Penh and Sihanoukville would be constructed by the World Bank's Project.

Then, JICA Study Team has obtained the information about the related World Bank's project "Cambodia Rural Electrification and Transmission Project" (RE & T project) in Cambodia, and the other related plans.

2.4.1. Information about RE & T Project

The RE & T project consists of the following equipment and systems:

- 220 kV interconnection transmission line from Phnom Penh to Vietnam via intermediate Takeo substation, its total length is around 109 km.
- 220/110/22 kV substation at West Phnom Penh.
- Reinforcement of 115 kV grid in Phnom Penh area, connecting the West Phnom Penh S/S to the existing substations, GS1, GS2 and GS3.

The transmission lines from Takeo to Kampot and from Kampot to Sihanoukville are not included in the present scope of work (Phase 1) of the project. And these transmission lines are now ranked as one of the second stage development projects.

Total cost of the RE & T project is estimated around 89 Million US$, including contingencies and interest during construction. The transmission component is, of which cost is estimated around 44 Million US$, planned to be co-funded by JBIC and IDA, but agreement on co-finance between the World Bank and JBIC is not yet settled.

Due to this circumstance, the time schedule of the transmission project is likely to be further delayed. The expected commissioning time has been already changed from 2003 to 2004 in the latest report of the project.

The above transmission line of RE & T Project is to be connected with the transmission line from Chau Doc Substation in Vietnam, and extended to O Mon Power Station via Thot Not Substation.

According to the Vietnam's power development plan as of June 2001, the implementation schedule of the above transmission line and power station is planned as below:

O Mon oil-gas fired power station (600 MW)	2004 - 2005
O Mon - Thot Not T/L, 220 kV double circuits (28 km)	2004
Thot Not - Chau Doc - Tien Bien T/L, 220 kV double circuits (96 km)	2003
Thot Not Substation	2002 - 2003
Chau Doc Substation	2003 - 2004

Thot Not - Chau Doc - Tien Bien transmission line is planned to be constructed by the World Bank's project.

2.4.2. Transmission Line between Takeo and Sihanoukville

Regarding a transmission line from Takeo to Kampot, the location of Kampot is about mid-point between Takeo and Sihanoukville, MIME/ EDC is considering to construct a 220 kV-double circuit transmission line by the year 2004 under German aid. However, at present, there is no concrete plan to construct a transmission line between Kampot and Sihanoukville.

Fig.2.4-1 shows the routes of transmission lines and locations of substations which are described above.

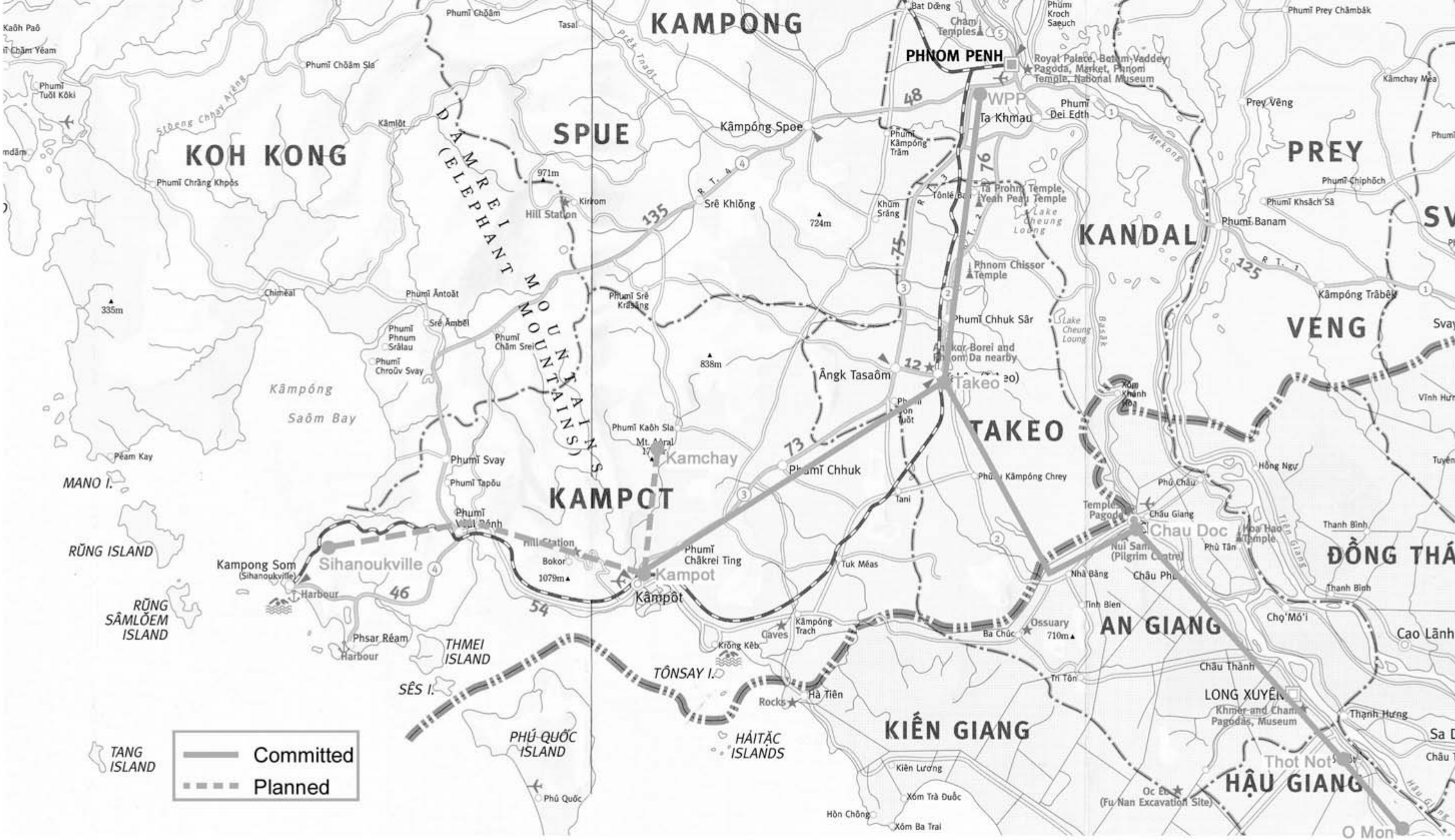


Fig.2.4-1 Plan of 220 kV Transmission Lines

3. Selection of Optimum Power Plant Type

3.1. Fuel for Power Plant

3.1.1. Available Fuels

Fuels for thermal power plants are generally heavy fuel oil, diesel oil, naphtha, natural gas, liquefied natural gas and coal.
For this project, heavy fuel oil and diesel oil are suitable at present and natural gas will be added in future as described below.

(1) Heavy Fuel Oil, Diesel Oil and Naphtha

Commercial energy sources currently consumed in Cambodia are heavy fuel oil, diesel oil, kerosene, gasoline and LPG, all of which are imported. Among the imported fuels, diesel and heavy fuel oil can be used as fuels for power plant.

Cambodia imports mainly those fuels from Singapore, Thailand and Vietnam. Imported petroleum products are transported by ship, and unloaded at the Sihanoukville oil terminal (Sokimex Oil Terminal near the power plant site) or transported to Phnom Penh by barge from Vietnam.

(2) Natural Gas

Natural gas is not available at present in Cambodia, but there are three options to make natural gas available in Cambodia, namely,

- Development of gas resources in Cambodian territory
- Development of gas resources in Cambodia- Thailand overlapping area
- Import of natural gas from the neighboring countries

(a) Development in Undisputed Cambodian Territory

So far, oil and gas wells with commercial scale have not been developed in Cambodia. Many companies tried gas and oil development in Cambodia from 1950s. However, all of those companies relinquished their exploration license up to 1998 due to no existence of expectable oil fields. Now Australia based oil/gas exploration company, Woodside Petroleum Ltd. is trying to develop gas fields.

In June 2001, the Cambodia Government and Woodside are going to make new exploration agreement on new area within Blocks 1 ~ 4 covering Koa Tang, Koah Pring, Apsara, Poulo Wai, Angkor and DA (refer to Fig. 3.1-1). They expect recoverable gas reserve of 2.7 TCF in this area. Gas consumption for 180 MW power plant is approx. 10 BCF/year. Therefore, the most powerful reservoir Angkor-1 (577 BCF) may serve the gas to the plant more than 55 years.

Woodside advises the period from PSC (Production Sharing Contract) to commercial supply is approx. 5 years, but, at moment PSC has not yet signed.

(b) Development in Overlapping Area

The overlapping area between Cambodia and Thailand is expected to reserve significant quantity of gas because this area is just on the geological extension of the area of Thai existing gas fields. Reserve of this area is estimated about 9 TCF. In June 2001 the memorandum of understanding (MOU) on co-development in the overlapping area was signed. But this MOU states only basic standpoint of co-development.

Priority of development in this area is not so high in Thai side, so Cambodian committee needs to take stronger leadership to accelerate the development schedule.

(c) Import from Neighboring Countries

Possible options of import of gas are from Thailand and Vietnam.

In case of Thailand, natural gas can be supplied from the existing gas field in the Gulf of Thailand. In case of Vietnam, possible supply sources of gas are gas fields located in the south of the Gulf of Thailand, but these gas fields are now under exploration.

A common key issue related the above options is a low economic viability caused by small size of gas demand in Cambodia. Therefore, increase of demand of gas would be the most effective factor to accelerate the realization of development or import of natural gas.

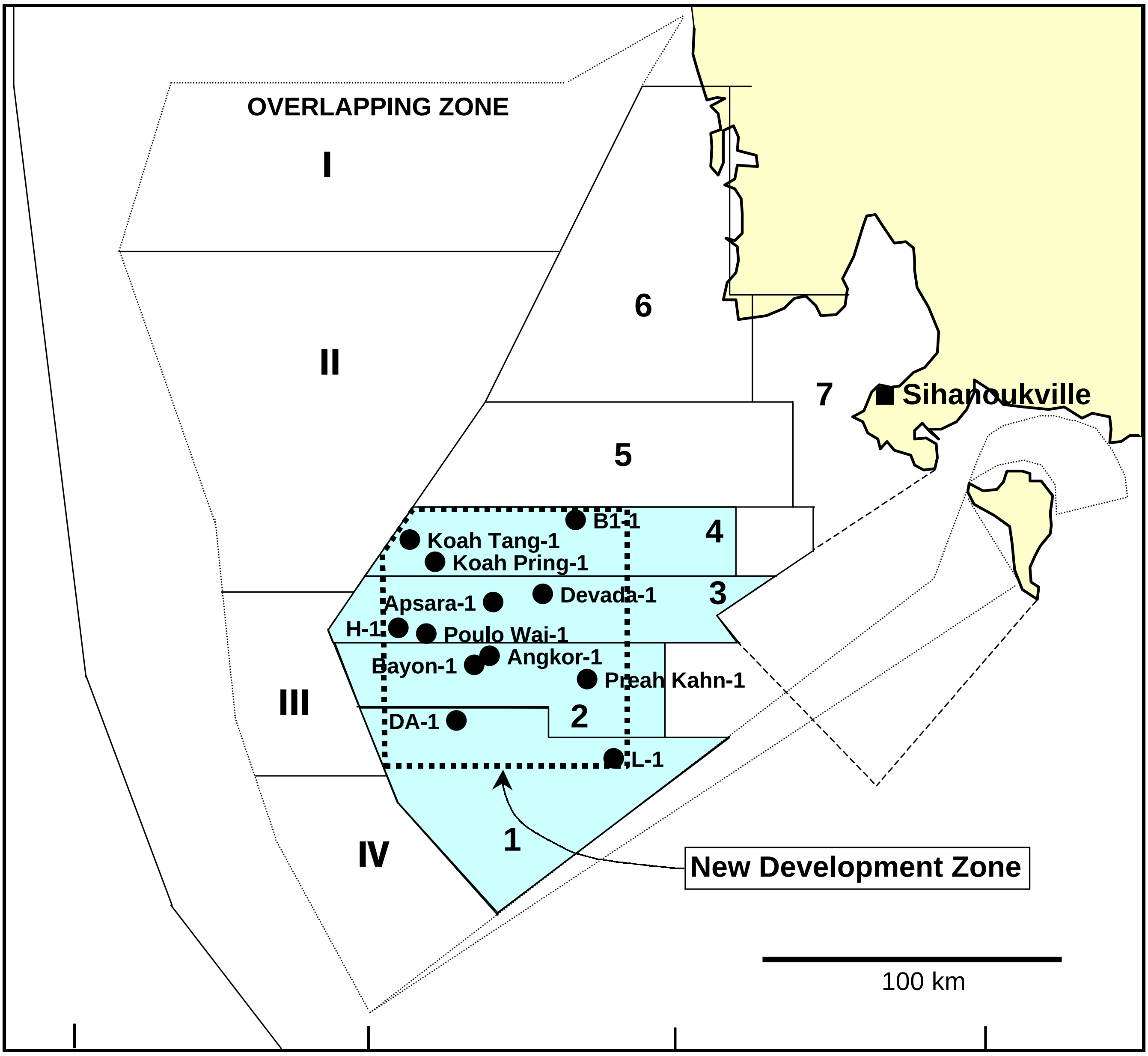


Fig.3.1-1 Gas and Oil Blocks (Offshore) in Cambodia

(3) Liquefied Natural Gas

Liquefied natural gas (LNG) is also not available in Cambodia at present. Origin of LNG may be Malaysia, Indonesia and Brunei. Construction cost of receiving and supply facilities for LNG, unloading jetty, storage reservoir, vaporizer, etc., will be approximately 130 to 170 Million US$ for 180 MW power plant. This cost is almost compatible to the power plant cost. Fuel price of LNG is generally higher than that of natural gas. Therefore LNG is not suitable for this project.

(4) Coal

Possibility of coal utilization is low judging for this project from the economic point of view, i.e., small scale of power plant and wholly importing of coal, etc. Cambodia has a indication of existence of coal deposit, but now it is not yet developed. Therefore, Cambodia has to import coal wholly. The total capacity of new power station will be 270 MW. The construction cost of jetty, unloading facility, storage and transfer facility to meet 270 MW is almost 130 Million US$. And the cost of power plant itself is also significantly higher than that of gas turbine combined cycle.

(5) Conclusion

In conclusion, only diesel oil and heavy fuel oil could be used as fuels for the new power station at present in Cambodia, and natural gas will be available in near future.

3.1.2. Fuel Prices

(1) Heavy Fuel Oil and Diesel Oil

EDC procures diesel oil and heavy fuel oil through competitive bidding by oil supply companies. The trend of prices of diesel oil and heavy fuel oil is shown in Fig. 3.1-2. The average prices of heavy fuel oil and diesel oil during the last 5 years, which are of CIF at Phnom Penh and excluding tax and duties, were 154 and 237 $/ton, respectively.

CIF Phnom Penh

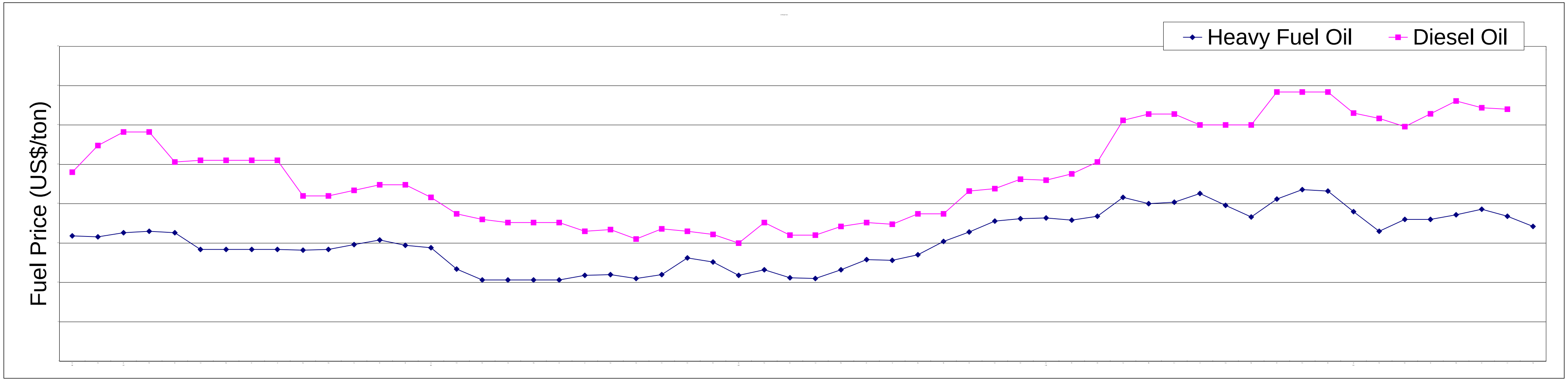
FuelType	1996 Nov	1996 Dec	1997 Jan	1997 Feb	1997 Mar	1997 Apr	1997 May	1997 Jun	1997 Jul	1997 Aug	1997 Sep	1997 Oct	1997 Nov	1997 Dec
Heavy Fue	159	158	163	165	163	142	142	142	142	141	142	148	154	147
Diesel Oil	240	274	291	291	253	255	255	255	255	210	210	217	224	224

FuelType	1998 Jan	1998 Feb	1998 Mar	1998 Apr	1998 May	1998 Jun	1998 Jul	1998 Aug	1998 Sep	1998 Oct	1998 Nov	1998 Dec
Heavy Fue	144	117	103	103	103	103	109	110	105	110	131	126
Diesel Oil	208	187	180	176	176	176	165	167	155	168	165	161

FuelType	1999 Jan	1999 Feb	1999 Mar	1999 Apr	1999 May	1999 Jun	1999 Jul	1999 Aug	1999 Sep	1999 Oct	1999 Nov	1999 Dec
Heavy Fue	109	116	106	105	116	129	128	135	152	164	178	181
Diesel Oil	150	176	160	160	171	176	174	187	187	216	219	231

FuelType	2000 Jan	2000 Feb	2000 Mar	2000 Apr	2000 May	2000 Jun	2000 Jul	2000 Aug	2000 Sep	2000 Oct	2000 Nov	2000 Dec	2001 Jan	2001 Feb	2001 Mar	2001 Apr	2001 May	2001 Jun	2001 Jul	2001 Aug	Ave
Heavy Fue	182	179	184	208	200	202	213	198	183	206	218	216	190	165	180	180	186	193	184	171	154
Diesel Oil	230	238	253	306	314	314	300	300	300	342	342	342	315	308	298	314	330	322	320		237

Note: The above fuel prices exclude tax and duties.



Source: Information from EDC

Fig. 3.1-2 Fuel Price in Phnom Penh (CIF) Purchased from CUPL

Table 3.1-1 shows the tax and duties charged to the fuels. The import tax rate of diesel oil is 20 % and that of heavy fuel oil is 7 %. VAT of 10 % is applied to all kinds of fuels.

Table 3.1-1 Taxes for Fuels

Kind of Fuel	Custom Cost ($)	Import Tax		Exceptional Tax		Social Funds [*1] ($)	Sub Total	VAT		Grand Total	
		%	Amount ($)	%	Amount ($)			%	Amount ($)	Amount ($)	%
Gasoline	320	50	160.00	20	96.00	1.10	257.10	10	57.71	314.81	98.4
Diesel Oil	275	20	55.00	-		0.94	55.94	10	33.09	89.03	32.4
Heavy Fuel Oil	129	7	9.03	-		0.81	9.84	10	13.88	23.72	18.4
Gas	325	7	22.75	-			22.75	10	34.78	57.53	17.7
Lubricant	160	20	32.00	20	38.40		70.40	10	23.04	93.44	58.4

Note; *1 : 3 Riel/1

(2) Natural Gas

Natural gas is not used in Cambodia, so there is no price at present.

The prices of natural gas which are traded in the neighboring countries are reported as below:

- Erawan gas in the Gulf of Thailand — less than 2.2 $/MMBTU at wellhead
- Average price in the Gulf of Thailand — 2.5 $/MMBTU at wellhead
- Yadana gas imported from Myanmar to Thai. — 2.5 $/MMBTU at Thai border
- Nam Con Son gas from the South China Sea — 2.5-3.0 $/MMBTU at power plant site

From the above data, the price of Cambodia gas is assumed around 2.5 to 3.0 $/MMBTU at wellhead considering drilling effect of relatively small capacity of each gas reservoir. The assumed construction cost of 12 inch and 170 km length, of which capacity meets to 270 MW power plant, is assumed around 90 Million US$. This cost affects around 1.0 to 1.5 $/MMBTU to the gas price at Sihanoukville on the conditions of discount rate of 15 % and payback period of 20 years, but effected magnitude is varied depending on the amount of gas demand..

Therefore, natural gas at power plant site would be ranged 3.5 ~ 4.5 $/MMBTU.

3.2. <u>Candidate Power Plant Types</u>

Power plant types widely used for utility power stations in the world are as follows:

- Gas Turbine Combined Cycle (GTCC) Power Plant
- Diesel Power Plant
- Conventional Power Plant (Boiler/Steam Turbine System)
- Open-cycle Gas Turbine Power Plant

In this study, three kinds of plant type (Gas Turbine Combined Cycle, Diesel Generator and Conventional Power Plant) except Open-cycle Gas turbine are compared for Sihanoukville Power Plant which are planned to be operated as base-load power station.

3.2.1. Gas Turbine Combined Cycle Power Plant

Main equipment of GTCC are gas turbine, heat recovery steam generator (HRSG), steam turbine, and generator. Fig.3.2-1 shows the system diagram of GTCC.
GTCC uses natural gas as main fuel and diesel oil as back-up fuel.

3.2.2. Diesel Power Plant

Diesel Power Plant consists of diesel engine and generator. Fig.3.2-2 shows the system diagram of Diesel Power Plant. There are three types of diesel engine, i.e. high-speed, middle-speed and low-speed. High speed diesel generator is excluded from this study because of its very small capacity. Low speed diesel engine has higher thermal efficiency but it is more expensive. In Cambodia, middle speed diesel is usually used. Both down-speed and middle-speed engines use heavy fuel oil.

3.2.3. Conventional Power Plant

Main equipment of Conventional Power Plant are boiler, steam turbine, and generator. Fig.3.2-3 shows the system diagram of Conventional Power Plant. Heavy fuel oil is used as fuel.

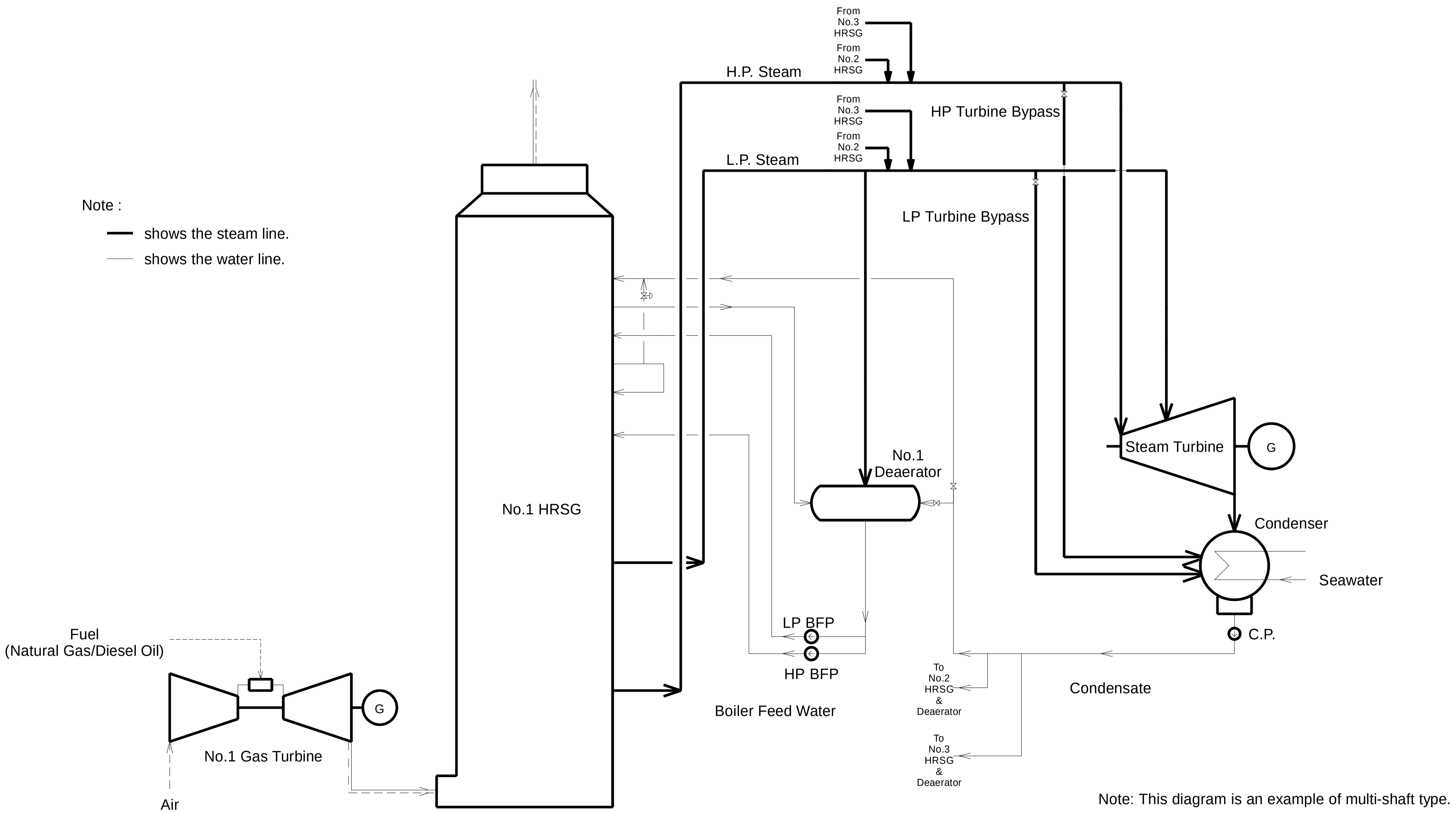


Fig.3.2-1 System Diagram of Gas Turbine Combined Cycle Power Plant

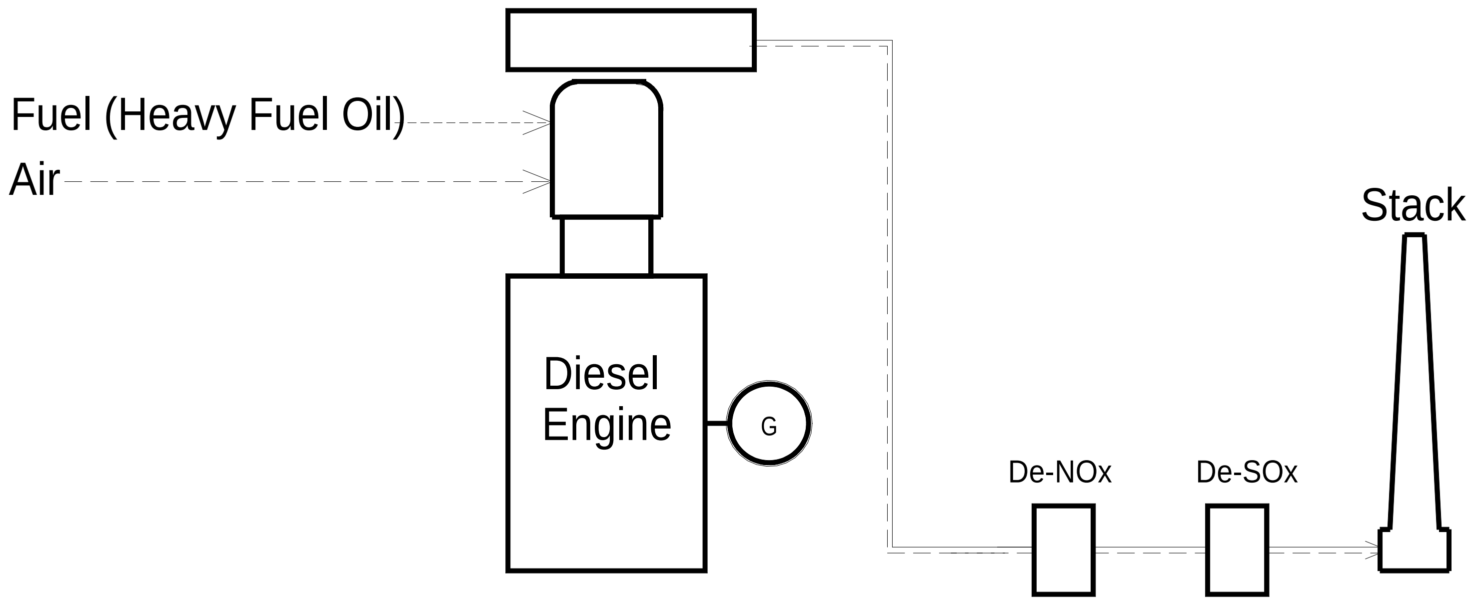


Fig.3.2-2 System Diagram of Diesel Power Plant

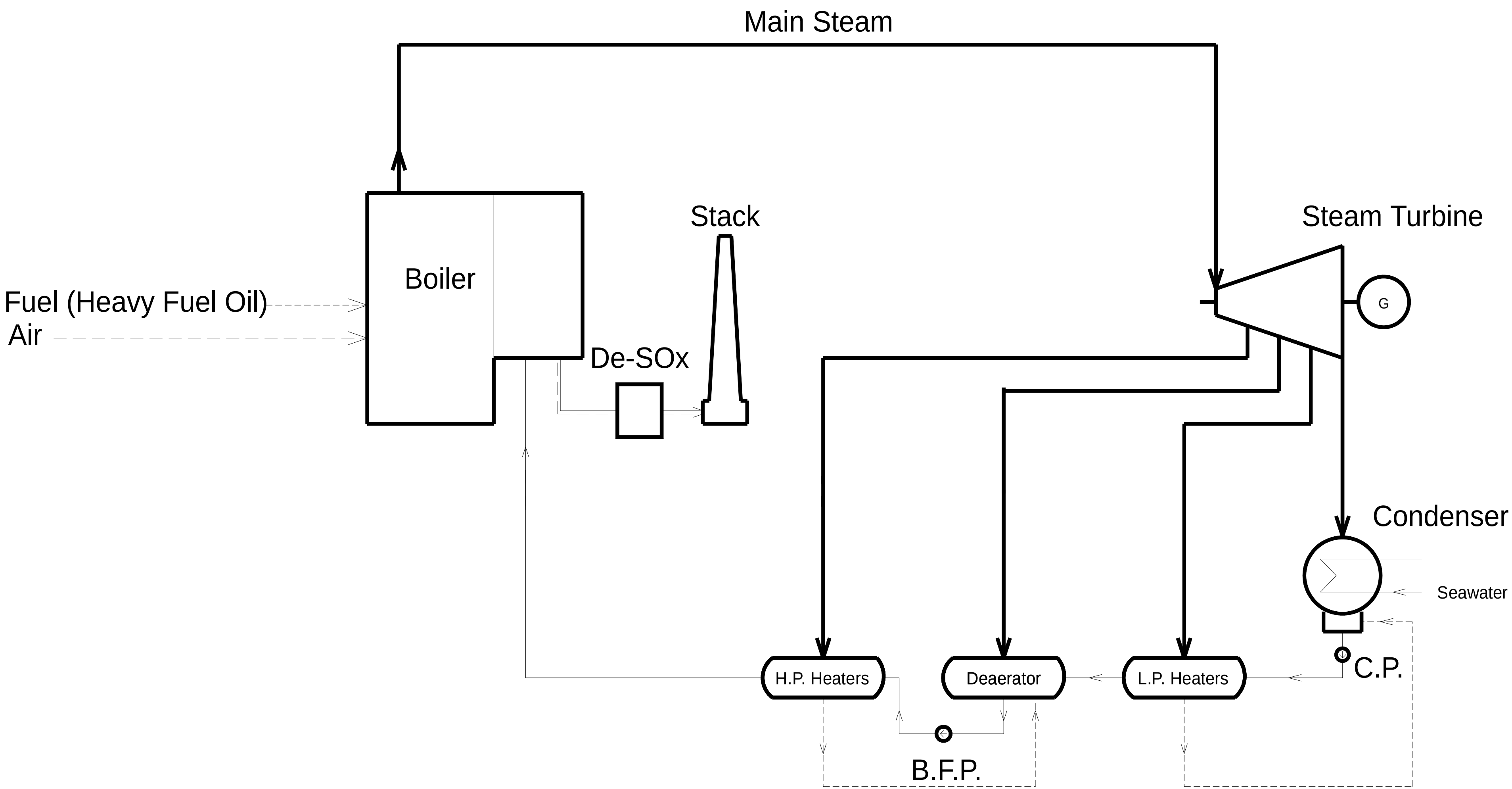


Fig.3.2-3 System Diagram of Conventional Power Plant

3.3. Technical and Environmental Comparison of Power Plant Types

Table 3.3-1 shows technical comparison of each power plant type. Table 3.3-2 and Table 3.3-3 show the emission levels in each power plant and assumed quantity of air pollutants discharged from each power plant of 180 MW capacity respectively.

As shown in Table 3.3-1, GTCC is superior to other candidates at the points of plant performance and construction cost. The second is Middle Speed Diesel. Conventional has no advantage compared to others. From the environmental point of view, GTCC is also the most suitable because of zero emission of SO_2, the second lowest of NOx emission and the lowest emission of CO_2. SOx and NOx discharged from both Diesel Power Plants are significantly higher than those from other type of power plant inspite of installation of mitigation plants. However, the final decision of plant type should be made after considering economic comparisons.

Table 3.3-3 Quantity of Air Pollutant Discharged from Each Power Plant

	NOx as NO_2 ton/year	SOx as SO_2 ton/year	CO_2 ton/year
GTCC	928	0	343,000
Diesel (Middle Speed)	3,766 *1	1,353 *2	527,000
Diesel (Low Speed)	3,335 *1	1,198 *2	466,000
Oil-fired Conventional	868	506 *2	596,000

*1 : after DeNOx system *2 : after DeSOx system

Table 3.3-1 Comparison of Type of Power Plant

Item		Gas Turbine Combined Cycle	Diesel (Middle Speed)	Diesel (Low Speed)	Conventional (Oil-fired Thermal)
Construction Cost		870US$/kW	1,370US$/kW	2,020US$/kW	1,340US$/kW
Fuel		Natural Gas	Heavy Fuel Oil	Heavy Fuel Oil	Heavy Fuel Oil
Efficiency (LHV)		Approx. 50%	Approx. 43%	Approx. 49%	Approx. 39%
Auxiliary Power Consumption Ratio		Approx. 2.8%	Approx. 4.6%	Approx. 4.6%	Approx. 6.7%
Environmental Mitigating Measures	Air Pollution	not necessary	necessary	necessary	necessary
	Hot Water Discharge	necessary	not necessary	not necessary	necessary
Ease of Operation		Good	Better	Better	Good
Reliability		Good	Better	Better	Good

LHV : Low Heating Value

Table 3.3-2 Emission Levels in Each Power Plant

Item	Cambodian Standard	Gas Turbine Combined Cycle	Diesel Generator (Middle Speed)	Diesel Generator (Low Speed)	Conventional Power Plant
NOx	1,000 mg/m^3 (487 ppm)	< 150 ppm	< 1,500 ppm	< 1,500 ppm	< 300 ppm
SOx	500 mg/m^3 (175 ppm)	-	< 700 ppm	< 700 ppm	< 2,200 ppm
Particulate	100 mg/m^3	< 5 mg/m^3	< 250 mg/m^3	< 250 mg/m^3	< 200 mg/m^3

Note : Cambodian standard is based on the sub-decree on Control of Air Pollution and Noise.
The maximum concentration of sulfur for diesel oil and heavy fuel oil is 0.2 % and 3.5 % respectively.
Emission levels for Gas Tribune Combined Cycle are based on natural gas, because diesel oil is used as back-up fuel.
Above concentrations are based on 760 mmHg, 0°C condition, and the emission levels of NOx and Particulates are referred to typical maximum level given by main manufacturers.

3.4. <u>Economic Comparison</u>

3.4.1. Purpose

The purpose of the economic comparison is to study the most economic power plant type among the alternative candidates that will be introduced to Cambodia.

3.4.2. Methodology for Comparison

The following economic indicators are used for the economic comparison.

(1) Net Present Value of Total Cost (NPV)

(2) Levelised Production Cost at Sending-out (LPC)

All alternative candidates are assumed to be the same kWh and kW values at the sending-out (at powerhouse exit).

3.4.3. Types of Power Plants

Four (4) power plant types as mentioned in the preceding sections are used in the economic comparison.

(1) GTCC Power Plant

(2) Diesel Power Plant (Middle Speed)

(3) Diesel Power Plant (Low Speed)

(4) Conventional Power Plant

Unit construction cost, operation & maintenance cost, fuel type, fuel cost, rate of station use, forced outage rate and scheduled maintenance days are shown in Table 3.4-1.

3.4.4. Prices in Economic Comparison

(1) Unit Construction Cost of Power Plant

The unit construction cost expressed in US$ term is used as the border price.

(2) Fuel Prices

The fuel prices of CIF (Cost, insurance and freight) are used except natural gas because the all oil fuels in Cambodia are imported from overseas. Averaged CIF fuel prices for the period from 1996 to 2001.

Concerning the natural gas, which is expected to be explored in Cambodia in future, 4.0 $/MMBTU (L.H.V. base) at power plant site including the markup is assumed.

3.4.5. Results of Economic Comparison

The results of economic comparison for the four (4) power plant types are summarized in Table 3.4-2. The relative calculation sheets are demonstrated in Table 3.4-3 and Fig.3.4-1 shows the breakdown of production cost.

Table 3.4-2 Net Present Value and Levelised Production Cost

Type	Natural Gas Combined Cycle	Diesel (Middle Speed)	Diesel (Low Speed)	Oil-fired Conventional
Fuel Price	4.0 $/MMBTU (- $/ton)	3.99 $/MMBTU (154 $/ton)	3.99 $/MMBTU (154 $/ton)	3.99 $/MMBTU (154 $/ton)
NPV	412.1 M.$	591.4 M.$	694.8 M.$	601.2 M.$
LPC	5.52 ¢/kWh	7.92 ¢/kWh	9.30 ¢/kWh	8.05 ¢/kWh
Fuel	NG	HFO	HFO	HFO

A combined cycle power plant presents the lowest net present value of total cost and accounts for 70%, 59%, and 69% of middle speed diesel, lower speed diesel and conventional respectively.

Concerning the levelised production cost at sending-out level, natural gas-fired combined cycle power plant is proven to be far least among the alternative candidates.

According to the above results, combined cycle power plant is the most economic power plant.

Table 3.4-1 Characteristics of Candidates of Power Plants and Fuel Cost

Name of Plant	Unit Capacity	Installed Cost	Construction Period	Disbursement Schedule		SMD	FOR	Station Use	Plant Life	Fixed O/M Cost	Variable O/M Cost	Fuel Type
	MW	US$/kW	Years	1st year	2nd year	days/year	%	%	Years	$/kW-year	$/MWh	
Combined Cycle	90	870	2	40%	60%	49	8	2.8	20	20	1.0	NG
Diesel (Middle Speed)	90	1,370	2	50%	50%	28	20	4.6	20	21	3.0	HFO
Diesel (Low Speed)	90	2,020	2	50%	50%	28	20	4.6	20	21	3.0	HFO
Oil-fired Conventional	100	1,340	2	40%	60%	53	8	6.7	20	20	3.6	HFO

Note: SMD =Scheduled Maintenance Days, FOR=Forced Outage Rate, NG = Natural Gas, HFO=Heavy Fuel Oil

Installed costs of Diesel and Oil-fired Conventional include the mitigation equipment costs against the air pollution.

Plant Type	Fule Type	Fuel Price*	Efficiency	Fuel Cost
		US$/MMBTU	BTU/kWh	US$/MWh
Combined Cycle	NG	4.00	6,829	27.32
Diesel (Middle Speed)	HFO	3.99	7,888	31.49
Diesel (Low Speed)	HFO	3.99	6,987	27.89
Oil-fired Conventional	HFO	3.99	8,729	34.85

Note: *Fuel Price based on L.H.V. (Low Heating Value)

Table 3.4-3 Comparison Among the Power Plant Candidates

Year		-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	
Sending-out	GWh			544.1	574.7	842.9	965.6	1027	1073	766.3	766.3	766.3	766.3	766.3	766.3	766.3	766.3	766.3	766.3	766.3	766.3	766.3	766.3	383.2	383.2	
Discount Rate	10.0%																									
Conversion Factor		1.2100	1.1000	1.0000	0.9091	0.8264	0.7513	0.6830	0.6209	0.5645	0.5132	0.4665	0.4241	0.3855	0.3505	0.3186	0.2897	0.2633	0.2394	0.2176	0.1978	0.1799	0.1635	0.1486	0.1351	Sum
NPV of Sending-out	GWh	0.0	0.0	544.1	522.5	696.6	725.5	701.3	666.2	432.6	393.3	357.5	325.0	295.4	268.6	244.1	222.0	201.8	183.5	166.7	151.6	137.9	125.3	56.9	51.8	7470.2

1 *Combined Cycle (Natural Gas-fired)*

Net Present Value of Cost 412.1 M.US$ — Levelised Production Cost 5.52 c/kWh

Generation Energy	GWh			559.8	591.3	867.2	993.4	1056	1104	788.4	788.4	788.4	788.4	788.4	788.4	788.4	788.4	788.4	788.4	788.4	788.4	788.4	788.4	394.2	394.2	Sum
Construction Cost	M.US$	31.32	46.98	31.32	46.98																					156.60
Fixed O/M Cost	M.US$			1.80	1.80	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	3.60	1.80	1.80	72.00
Variable O/M Cost	M.US$			0.56	0.59	0.87	0.99	1.06	1.1	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.79	0.39	0.39	17.01
Fuel Cost	M.US$			15.29	16.15	23.69	27.14	28.86	30.16	21.54	21.54	21.54	21.54	21.54	21.54	21.54	21.54	21.54	21.54	21.54	21.54	21.54	21.54	10.77	10.77	464.39
Cost Total	M.US$	31.32	46.98	48.97	65.52	28.16	31.73	33.52	34.86	25.93	25.93	25.93	25.93	25.93	25.93	25.93	25.93	25.93	25.93	25.93	25.93	25.93	25.93	12.96	12.96	710.00
NPV as of Year 1	M.US$	37.9	51.68	48.97	59.56	23.27	23.84	22.89	21.64	14.64	13.31	12.10	11.00	10.00	9.09	8.26	7.51	6.83	6.21	5.64	5.13	4.66	4.24	1.93	1.75	412.05

2 *Diesel (Middle Speed)*

Net Present Value of Cost 591.4 M.US$ — Levelised Production Cost 7.92 c/kWh

Generation Energy	GWh			570.4	602.5	883.7	1012	1077	1125	803.4	803.4	803.4	803.4	803.4	803.4	803.4	803.4	803.4	803.4	803.4	803.4	803.4	803.4	401.7	401.7	17321.2
Construction Cost	M.US$	67.75	67.75	67.75	67.75																					271.0
Fixed O/M Cost	M.US$			2.08	2.08	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	2.08	2.08	83.0
Variable O/M Cost	M.US$			1.71	1.81	2.65	3.04	3.23	3.37	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	1.21	1.21	52.0
Fuel Cost	M.US$			17.96	18.97	27.83	31.88	33.9	35.42	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	25.3	12.65	12.65	545.5
Cost Total	M.US$	67.75	67.75	89.5	90.61	34.63	39.07	41.28	42.94	31.86	31.86	31.86	31.86	31.86	31.86	31.86	31.86	31.86	31.86	31.86	31.86	31.86	31.86	15.94	15.94	951.5
NPV as of Year 1	M.US$	81.98	74.53	89.50	82.37	28.62	29.35	28.19	26.66	17.98	16.35	14.86	13.51	12.28	11.17	10.15	9.23	8.39	7.63	6.93	6.30	5.73	5.21	2.37	2.15	591.4

3 *Diesel (Low Speed)*

Net Present Value of Cost 694.8 M.US$ — Levelised Production Cost 9.3 c/kWh

Generation Energy	GWh			570.4	602.5	883.7	1012	1077	1125	803.4	803.4	803.4	803.4	803.4	803.4	803.4	803.4	803.4	803.4	803.4	803.4	803.4	803.4	401.7	401.7	17321.2
Construction Cost	M.US$	99.89	99.89	99.89	99.89																					399.6
Fixed O/M Cost	M.US$			2.08	2.08	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	4.15	2.08	2.08	78.9
Variable O/M Cost	M.US$			1.71	1.81	2.65	3.04	3.23	3.37	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	2.41	1.21	1.21	49.6
Fuel Cost	M.US$			15.91	16.8	24.65	28.23	30.02	31.37	22.41	22.41	22.41	22.41	22.41	22.41	22.41	22.41	22.41	22.41	22.41	22.41	22.41	22.41	11.2	11.2	460.7
Cost Total	M.US$	99.89	99.89	119.6	120.6	31.45	35.42	37.4	38.89	28.97	28.97	28.97	28.97	28.97	28.97	28.97	28.97	28.97	28.97	28.97	28.97	28.97	28.97	14.49	14.49	988.7
NPV as of Year 1	M.US$	120.9	109.88	119.59	109.62	25.99	26.61	25.54	24.15	16.35	14.87	13.51	12.29	11.17	10.15	9.23	8.39	7.63	6.94	6.30	5.73	5.21	4.74	2.15	1.96	694.8

4 *Oil-fired Conventional*

Net Present Value of Cost 601.2 M.US$ — Levelised Production Cost 8.05 c/kWh

Generation Energy	GWh			583.3	616.1	903.6	1035	1101	1150	821.5	821.5	821.5	821.5	821.5	821.5	821.5	821.5	821.5	821.5	821.5	821.5	821.5	821.5	410.8	410.8	
Construction Cost	M.US$	50.89	76.34	50.89	76.34																					254.46
Fixed O/M Cost	M.US$			1.90	1.90	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	3.80	1.90	1.90	72.20
Variable O/M Cost	M.US$			2.10	2.22	3.25	3.73	3.96	4.14	2.96	2.96	2.96	2.96	2.96	2.96	2.96	2.96	2.96	2.96	2.96	2.96	2.96	2.96	1.48	1.48	60.84
Fuel Cost	M.US$			20.33	21.47	31.49	36.07	38.36	40.08	28.63	28.63	28.63	28.63	28.63	28.63	28.63	28.63	28.63	28.63	28.63	28.63	28.63	28.63	14.32	14.32	588.62
Cost Total	M.US$	50.89	76.34	75.22	101.93	38.54	43.60	46.12	48.02	35.39	35.39	35.39	35.39	35.39	35.39	35.39	35.39	35.39	35.39	35.39	35.39	35.39	35.39	17.70	17.70	976.12
NPV as of Year 1	M.US$	61.58	83.97	75.22	92.66	31.85	32.76	31.50	29.82	19.98	18.16	16.51	15.01	13.64	12.40	11.28	10.25	9.32	8.47	7.70	7.00	6.37	5.79	2.63	2.39	601.24

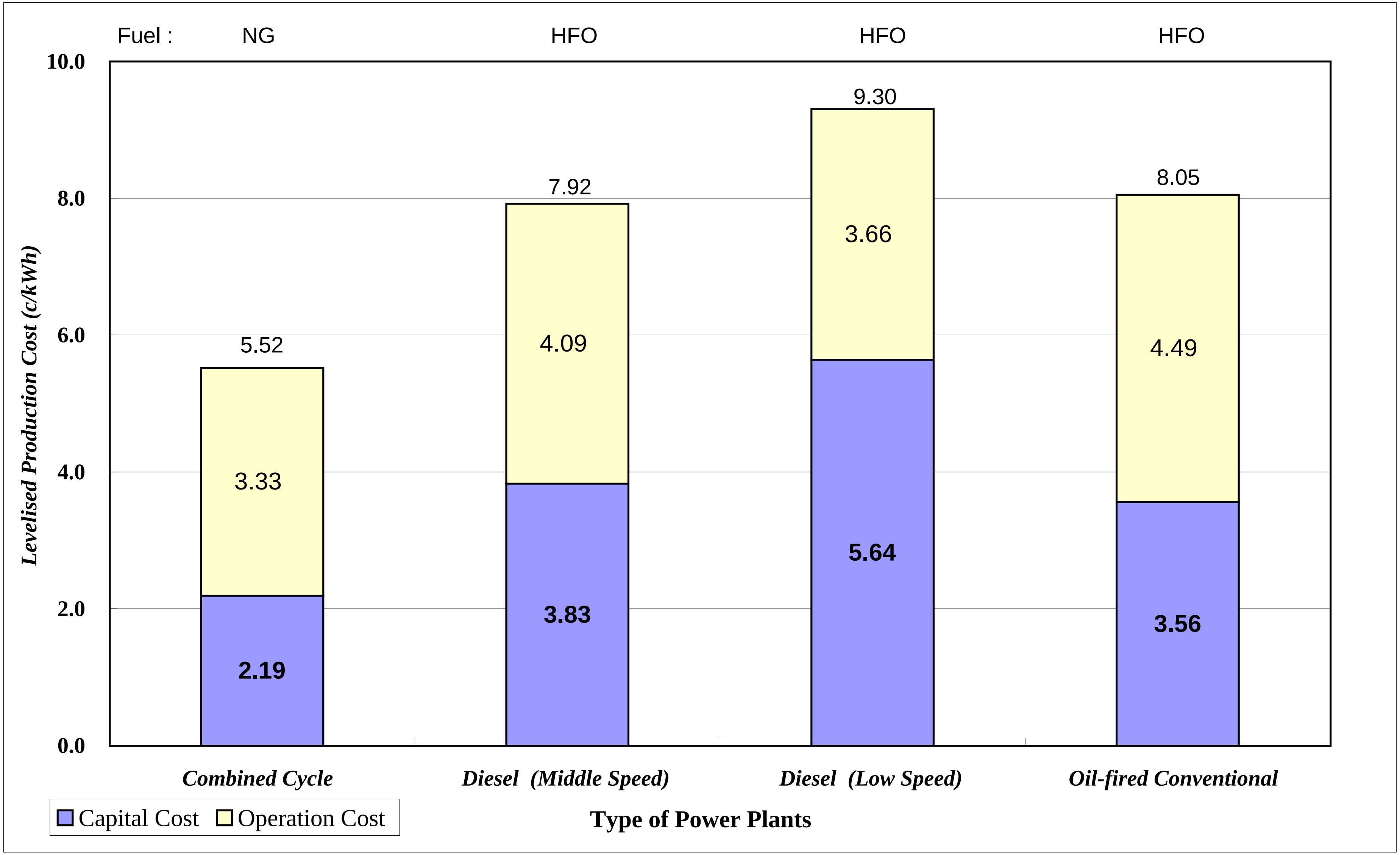


Fig. 3.4-1 Comparison of Production Cost Components at Plant excluding Taxes imposed on Fuel (10%Discount Rate)

3.5. Conclusion

3.5.1. Technical and Environmental Aspect

Combined cycle is superior to the others in plant performance and environmental aspect. Compared to oil-fired middle speed diesel usually used in Cambodia, combined cycle power plant can reduce about 75% of NOx and 100% of SOx, about 35% of CO_2 emission. From environmental point of view, such as prevention of air pollution and greenhouse effect, it is preferable to select combined cycle power plant as the plant type of Sihanoukville Power Plant.

As a gas turbine has been used since 1960's and a combined cycle power plant has been applied since 1980's even in neighboring countries of Southeast Asia such as Indonesia and Bangladesh, introduction of a combined cycle power plant to developing countries seems to bring no serious technical problem. Also in Cambodia, introduction of combined cycle power plant is possible through appropriate technical training.

3.5.2. Economic Aspect

A combined cycle power plant has been proved to be the most economic power plant type in the course of the economic comparative studies, consisting of net present value of total cost, annual levelised cost under the assumed conditions.

3.5.3. Conclusion of Optimum Type Power Plant

From comparative evaluation in technical and economic and environmental aspects, gas turbine combined cycle power plant is considered most suitable for Cambodia.

On the other hand, since EDC has no operation experience concerning gas turbine combine cycle including a gas turbine itself, the technical training for EDC staffs will be required based on the technical training schedule, which will incorporate the timing of the project implementation.

4. Selection of Power Plant Site

4.1. Investigated Sites

For selection of site for the power plant, five sites (OP-1 to OP-5), which are located in Stung Hav District of Kron Preah Sihanouk Province, were investigated.

On the way of investigation, it was turned out that the land of OP-3 could not be acquired. Therefore, the detailed evaluation are carried out for four sites except OP-3.

After comparing each site in the aspects of environmental impact, land acquisition cost and construction/operation cost, OP-4 was selected as the most preferable site for the Sihanoukville power plant.

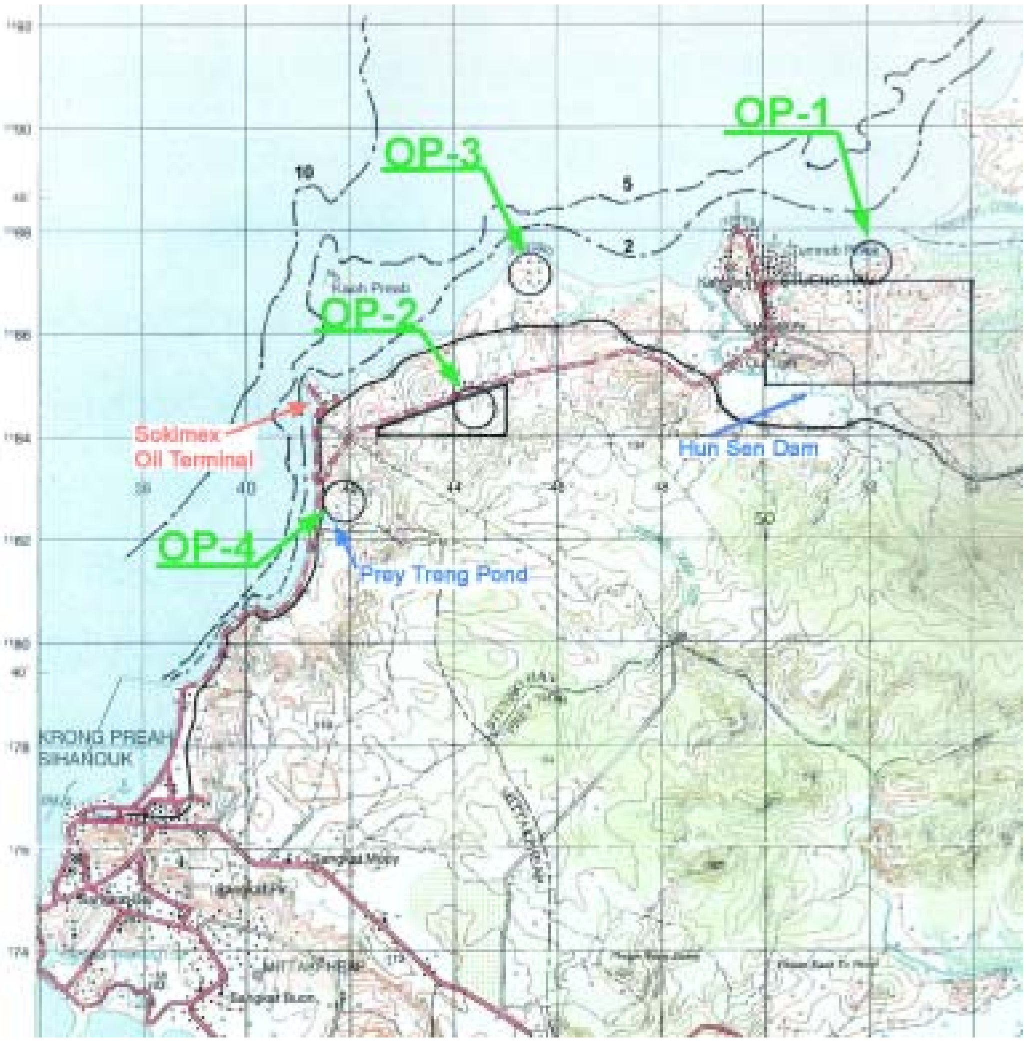


Fig.4.1-1 Location of Candidate Sites

4.2. Investigation Results of Candidate Sites

Summarized characteristics of each site are as follows:

OP-1 : OP-1 site is located in the easternmost area among the sites and farthest from Sokimex Oil Terminal. There is mangrove forest and wet land in the coastline, and the sea in front of the site is very shallow. Therefore, this site is not good for utilizing the seawater as cooling water.
The site is far from the trunk road, so a long access road needs to be constructed. In addition, there is an old temporary and rotten bridge on the trunk road from Sihanoukville, which requires to be replaced or rehabilitated for transporting materials and equipment from the port to the site.

OP-2 : OP-2 site is located on the hill near Sokimex Oil Terminal. This location is preferable for transportation of fuel oil, but not preferable to obtaining cooling water due to the long distance from the sea.
The site has good accessibility because the trunk road runs on the site area.

OP-4 : OP-4 site lies just on the south of Sokimex Oil Terminal. This location is preferable for transportation of fuel oil. Furthermore, the site is close to the sea and the sea in front of the site is relatively deep. This condition is the best for utilizing the seawater as cooling water among the sites.
On the other hand, a relatively high and steep mountain is located in the northeast and the east ends of the site area. This situation may have some restriction on future expansion of power plant larger than 270 MW. The site has good accessibility and transportation condition because the trunk road and the railroad run beside the site.

OP-5 : OP-5 site is located just on the east of Sokimex Oil Terminal. This location is suitable to transportation of oil fuel. The sea in front of the site is relatively deep (but not so deep as OP-4), so the seawater can be used as cooling water.
The serious disadvantage of this site is its topographic feature. The site is hilly and bisected by a valley, and the river runs in the middle of it. This landform causes a large-scale civil works, such as rerouting of the river, large amount of soil excavation and/or reclamation.

4.3. Possibility of Land Acquisition and Price of Land

According to the investigation done by MIME/EDC, there is no objection to the possibility of land acquisition for all sites except OP-3.

The expected price of land of each site informed by the Sihanoukville Municipality is as follows:

OP-1	:	approx. 2.0 $/m^2$
OP-2	:	approx. 3.0 $/ m^2$
OP-4	:	approx. 2.3 $/ m^2$
OP-5	:	approx. 3.0 $/ m^2$

4.4. Evaluation of Environmental Impact

Few houses or no houses were observed in all sites. Therefore, no major relocation issue exists for any sites.

Valuable habitats, other protected species, cultural heritage, etc. were not observed in any sites. All sites are far from the nearest protected area or National Park.

OP-5 has a problem of large mass of soil disposal. Earth moving to achieve a plant grade that is low enough for economical pumping of cooling water will require offsite spoil disposal of 4.5 million m^3.

4.5. Comparison of Construction Cost and Operation Cost

Based on the characteristics of each site, the difference of construction cost and operation cost for each site were estimated and compared.

The difference of construction costs were calculated on the basis of the following preconditions:

(1) Power plant generation capacity is 180 MW.

(2) Power plant type is a gas turbine combined cycle, of which condenser cooling system is:

OP-1	:	Air-cooled condenser
OP-2	:	Air-cooled condenser
OP-4	:	Seawater-cooled condenser
OP-5	:	Seawater-cooled condenser

(3) Fuel oil is transferred by oil pipeline from Sokimex Oil Terminal to the plant along the railroad.

(4) For OP-1 fresh water is supplied from Hun Sen Dam. For OP-OP-2, OP-4 and OP-5 fresh water supplied from Prey Treng Pond.

(5) Substation is located in the power plant area. Transmission line from Takeo will be connected directly to the power plant substation.

(6) Acquisition prices of land are as mentioned in Clause 4.3.

In addition to the construction costs, the difference of operation costs were also calculated because of difference of plant efficiency between the plant with seawater-cooled condenser and the plant with air-cooled condenser. The plant with seawater condenser has a higher power generation efficiency than that with air-cooled condenser due to its lower attainable vacuum in condenser. The difference of operation costs are calculated as Net Present Value of the difference of cumulative operation cost over the economic plant life of 20 years.

The length of gas pipeline is considered the same for all sites.

Cost comparison results calculated based on the above is summarized below:

	(Unit : Million US $)
OP-1	+ 16.5
OP-2	+ 10.6
OP-4	Base
OP-5	+ 28.9

Among the above four sites, OP-4 shows the minimum construction and operation cost.

5. Results of Detailed Site Investigation

5.1. Results of Topographic, Geological, Hydrological, Bathymetric, Offshore Geological, and Oceanographic Investigation

5.1.1. Topographic

As a result of topographic survey, the area is generally flat in the southern part with height of EL.1 ~ 8 m, and a slope of approximately 1/70 and 1/50 in west-east direction and in north-south direction, respectively. Northern and eastern edges are surrounded by foot of mountains with mild slopes to gradually steep slope. South part of the area is partly extended by pond and two creeks are flowing into the pond.

5.1.2. Geology

General topography of the site area is characterized by relatively low reliefs to moderately high peaks of 100 - 211 m. Sandstone of Upper Jurassic-Cretaceous in age (upper sandstone) is the major rock underlying the Sihanoukville area.

General outcrops in many places are sandstone, conglomeratic sandstone, siltstone and interbedding shale. Bedding planes of rocks strike is N50 - 70E, with gentle dipping of 5 - 10 degree NW toward the sea.

The overburden is composed mostly of layers of sand, and silty clay; having thickness from 4.35 - 25.75 m. Rather thick (19 - 26 m) overburden has been found in the area between two canals and swamps on southern boundary of the site. The overburden sand is thinning northwards.

5.1.3. Hydrology

The discharge at Hun Sen Dam and Prey Treng Pond are calculated from water levels just upstream of each weir. In the dry season, water discharge observed at Prey Treng Pond is approximately 17 lit/sec in the end of February 2001, that is slightly larger than that of Hun Sen Dam, where the overflow discharge is approximately 10 lit/sec.

The rainfall in the dry season of 2000 November - 2001 March has a return period of approximately 1.4 year based on a series of rainfall quantity in dry season from 1991 to 2001.

As a result, the Prey Treng Pond can be the most preferable fresh water source for the power plant.

5.1.4. Bathymetry

The site area is facing a beach with length of approximately 1.0 km, north-south direction. Beach slope is approximately 1/50 and gradually becomes mild offshore wards with sea bed slope up to approximately 1/500 at 1.0 km offshore from the beach.

Sea bed formation is relatively simple and no extraordinary undulation.

5.1.5. Offshore Geology

Four (4) offshore borings were conducted in the proposed site area for the combined cycle power plant.

The upper soil layers consist of very loose sandy soil beneath the sea. At Borehole No.BH-11, the upper layer consists of loose to medium dense sand. Sandstone was encountered below the sandy deposit at depths of 4.5 to 9.5 m from the sea bed.

5.1.6. Oceanography

According to the tide level observation, the following tidal parameters are obtained:

CDL	(Chart Datum Level)	=	- 1.07 m + MSL*
MHWL	(Mean High Water Level)	=	0.37 m + MSL *
MSL	(Mean Sea Level)	=	+ 0.08 m + MSL *
MLWL	(Mean Low Water Level)	=	- 0.17 m + MSL *
HHWL	(Highest High Water Level)	=	+ 1.17 m + MSL *
LLWL	(Lowest Lower Water Level)	=	- 1.06 m + MSL *
Ground Level		=	+ 4.10 m + MSL *

* MSL at Hatien in Vietnam

5.2. Results of Environmental Baseline Survey

The environmental baseline survey works were carried out from Sepetember 2000 to August 2001. Full results and documentation are presented in “Environmental Baseline Survey on the Sihanoukville Combined Cycle Power Development Project Final Report” (hereinafter referred as TEAM’s Report), which was prepared by TEAM.
Information obtained from the environmental baseline survey is incorporated into “Environmental Impact Assessment Report for the Sihanoukville Combined Cycle Power Development Project” that was prepared separately by the JICA Study Team but included as a supporting report of the EIA. The field surveys are organized into 10 categories of tasks as follows:

5.2.1. Land Use Survey and Mapping

Land use survey and mapping were carried out for the areas of the plant site, oil pipeline corridor and the area within a 30-km radius from the site.
The plant site is covered mostly (86%) by grassland and brush/secondary forest. The west side of the site extends to the sea and includes an existing road and railway.
Other site areas are also covered by grass and bush but forest is the dominant land use within the 340-km radius.

5.2.2. Demography Survey

In 1998, the total populations of Krong Preah Sihanouk and Stung Hav District, where the plant site is located in, were about 156,000 and 13,000, respectively. Females (50.6 %) slightly outnumber males. Age distribution is strongly skewed toward persons under 15 years of age.
About half of the economically active persons are in the primary sector (agriculture, forestry, fishing, etc.). About 11 % are in the secondary sector (mining and manufacturing) and about 38 % are in the tertiary sector (services).
Education levels of the literate population are low, and about 83 % is “completed” or “attended but never completed” primary school.
Main source of water is dug well, main source of lighting is kerosene lamp, and main source of fuels is firewood.

Only 6 households reside on the site and 4 on the spoil disposal area.

5.2.3. Socio-Economic Survey

(1) Traffic Survey

The 24- hour traffic survey for the wet season and the dry season was carried out at three representative locations between Shianoukville Port and Sokimex Oil Terminal. One location (TC1) is located at Tamnop Rook Village, an area of high pedestrian traffic near Sihanoukville Port, between the port and the project site. Another two locations (TC2 and TC3) are located in a sparsely populated area near the project site.

At TC1 counts of pedestrian and vehicular traffic ranged 10,000 ~ 12,000 counts in the dry season and 7,000 ~ 8,000 counts in the wet season, respectively. Most of the counts were motorcycles. Counts at TC2 and TC3 were significantly lower than that at TC1, about one seventh of TC1.

(2) Structures along Road near Site

The number of structures along the road between Sihanoukville Port and Sokimex Oil Terminal were identified.

There are 691 structures within 20 m of the road. Of these, 406 (58.7 %) are dwellings, 262 (37.9 %) are shops, others are factories and government offices

(3) Profile of 30-km Radius

Notable findings are as follows:

- large numbers of pupils are in school (especially elementary school)
- large numbers of households are involved in fishing
- small numbers, small scale and resource base of manufacturing facilities
- small numbers of hospital patients and skilled staff in relation to the size of the population

(4) Profile of Plant Site, Pipeline Corridor and Laydown Area for Stage 3

The notable findings in interview with 39 heads of households located within these areas or near the plant site are as follows:

- average household size (about 5 persons)
- average age (23 years)
- employment (20 have a single occupation and the others have multiple occupations)
- average annual household income (about $1,500)
- residential land ownership (100 % own their residential land)
- knowledge of the project (about 46 % were aware of the project)
- expectations concerning resettlement (33 % preferred to move to Sihanoukville Town , 95 % expected cash compensation for resettlement and 59 % expected new land for resettlement and community functions)

5.2.4. Archaeological Survey

The archaeological survey to determine the possibility of existence of archaeological materials was carried out including (i) literature search, (ii) on-site inspections of the plant site, oil pipeline corridor and laydown area for Stage 3, (iii) interviews with local residents, and (iv) soil sampling and test digs in selected locations. However there was no indication suggesting the existence of such materials in these areas.

5.2.5. Terrestrial Ecological Survey

The search for protected species of wildlife on project areas began with a literature search of international sources such as IUCN's Red Data Book and Cambodian sources such as the Ministry of Agriculture, Forestry and Fisheries' "Declaration on the Species Listed of Wild Game Forbidden to be Hunted".

On the basis of the above sources, the survey was conducted with interviews to the local residents and actual observation by the competent biologists.

Except for several protected birds observed in the vicinity of Hun Sen Dam and Prey Treng Pond, none of the protected species were observed on or near the site by the study team, or were described by local residents as having been observed in the region in recent years.

The inventory of trees, of which diameter is larger than 10 cm DBH, on the plant site was also prepared. It revealed 302 such trees on the plant site and 147 within the oil pipeline corridor.

5.2.6. Water Quality and Aquatic Ecology Survey

The water quality and aquatic ecology survey was conduced, for the dry season and the wet season, at three locations: in the reservoir behind Hun Sen Dam, in the stream downstream of Hun Sen Dam, and in Prey Treng Pond.

The survey of biota included plankton (microscopic plants and animals), benthos, fishes, aquatic vegetation birds, and other fauna.

At the above areas, 18 protected species of birds were observed. And 8 protected species of wildlife reported by local residents as having been observed in the past. But none of these have been observed in recent years.

5.2.7. Marine Ecology and Fisheries Survey

Port surveys of Sihanoukville and Stung Hav Ports were conducted 8 times between late September 2000 and early August 2001. They confirmed that extensive fisheries efforts and captures are occurring in coastal areas in the region of the project site.

According to interviews with fishermen and a few direct observations, the protected species of marine biota observed in the project region (30-km radius) were dolphins, sharks, whales, sea turtles, coral reefs, mangrove forests, etc.

Regarding marine ichthyoplankton, forty-eight samples were collected during 8 sampling periods from six sampling locations in the vicinity of the proposed locations of the intake and discharge structures. The results included eggs and larvae of 42 families that concentrations of ichthyoplankton are lower in the immediate vicinity of the intake and discharge structures than in deeper parts of the adjacent seas.

5.2.8. Air Quality and Noise Survey

The existing air quality, point sources of air pollution within 30-km radius were surveyed and listed in the inventory. Except a few sources such as Sihanoukville Port and Sokimex Oil Terminal no significant air pollution sources were observed.

The present air quality was measured at 2 representative points, but the results showed that the concentrations of both SO_2 and NO_2 were far below than the standards of Cambodia and the World Bank Guidelines.

Noise levels were measured over 24 hours at three locations during the rainy season and the dry season. All measurement results indicate low ambient sound levels. The highest integrated sound levels observed were around 60 dB(A). Event-based sampling revealed that the highest instantaneous sound levels were associated with passing trains (about 85 dB(A)) and large trucks (about 79 dB(A)).

5.2.9. Simulation Analysis of Thermal Diffusion of Cooling Water

Monitoring of seawater temperature, current speed /direction and conductivity were carried out during the wet season the dry season at the project site region. In addition, the data of bathymetric maps presented by the oceanographic investigation and the data of tidal water levels measured at the Sihanoukville port were collected and compiled. The results of these and other data were used for the simulation analysis of thermal diffusion of cooling water.

The model for the simulation is "AQUASEA".

The simulation calculations were carried out for the ultimate plant capacity of 270 MW for the wet season vs. the dry season, and for uniform mixing between surface and bottom vs. mixing in only the top 2.5 m of the water column.

The calculation results confirmed that the guidelines of the World Bank for temperature rise of less than 3 deg. C at a 100-m radius from the discharge point is easily attainable. The extended area of thermal plume is limited to a small fraction of coastal area in the vicinity of the project, suggesting that impacts on marine fisheries or other species will not be significant. However, 0.5 deg. C temperature rise is likely to extend over the intake structure about half of the time in the wet season.

5.2.10. Estimation of Ground Level concentrations of Flue Gas Emissions

Using the simulation calculation model of "USEPA Industrial Source Complex 3 model (ISC3)", the calculations to estimate the ground level concentrations of NO_2, SO_2, CO and TSP were carried out.

The simulation calculation was carried out for many options to see the effects by the differences of staged development, fuel types and the stack systems.

The results are summarized as follows:

- For all pollutants studied, the maximum ground level concentrations consistently occur at the hilltops east and southeast of the plant site.
- Ground level concentrations at Sihanoukville, Sokimex Oil Terminal and Stung Hav (the receptor areas) are significantly lower than the maximum concentrations at the aforementioned hilltops.
- One stack per stage (common stack) is better for atmospheric dispersion than three stacks per stage.
- The most difficult standard to satisfy is the 1-hour standard for SO_2 when diesel oil fired.

Finally, on the condition that this power plant will be expanded to 270 MW, the option of common stack with 50-m height (one stack for each stage, 3 stacks in total) will satisfy all Cambodian standards, provided that the fuel oil with sulfur content of less than 0.2% is used.

6. Environmental Regulations and Standards

6.1. Environmental Standards Related to the Plant

The existing environmental laws, sub-decrees and guidelines in Cambodia, which are related to the power plant project, are as follows:

- Law on “Environmental Protection and Natural Resource Management” (December 1996)
- Sub-Decree on “Environmental Impact Assessment Process” (August 1999)
- Declaration on “Guidelines for Conducting Environmental Impact Assessment Report” (March 2000, Draft)
- Sub-Decree on “Water Pollution Control” (April 1999)
- Sub-Decree on “Solid Waste Management” (April 1999)
- Sub-Decree on “Air and Noise Pollution Control” (July 2000)

In principle, the standards and limitation that are stipulated in the above laws, sub-decrees and guidelines are applied to the Plant. However, where there are gaps or ambiguities in the Cambodian standards in comparison with other international standards or guidelines, the World Bank or comparable guidelines are applied.

6.2. Environmental Standards Applied to the Plant

(1) Emission and Atmospheric Limitation

The following Cambodian standards will be applied to the Plant.

Parameter	Allowable Emission	Comparisons
NOx	1000 mg/m^3*	IBRD = 125 mg/Nm^3 for gas fuel, 165 mg/Nm^3 for diesel oil dry at 15% oxygen
Sox	By separate substance*	IBRD = 2,000 mg / Nm^3 & 0.20 tpd / MWe
SO_2	500 mg/m^3*	
SO_3	35 mg/m^3*	
H_2SO_4	35 mg/m^3*	
Dust (SiO_2)	100 mg/m^3*	IBRD total PM = 50 mg/Nm^3
VOC	By separate substance*	
CO	1000 mg/m^3*	

* Dry at 15 % oxygen, 1.013 bar and 0 °C will be used although it is not specified

For ambient air quality the following Cambodian standards will also be applied.

Parameter	1-hr average mg/m^3	8-hr average mg/m^3	24-hr average mg/m^3	1-yr average mg/m^3
NO_2	0.3	-	0.1	-
SO_2	0.5	-	0.3	0.1
TSP	-	-	0.33	0.1
CO	40	20	-	-
Ozone	0.2	-	-	-
VOC (one by one)				

(2) Liquid Effluent Limitation

The following Cambodian standards for waste effluents will be applied to the Plant.

Parameters	Units	Allowable Limits	
		Public Water Area and Sewer	Comparisons
Temperature	°C	< 45	IBRD = change ≤ 3
PH		5-9	IBRD = 6-9
BOD5	mg/l	< 80	-
COD	mg/l	< 100	-
Total Suspended Solids	mg/l	< 80	IBRD = 50
Total Dissolved Solids	mg/l	< 2000	-
Grease and Oil	mg/l	< 15.0	IBRD = 10
Detergents	mg/l	< 15.0	-
Nitrate	mg/l	< 20	-
Chlorine (free)	mg/l	< 2.0	IBRD = 0.2
Chloride (ion)	mg/l	< 700	-
Sulfate (as SO_4)	mg/l	< 500	-
Phosphate (PO_4)	mg/l	< 6.0	-
Iron (Fe)	mg/l	< 20.0	IBRD = 1
Chromium (Cr^{+3})	mg/l	< 1.0	IBRD = 0.5 total
Chromium (Cr^{+6})	mg/l	< 0.5	
Copper (Cu)	mg/l	< 1.0	IBRD = 0.5
Lead (Pb)	mg/l	< 1.0	-
Nickel (Ni)	mg/l	< 1.0	-
Zinc (Zn)	mg/l	< 3.0	IBRD = 1.0
Ammonia (NH_3)	mg/l	< 7.0	-
Dissolved oxygen (DO)	mg/l	> 1.0	-

Discharge to waste water to Prey Treng Pond should be avoided. Ambient water quality standards to be applied to coastal receiving waters are the following:

Coastal Water

Parameters and Units	Standard	Comparisons
PH	7.0 – 8.3	-
COD (mg/l)	2 – 8	-
Dissolved Oxygen (DO) (mg/l)	2.0 – 7.5	-
Coliform bacteria (MPN/100 ml)	<5000	-
Oil content (mg/l)	0	-
Total Nitrogen (mg/l)	0.2 – 1.0	-
Total Phosphorus (mg/l)	0.02 – 0.09	-

The size of the mixing zone for the thermal plume of the cooling water should follow the recommendation of the World Bank, so that the area of 3°C temperature rise should not extend more than 100 m from the point of discharge of the cooling water.

Chlorination of the cooling water also proceed as intermittent shocking rather than continuous chlorination in compliance with the World Bank’s guidelines.

(3) Solid Waste Disposal Limitation

Cambodian guidelines for solid waste disposal remain to be developed. In the absence of these guidelines the following general approaches should be applied to the project.

- Volume reduction by sorting, salvaging and selling
- Sorting of toxic and non-toxic residue
- Volume reduction through incineration of non-toxic residues
- Land-filling of non-toxic, non-combustible and non-salvageable residues
- Disposal of toxics through reputable vendors or through stabilization before land-filling

(4) Noise Limitation

The following limitations are applied to the Project in reference to the Cambodian standards.

At site boundaries and in adjacent areas that are dedicated to commercial and industrial uses, project- induced sound levels should not exceed 70 dB(A) at any time of the day.

At the house that is nearest to the site boundary, project-induced sound levels should not exceed 50 dB(A) between 22:00 and 6:00, 70 dB(A) between 18:00 and 22:00 and 75 dB(A) between 06:00 and 18:00.

6.3. **Preparation of EIA**

Power plant projects larger than 5 MW are required to complete an EIA report.
The legal framework and specific mandates for carrying out environmental impact assessment studies and reports in Cambodia are specified in the Ministry of Environment's August 11, 1999 Sub-Decree on Environmental Impact Assessment Process.
In principle, the EIA report prepared in this Project will follow the above sub-decree and draft Guidelines for Conducting Environmental Impact Assessment, which is not yet enacted at present.