3. Selection of Optimum Power Plant Type

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 near future as described below.

(1) Heavy Fuel Oil, Diesel Oil and Naphtha

Commercial energy sources currently consumed in Cambodia are mostly liquid fuels, all of which are imported. In 1995, Cambodia imported gasoline of 36,000 tons of oil equivalent (21.7% of the total quantity of imported liquid fuels), kerosene of 41,000 tons of oil equivalent (24.7%), diesel oil of 40,000 tons of oil equivalent (24.1%), heavy fuel oil of 46,000 tons of oil equivalent (27.7%) and others of 3,000 tons of oil equivalent (1.8%). (Source : Energy Statistics Yearbook 1988 ~ 1995, the United Nations)

Among the imported fuels, diesel and heavy fuel oils can be used as fuels for power plants. Naphtha, which IPP2 had considered as the main fuel, is available in Singapore (note : IPP2 contract has been suspended). However, it has no advantage compared to diesel oil because of higher price and more difficult handling. As of December 1999, the prices of fuels are as follows; Naphtha : 5.0 $/MMBTU, Diesel oil : 4.6 $/MMBTU, Heavy fuel oil : 3.5 $/MMBTU.

Cambodia imports mainly those fuels from Singapore, Thailand and Vietnam, and there are several oil companies to deal in petroleum products, such as Sokimex, SHELL, CALTEX, TELA, CUPL, etc. in Cambodia.

Imported petroleum products are transported by ship, and unloaded at Sokimex Oil Terminal that is located near the site for the Project, or transported by barge from

Vietnam to Phnom Penh through the Mekong River and unloaded there. The unloaded petroleum products are transported by tank car to each consumer such as power stations. Most of the tank cars have a capacity of 12 or 16 k*l*, and Sokimex has 5 tank cars with a capacity of 38 k*l*. Transportation of fuel oils by rail is also available because a siding of the railroad between Sihanoukville and Phnom Penh is routed through in Sokimex Oil Terminal. However, almost all of the rail cars required repairing due to superannuation. There are 34 rail cars with a capacity of 72 k*l*.

Sokimex Oil Terminal handles gasoline, diesel oil and heavy fuel oil, and the jetty of Sokimex Oil Terminal is used to unload petroleum products not only for Sokimex but also for SHELL, CALTEX and TELA. Sokimex Oil Terminal has never handled naphtha but Sokimex has an intention to deal with naphtha if there is a demand for it. The storage capacity of Sokimex Oil Terminal is 16,200 m^3 for heavy fuel oil (tank : $3 \times 5,400$ m^3), 49,500 m^3 for diesel oil (tank : $1 \times 10,500$ m^3 and $6 \times 6,500$ m^3) and 6,060m^3 for gasoline (tank : $2 \times 2,000$ m^3 and $2 \times 1,030$ m^3) and total 72,000 m^3. Furthermore, Sokimex has a plan to increase the capacity to 172,000 m^3. In addition, a storage tank with capacity of 25,000 m^3 was constructed in 2000 and 3 tanks with the same capacity are under planning. These tanks will be used for diesel oil. The new jetty to accommodate tankers up to 46,000 DWT was inaugurated in April 2001. Sokimex has a plan that the existing unloading facilities including under-sea pipe for tankers up to 5,000 DWT will go out of use after completion of the extension.

Sokimex Oil Terminal has one jetty (4.2 m deep completed in 1979) with the capacity to accommodate tankers up to 1,500 DWT. The rest is floating buoy associated with undersea pipe, build under an agreement between Sokimex and SHELL for temporary use with the capacity to accommodate tankers to the maximum of 5,000 DWT. The unloading time of 1,500 DWT tankers and 5,000 DWT tankers are about 6 hours and 12 to 16 hours respectively.

(2) Natural Gas

(a) Development in Undisputed Cambodian Territory

(i) Current Status of Gas Development

So far, oil and gas wells with commercial scale have not been developed in Cambodia.

In 1998, after poking around for seven-years, the four foreign firms that had drilled a total of nine wells in potential oil and gas fields offshore Cambodian territory, however they have walked away from their investments in Cambodia, because they had not found much oil/gas, and collapsed world oil prices had made exploration in Cambodia less interesting.

Although Australia based oil firm Woodside Petroleum Ltd. signed a Production Sharing Contract (PSC) with the Cambodia Government on Blocks 5 and 6 offshore, and completed the 2D seismic study, but no drilling, in 1998, they have relinquished Blocks 5 and 6, because of low prospectivety.

In June 2001, the Cambodian Government and Woodside are going to make new exploration agreement on new area within Blocks 1 ~ 4 covering Koah Tang, Koah Pring, Apsara, Poulo Wai, Angkor and DA (Refer to the dotted zone on Fig.3.1-1).

Woodside expects recoverable gas reserves of 2.7 TCF in this area using the past available data (Refer to Table 3.1-1).

As gas consumption for 180 MW gas turbine combined cycle power plant is approximately 10 BCF/year, the most powerful reservoir Angkor-1 may serve the gas to the plant more than 55 years.

Woodside assumes the average capacity and life of prospective wells approximately 3.5 BCF and two years respectively, because of relatively small capacity of each gas reservoir. These figures mean that approximately one hundred wells shall be drilled for 180 MW with 25 years plant life taking into account of the success rates as exploration and development wells. After signing of the contract, Woodside will start seismic analysis and well drilling for exploration, appraisal and development. As per their latest information, two exploration wells will be drilled in the first quarter of 2002 initially and after that four wells will be added and commercial operation is expected in 2006. As shown in Fig.3.1-2, it takes about 4 to 5 years up to commercial production.

Despite CNPA expected to sign the contract with development firm in July 2001, contract signing is delaying because of an uncertainty of gas price which is linked with future gas demand in Cambodia.

As several hundreds millions of dollar for platform, wells and pipeline cost shall be recovered by the gas price, this cost determines gas prices. And if resultant gas price is excessive high the negotiation comes to a deadlock.

Table 3.1-1 Recoverable Gas Reserve

Field	Natural Gas (BCF)
Koah Tang	335
Koah Tang Southwest	260
Koah Tang Northeast	255
Total of Koah Tang Fields	**850**
Koah Pring East-1	137
Koah Pring East-2	91
Total of Koah Pring Fields	**228**
Koah Poulo Wai North	150
Koah Pulo Wai	260
Total of Koah Poulo Fields	**410**
Apsara 1	312
Angkor 1	577
Da 1	309
Total of Aspara, Ankor and Da Fields	**1,198**
Grand Total	**2,686**

(BCF : Billion cubic feet) (Source : CNPA)

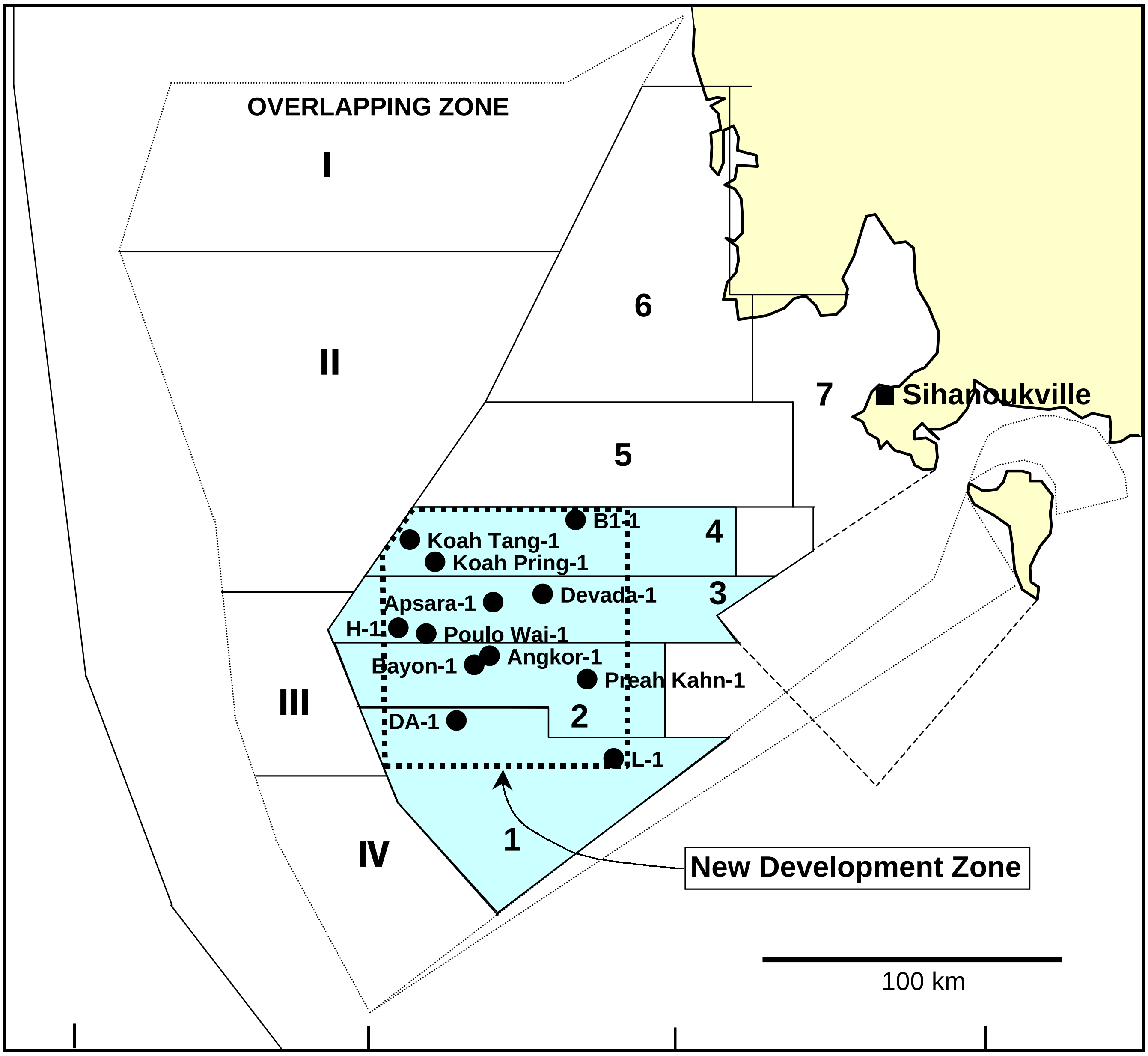


Fig.3.1-1 Gas and Oil Blocks (Offshore) in Cambodia

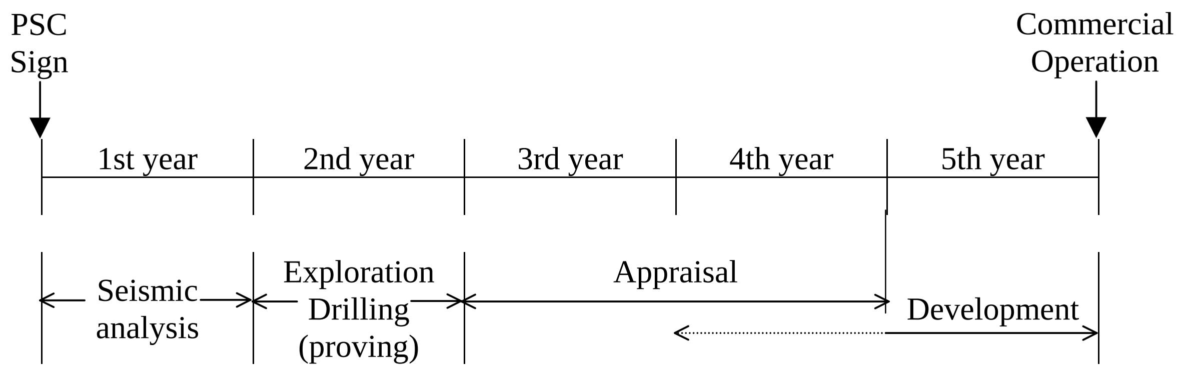


Fig.3.1-2 Natural Gas Development Schedule

(ii) History of Gas and Oil Development

The history of gas and oil development in Cambodia is not so long and started from 1950s when natural resource surveys were carried out off-shore and on land by France, China, Poland, the former Soviet, etc. However, the survey was not full-scale and was carried out in a small way only in specified areas.

The activities have been full-scale since 1969. The Cambodian Government of those days gave the right of oil exploration to French company and this marked a turning point in survey activity.

From 1969 to the beginning of 1970, Elf Aquitaine, a French company, carried out seismic surveys in Gulf of Thailand and drilled 3 trial wells. However, each well was dry and obtained no good result. Elf Aquitaine and Esso, as a consortium, carried out seismic surveys and drilled 2 wells in 1974 and discovered small-scale oil wells.

However, oil surveys declined rapidly and were suspended completely after that because domestic warfare got serious.

Geological surveys all over the country restarted from 1988. Gas and oil reserves were not discovered, but potential possibilities were promising. At that time a team of Russian geologists carried out investigations and made the judgment that there is potential possibility of gas and oil reserves in 6 areas of sedimentary rock. The East West Center estimated that reserves of crude oil and natural gas are 50 to 100 million barrels and 1,500 to 3,500 billion ft^3 respectively.

According to the Comprehensive Peace Agreement at the international conference of Paris held in October 1991, Cambodia determined to re-start large–scale development of gas and oil reserves. The Ministry of Industry took a step of opening petroleum field to foreign oil developers and put licenses of exploration out to tender. The investigation zone is the sedimentary rock area that the Russian team believed to be promising and is divided into 26 blocks (7 offshore blocks and 19 onshore blocks).

At the beginning, many companies declared their intention to make a bid but later declined due to insecure political situation. In 1991, the following 3 groups and 1 developer got licenses.

- Consortium among Enterprise Oil Exploration (UK 40% of investment ratio), Total (France 30%), British Gas (UK 20%) and Compagnie Europeanne des Petroles (France 10%) :
  Areas are Block 1 (4,700 km^2) and Block 2 (4,900 km^2) located about 150 km offshore southwest from Sihanoukville Port.
  PS Agreement for a period of 30 years
  Oil layer was discovered in Block 2 in 1994 and overall data acquisition started from September.

- Japan National Oil Company, JAPEX and Nisshoiwai (Japan):
  Area is Block 3 (4,000 km^2) located about 130 km offshore Gulf of Thailand
  The existence of oil was recognized in January 1994 but it was small-scale and not commercial. 2nd well is under drilling.

- Consortium among Premier Oil Pacific (UK 33.3% of investment ratio), Idemitsu (Japan 33.3%), Empolex (Australia 33.3%) :
  Area is Block 4 (4,775 km^2) located offshore Gulf of Thailand.
  Oil well was discovered in March 1994.

- Nawa Oil (Hungary) :
  Areas are Block 5 located offshore Gulf of Thailand and Block 9 lo-

cated onshore.

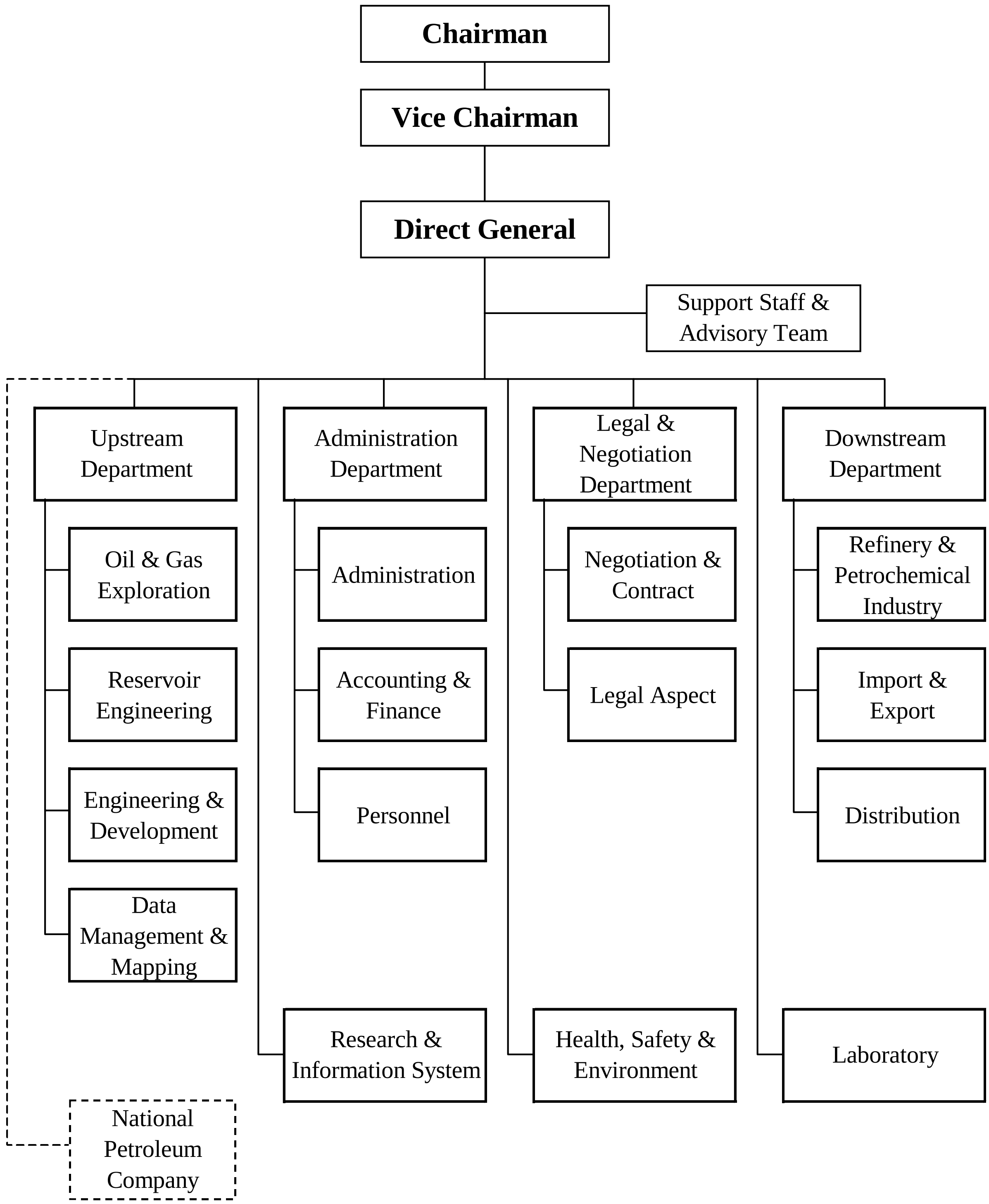
It withdrew entirely due to nonfulfillment.

Subsequently, 2 offshore blocks and 18 onshore blocks were put to tender in 1992 and 4 groups, Cairn Energy (UK), Marimex BV (Netherlands), Technitrade International (Netherlands) and a Taiwanese consortium of Overseas Petroleum Co. and Chinese Petroleum Co. were approved to get licenses for investigation. However, the Taiwanese consortium withdrew just before contract and 2 Dutch companies were cancelled because they could not prepare and mobilize within a definite period of time though they had signed contracts.

(iii) Government Office related to Oil and Gas Management

In December 1998 the Cambodian Government integrated former organizations, established the Cambodian National Petroleum Authority (CNPA) and gave it responsibility for overall control of petroleum from oil exploitation to marketing.

Fig.3.1-3 shows the organization chart of CNPA.



Royal Decree on the Nomination of the Board of Management for the Cambodian National Petroelum Authority

Fig.3.1-3 Proposed Organizational Chart of Cambodian National Petroleum Authority

(b) Development in Overlapping Area

There are overlapping claims by Cambodia and Thailand to one offshore area where significant quantity of gas is expected, because these are just on the geological extension of the area where Thai gas wells have been developed. Reserves in this area are estimated about 9 TCF by a Japanese oil firm.

Each government has issued a license to different four foreign joint ventures for exploration of oil/gas in the early 1970s, but the dispute of the territory has prevented any exploration.

After 30 years over argument, both countries signed an agreement on potential oil/gas exploration in a 27,000 km^2 area in June 2001.

The Memorandum of Understanding (MOU) on the "Overlapping Maritime Claims" states;

1) Neither country can allow oil/gas drilling until each agrees on a resolution to the dispute
2) Split revenue between two countries 50/50
3) Set up a joint committee to continue working toward a solution for the next six months

This MOU may break the deadlock over the overlapping claims and there might be much progress, but states only basic standpoint.

On the other hand, the priority of the Thailand Government concerning gas/oil development is;

1st ....Thai/Malaysia overlapping zone
2nd ....Renovation/Exploration in/around existing wells
3rd or 4th .....Thai/Cambodia overlapping zone

This means that Cambodian committee member should take stronger leadership to accelerate the developing schedule which has a tendency to a tremendous delay normally.

(c) Import from Neighboring Countries

(i) Import from Thailand

At present Thailand seems to be most likely gas supplier to Cambodia because Thailand has many existing and many developing gas fields in the Gulf of Thailand (refer to Fig.3.1-4), and produced natural gas in this area can be transferred directly to Sihanoukville by offshore gas pipeline.

The JICA Study Team has contacted with and obtained some information from Mitsui Oil Exploration Company (MOECO) who is one of the main gas suppliers in Thailand. MOECO is producing natural gas in the Gulf of Thailand and supplying it to PTT (Petroleum Authority of Thailand) in the form of joint supplier with Unocal Thailand, Ltd. Unocal-MOECO co-venture is the largest gas producer in Thailand. They supplied natural gas of around 1,000 MMCFD to PTT in 1999; this amount corresponded to about 60 % of total demand of Thailand in 1999. Therefore Unocal-MOECO is considered to be the most possible gas supplier to Cambodia.

MOECO suggests that they could afford to supply natural gas to Cambodia in future from the viewpoint of their ample production capacity. However, to import natural gas from Thailand, there some issues to be concluded as described below:

① The partner of co-venture, Unocal, is one of the members of 4-company's group that plans to built a gas turbine combined cycle power plant in Sihanoukville. Unocal joins with this group as fuel supplier. Therefore they have to dissolve firstly their agreement of co-development of IPP so that they may become gas supplier for this Project.

② In general, for import of natural gas from other countries including Thailand, the agreement on fuel trade between two concerned countries will be necessary. This kind of agreement usually would take a long time to conclude unless an interest of country accords with each other; namely, ③ At present the supply capability of natural gas in Thailand has an enough margin over the demand due to the recent economic depression in Thailand and import of Yadana gas from Myanmar that has commenced in the late last year. However, due to the recent Thai government policy to promote utilizing natural gas and gradually drying up of the existing fields, it is assumed that several new gas resources with ample capacity will be required to be developed after the year 2007- 2008. This time of 2007-2008 might correspond to the time of completion of Sihanoukville Power Plant. Therefore it is expected that Thai government would be reluctant to supply natural gas to Cambodia.

④ The demand of natural gas in the Project is rather small for commercialization of gas supply from Thailand. Approx. 300 km length gas pipeline would be required to be constructed from the existing gas fields to Sihanoukville. The length of 300 km itself is unlikely so long, but smaller size of pipeline needs a higher construction cost per unit volume of transferred gas. Unocal suggested to MIME that a minimum electric generation capacity to assure economic viability would be around 300 MW.

To realize the supply of natural gas from Thailand in time, the above issues should be concluded soon.

(ii) Import from Vietnam

The natural gas to Vietnam is now supplied solely from the offshore gas fields located in the South China Sea. Meanwhile, in Vietnamese territory in the south of the Gulf of Thailand, some developers are working to develop new gas resources. Joint developer of MOECO/Unocal/PTTEP/PVE is one of these developers, and they have a plan to supply natural gas from this area to power stations that are located or to be located in future in the Mekong delta area of Vietnam.

In 2000, they have drilled seven test wells in total in the western offshore area of Vietnam, approx. 300 km apart from Sihanoukville. According to their test well results, they estimate that the recoverable gas volume may be around 1 ~ 5 TCF. They intend to supply this natural gas to the second stage of O Mon Power Station (300 MW) and IPP power station(s) from 2007-2008. However, at present, the construction of the second stage of O Mon Power Station is not yet finalized to construct, furthermore there is no specific plan about IPP at present. Therefore they are now seeking specific consumers for realizing this project and consider supplying to Cambodia as one of the feasible options. But this option may also have a political complexity depending on the intention of Vietnamese government as the case of Thailand described above.

As discussed in the above, regarding the possibility of natural gas, all options, i.e. the development in Cambodian territory, the development in overlapping zone and the import from Thailand or Vietnam, have several kinds of issues to be solved at present. A common key issue that is related to all options is a low economic viability which is arisen from a relatively small size of gas demand expected in Cambodia. Therefore, increase of demand requirement, with introducing a gas-consumed industry as well as a power generation, would be the most effective factor, which accelerates the realization of development or import of natural gas.

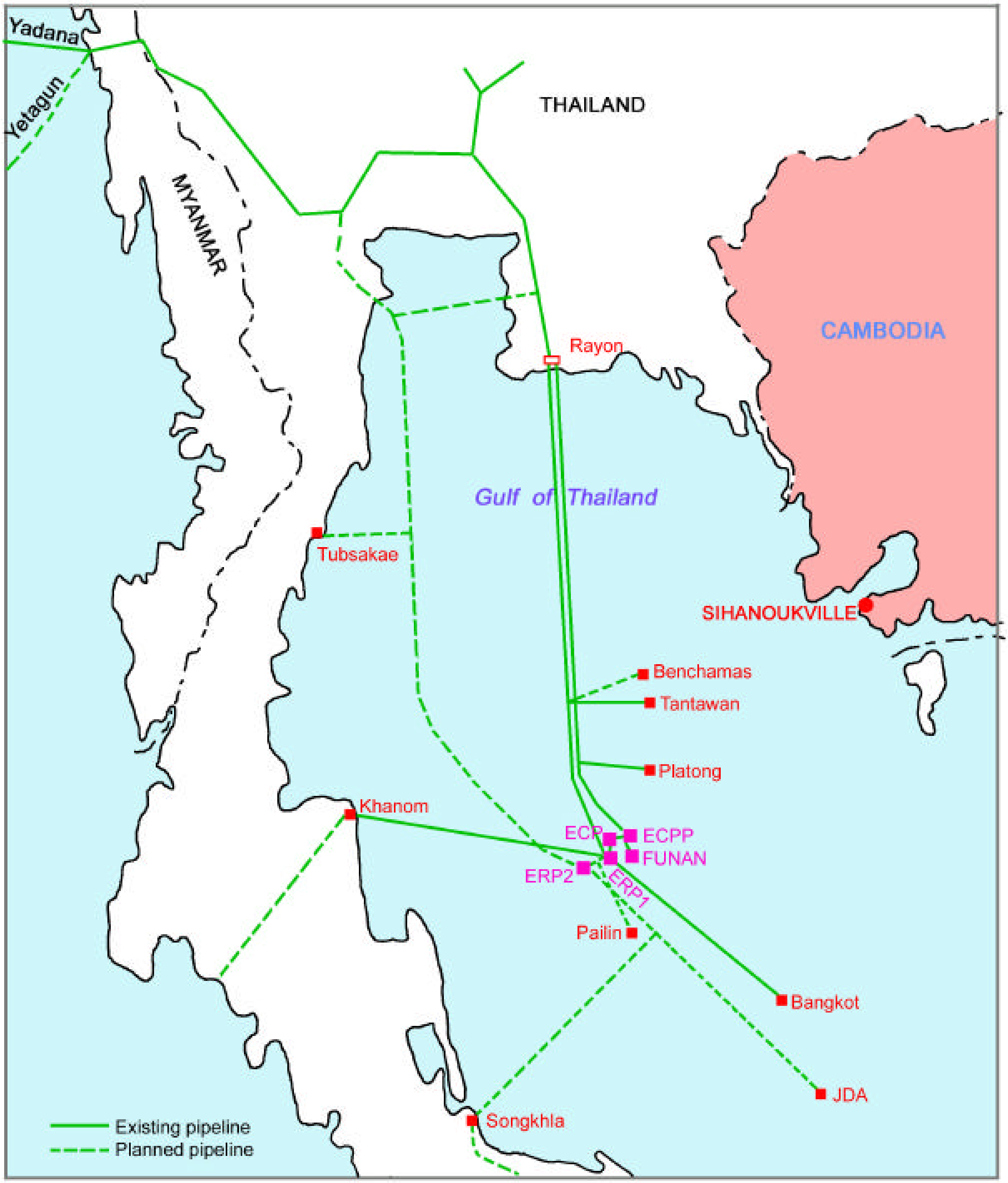


Fig.3.1-4 Natural Gas Fields and Gas Pipelines of Thailand

(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. Receiving and supply facilities for LNG consist of unloading jetty, storage reservoir, BOG compressors, vaporizer, transfer piping system, etc. Capacity of storage reservoir is approximately 40,000 m^3 for 180 MW power plant. Construction cost of these facilities will be approximately 130 to 170 Million US$, which 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, 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 if coal is used for power plant. Furthermore, there is no coal unloading facilities in Cambodia, so that it is necessary to construct a new coal unloading facility in the power station. The total capacity of new power station will be 270 MW when the 3-stage development is completed. Therefore, it might be necessary to construct jetty, unloading facility and coal storage facility to meet the requirement of this 270 MW ultimate capacity. That may results in excessive initial investment, i.e. additional cost is more than 130 Million US$. 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

Electricite du Cambodge (EDC) procures fuel oils from selected company through periodic competitive bidding by several oil companies such as Sokimex, CALTEX, SHELL, TOTAL, CUPL, etc. At present, the contract covers 2 years for heavy fuel oil and 3 months for diesel oil.

Contracted fuel price is composed of a standard fuel price at Singapore and an oil company's handling cost (premium) including transportation cost. The amount of premium is fixed during the contract period but the standard fuel price at Singapore varies every hour, so that the fuel price at consumer is not constant.
The example of the price of heavy fuel oil is shown in Table 3.1-2.

The import tax, exceptional tax and social funds are added to the above-mentioned fuel price. Among these taxes, the exceptional tax is applied to only gasoline and lubricants. And the social funds are applied to gasoline, diesel oil and heavy fuel oil.

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. Refer to Table 3.1-3.

Base fuel price used for calculation of taxes is not an actual fuel price but a fixed standard price decided by the custom office. However, if an actual fuel price exceeds the standard fuel price, the actual fuel price is used for calculation of taxes.

New projects will be exempted from taxes only in the first year of operation.

Fig.3.1-5 shows the trend of heavy fuel oil and diesel oil prices for the last five years, from Nov. 1996 to Aug. 2001. The average prices of diesel oil and heavy fuel oil during the last five years, which are of CIF at Phnom Penh and excluding tax and duties, were 154 and 237 $/ton, respectively.

Table 3.1.-2 Example of Heavy Fuel Oil Price

(Unit : $/MT)

Date	Singapore Market Price		Average
	Low	High	
30th Nov., 1999	138.75	139.75	139.250
01st Dec., 1999	137.50	138.50	138.000
02nd Dec., 1999	139.00	139.25	139.125
03rd Dec., 1999	141.00	141.50	141.250
06th Dec., 1999	142.25	143.00	142.625
Average			140.050
Premium			41.000
Price (CIF at Station)			181.050

Table 3.1-3 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

CIF Phnom Penh

FuelType	1996 Nov	1996 Dec	1997 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	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

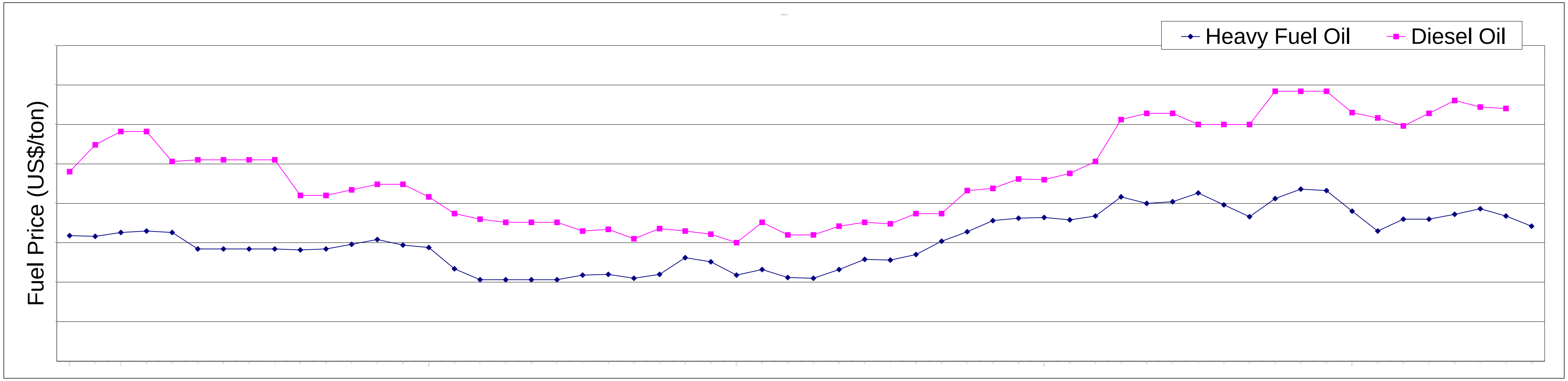
FuelType	1998 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heavy Fue	144	117	103	103	103	103	109	110	105	110	131	126
Diesel Oil	208	187	180	176	176	176	165	167	155	168	165	161

FuelType	1999 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	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	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heavy Fue	182	179	184	208	200	202	213	198	183	206	218	216
Diesel Oil	230	238	253	306	314	314	300	300	300	342	342	342

FuelType	2001 Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Ave
Heavy Fue	190	165	180	180	186	193	184	171	154
Diesel Oil	315	308	298	314	330	322	320		237

Note: The above fuel prices exclude tax and duties.



Source: Information from EDC

Fig. 3.1-5 Fuel Price in Phnom Penh (CIF) Purchased from CUPL

(2) Natural Gas

Natural gas is not used in Cambodia, so there is no price at present. Natural gas price at site consists of wellhead price and submerged pipe cost. Wellhead gas prices are less than 2.2 $/MMBTU at Erawan gas filed which is the biggest gas filed of Unocal who is the biggest gas supplier in the Gulf of Thailand (i.e., Unocal supplies about 1,000 MMCFD out of 1,800 MMCFD of total consumption of Thailand) and about 2.5 $/MMBTU on an average in the Gulf of Thailand. The reason of cheaper price at Erawan would be the effect of more than 1,000 wells drilling. The price of Yadana gas from Myanmar is 2.5 $/ MMBTU at Thai border and in southern Vietnam about 2.5 ~ 3.0 $/MMBTU.
In case of development in Cambodian gas fields, as each reservoir capacity is smaller than that of other countries, well drilling cost might run up. Therefore wellhead price is estimated around 2.5 ~ 3.0 $/MMBTU.

Gas pipeline cost from the fields to Sihanoukville is estimated about 140 Million US$ by CNPA and Woodside Co. for 24” pipe diameter and 170 km length. This cost can be considered as reasonable considering adjusted value of 158 Million US$ from actual value for 24” pipe and 120 km length in Thailand.
Using this estimation, pipe cost for 12 inch which is suitable size for 270 MW is calculated about 90 Million US$. This cost is equivalent to 1.0 ~ 1.5 $/MMBTU depending on the operation load in case of discount rate of 15% and payback period of 20 years.

Therefore, natural gas price at power plant site would be around 3.5 ~ 4.5 $/ MMBTU as a criterion depending on depreciation period and well drilling cost, etc.

3.1.3. Typical Analysis of Fuels

Tables 3.1-4 and 3.1-5 show the typical specification of diesel oil and heavy fuel oil, respectively.
Tables 3.1-6 and 3.1-7 show the analyses of samples from diesel oil and heavy fuel oil, respectively. These data were submitted by Sokimex. According to the result, sulfur content is 0.03%, which is incredibly low compared to the specified maximum value of 0.25%.

In general, analysis of fuel is carried out by each tank car. However, at present Sokimex Oil Terminal has no analyzing devices, therefore, analysis of fuel is carried out at his laboratory in Phnom Penh.

Table 3.1-8 shows standard specification for Singaporean oil which shows higher sulfur content.

New environmental law was drafted in 2000 and authorized without any amendment in 2001. Sub-decree on air and noise pollution control limits sulfur and lead content in its Chapter 2, Article 10, Annex 8 (Refer to Table 3.1-9). According to the standard the permitted sulfur content in diesel oil is 0.2%. Diesel oil imported from Thailand may pass this new regulation because of their lower sulfur content in the standard oil, but oil from Vietnam or Singapore shall be analyzed carefully.

Table 3.1-10 shows an example of specification of gas in the Gulf of Thailand.
Properties of gas in the Gulf of Thailand varies in large, i.e., generally less CO_2 content and more oil in the northern area and less oil and more CO_2 in the southern area. Approximately well containing about 70% of CO_2 may be discovered in near Indonesia. The zone which will be developed by Cambodia may be gas and oil mixing zone and actual analysis of gas in this area must be observed closely.

Table 3.1-4 Distillate Fuel Quality Specification

	Unit	Test Methods	Limits
Kinematic Viscosity at 40°C	cSt	ASTM D445	1.7 - 5.50
Density at 15°C	kg/l	ASTM D1298	0.820 - 0.870
Gross Calorific Value	Btu/lb	ASTM D240	19,100
Sulphur	wt%	ASTM D1266	0.50 max
Ash	wt%	ASTM D482	0.01 max
Microcarbon Residue	% max.	ASTM D4530	0.05 max
Sediment by Extraction	wt%	ASTM D473	0.01 max
Water by Distillation	vol%	ASTM D95	0.05 max
Flash Point	°C	ASTM D93	66 min
Pour Point	°C	ASTM D97	9 max
Cetane Index	-	ASTM D976	45.5 min
Colour	-	ASTM D1500	2.0 max
Distillation, 90% recovery	°C	ASTM D86	370 max
Corrosion, Copper (3h@ 100°C)	-	ASTM D130	1 max
Strong Acid Number	mgKOH/g	ASTM D974	nil
Total Acid Number	mgKOH/g	ASTM D974	0.25 max

(Source : EDC)

Table 3.1-5 Fuel Oil Quality Specification

	Unit	Test Methods		Limits
Kinematic Viscosity at 50°C	cSt	IP 71	ASTM D445	180 max
Flash Point (PMCC)	°C	IP 34	ASTM D93	66 min
Relative Density at 15.6/15.6°C	kg/l	IP 160	ASTM D1298	0.95 max
Pour Point	°C	IP 15	ASTM D97	21 max
Sulphur	wt%	IP 61	ASTM D1266	3.5 max. 3.0 annual average
Vanadium	mg/kg	IP 285T	ASTM D1548	95 max
Sodium	mg/kg	IP 288T	ASTM D1318	50 max
Carbon Residue (Conradson)	wt%	IP 13	ASTM D189	13.0 max
Sediment by Extraction	wt%	IP 53	ASTM D473	0.10 max
Ash	wt%	IP 4	ASTM D482	0.10 max
Water by Distillation	vol%	IP 74	ASTM D95	0.50 max
Gross Calorific Value	Btu/lb	IP 12	ASTM D240	18,500 min
Asphaltenes	wt%	IP 143/84		5 max
Aluminium & Silicon	mg/kg	IP 377	ASTM D5484	60 max

(Source : EDC)

Table 3.1-6 Analysis Data of High Speed Diesel Fuel

Tested by Alliance Refining Company Limited

Property	Units	Test Method	Specified Value	Result
Appearance	-	Visual	Pass	Pass
Ash	wt%	ASTM D482	0.01 max	<0.001 [*1]
Carbon Residue on 10% Distillation Residue, Micro Method	wt%	ASTM D4530	0.05 max	0 [*1]
Calculated Cetane Index or Cetane Number	-	ASTM D976 or ASTM D613	47 min	56.49
Color, ASTM	-	ASTM D1500	2.0 max	0.5
Corrosion, Copper Strip 3 hr. at 50°C	-	ASTM D130	1 max	1a
Density at 15°C	g/ml	ASTM D4052	0.810 - 0.870	0.8297
Distillation :	°C	ASTM D86		
10% Recovered				217.8
50% Recovered				278.5
90% Recovered			357 max	350.1
95% Recovered				366.5
Flash Point	°C	ASTM D93	66 min	73.5
Pour Point	°C	ASTM D97	9 max	-9
Sulfur Content	wt%	IP336	0.25 max	0.03
Viscosity, Kinematic at 40℃	cSt	ASTM D445	1.8 - 4.1	3.196
Water & Sediment	vol%	ASTM D2709	0.05 max	0.005

(Source : Sokimex)

Sampling Date : 19 Feb., 2000

*1 This test is performed on a 6-monthly basis. The result was obtained from sample dated 03 Dec., 1999.

Table 3.1-7 Analysis Data of Fuel Oil No.2

Tested by Alliance Refining Company Limited

Property	Units	Test Method	Specified Value	Result
Ash	wt%	ASTM D482	0.1 max	0.018 *1
Density at 15°C	g/ml	ASTM D4052	0.990 max	0.9361
Flash Point	°C	ASTM D93	60 min	62.5
Heat of Combustion, Gross	kcal/kg	ASTM D4868	9,900 min	10,407
Pour Point - Summer(1 March - 31 October) - Winter (1 November - 28 February)	°C	ASTM D97	 24 max 18 max	 -9 *2
Sodium plus Vanadium	mg/kg	IP 288	200 max	23.2
Sulfur Content	wt%	ASTM D4294	2.0 max	1.75
Viscosity, Kinematic at 50℃	cSt	ASTM D445	90 - 180	168.9
Water & Sediment	vol%	ASTM D1796	1.0 max	0.10

(Source : Sokimex)

Sampling Date : 25 Dec., 1999

*1 This test is performed on a 6-monthly basis. The result was obtained from sample dated 09 July, 1999.
*2 This test is performed on a monthly basis. The result was obtained from sample dated 01 Dec., 1999.

Table 3.1-8 Standard Specification for Singapore Oil

Diesel Oil

No.	Test Definition	Method ASTM	Range	Type
1	Appearance	Visual	-	
2	Color ASTM	D-1500	Max.	1.5
3	Density at 15°C	D-1298	Max.	0.8500
4	Copper Corrosion (3h, 50°C)	D-130	Max.	No.1
5	Distillation - I.B.P, °C - 10%, °C - 50%, °C - 90%, °C	D-86	 Min. Max. Max. Max. Max.	 150 170 230 300 365
6	Flash Point	D-93	Min.	60
7	Pour Point, °C	D-97	Max.	+10
8	Ash Content, %WT	D-482	Max.	0.01
9	Water Andsediment, 5 vol.	D-1796	Max.	0.05
10	Sulfur Content, %WT	D-1216	Max.	0.70
11	Cetane Inde	D-976	Min.	45
12	Water by Distillation	D-95	Max.	0.50
13	Acid Number, mgKOH/g	D-664	Max.	0.25
14	Carbon Residue, %WT	D-189	Max.	0.05
15	Kinematic Viscosity at 40°C, cst	D-445	Max. Min.	1.4 5.0

(Source : EDC)

Heavy Fuel Oil

No.	Test Definition	Method ASTM	Range	Type
1	Density at 15°C	D-198	Max.	0.985
2	Flash Point, °C	D-93	Min.	60
3	Pour Point, °C	D-97	Max.	15
4	Sulfur Content, %WT	D-1266	Max.	3.5
5	Ash, %WT	D-482	Max.	0.1
6	Sediment by Extraction % vol.	D-96	Max.	0.25
7	Water by Distillation, % vol.	D-95	Max.	1.0
8	Kinematic Viscosity at 40°C, cst	D-445	Max.	170
9	Carbon Residue, %WT	D-189	Max.	8.0

(Source : EDC)

Table 3.1-9 Sulfur and Lead Standard permitted to Fuel and Other Combustion Substances

No.	Combustion Substance	Sulfur (S)	Lead (Pb)
1	Dark fuel	1.0%	
2	Diesel	0.2%	
3	Petrol	-	0.15 g/l
4	Coal	1.5%	

Remark : This standard applied to control concentrations of sulfur, lead, Benzene and hydrocarbons contains in fuel and coals.

(Source : Cambodian Environmental Law)

Table 3.1-10 Properties of Typical Natural Gas

Components	Unit	
CO_2	vol. %	1.65
N_2	vol. %	1.92
CH_4	vol. %	95.49
C_2H_6	vol. %	0.72
C_3H_8	vol. %	0.07
C_4H_{10}	vol. %	0.02
C_5H_{12}	vol. %	0.10
High Heating Value	kJ/Nm^3	38,700
Low Heating Value	kJ/Nm^3	34,920

3.2. Candidate Power Plant Types

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

Conventional power plant is the most popular because it can use many kinds of fuel such as coal, oil and natural gas. GTCC has high thermal efficiency and is used in the area where clean fuels such as natural gas and diesel oil are available. Diesel generator is widely used for scattered power sources. Open-cycle gas turbine is mainly used as standby source for peak load due to its low thermal efficiency.

In this study, three kinds of plant type (GTCC, diesel power plant 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 system diagram of GTCC. Fuel is burnt in combustor of gas turbine, combustion gas rotates the turbine rotor, that turns the generator. This is the first stage of generation. Then, exhaust gas flows into HRSG and heats the boiler water in the heat exchanger tubes of HRSG. The boiler water is converted to the steam, which is induced into steam turbine and rotates the steam turbine generator. This is the second stage of generation.

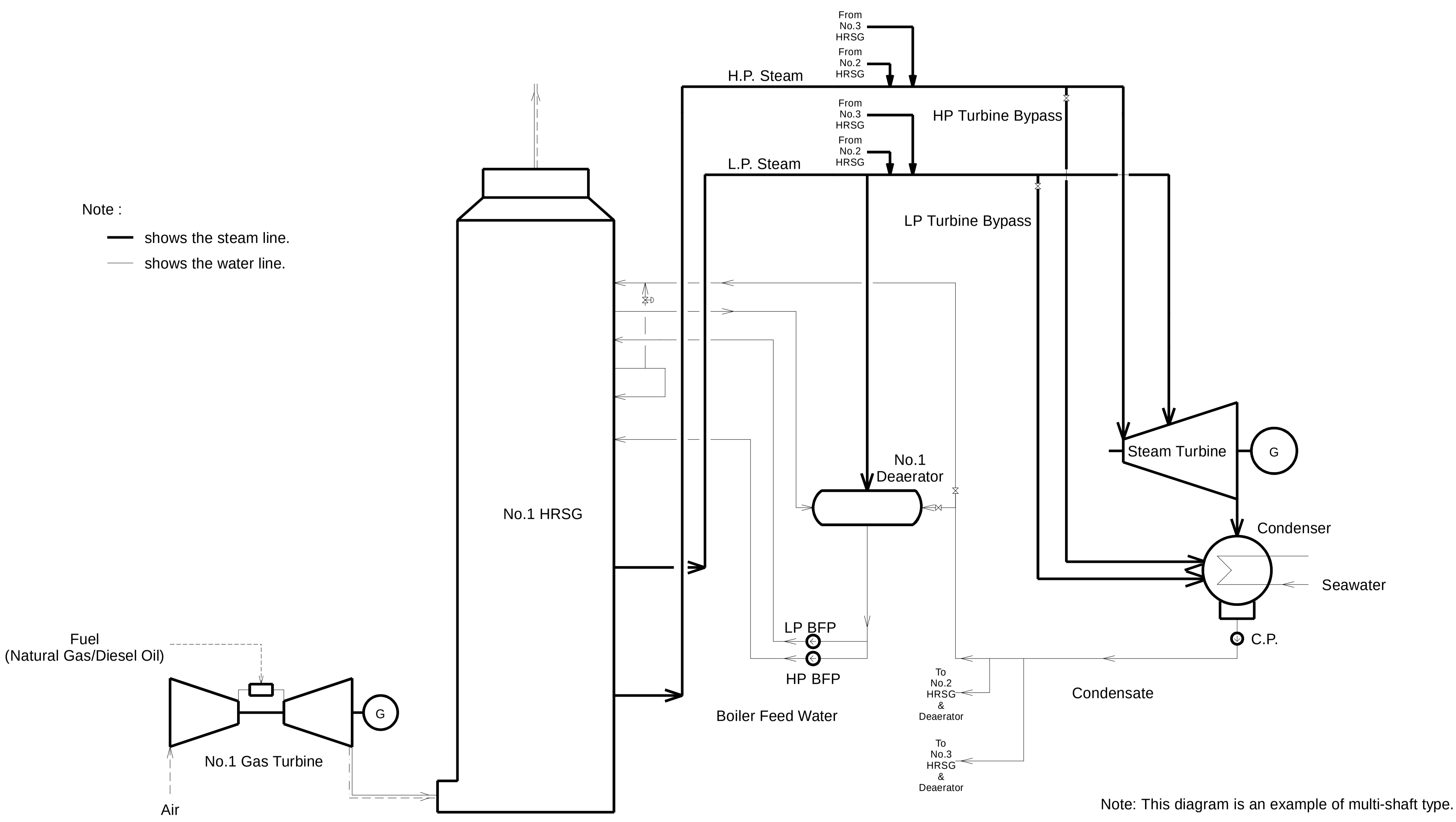


Fig.3.2-1 System Diagram of Gas Turbine Combined Cycle Power Plant

3.2.2. Diesel Power Plant

Diesel power plant consists of diesel engine and generator. Diesel engine is used for prime mover for automobile, ship, and electric 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. As for rotation speed, revolution of middle speed diesel engine is around 400 ~ 700 r.p.m. and that of low speed diesel is around 150 r.p.m. Low speed diesel engine has higher thermal efficiency but it is more expensive. In Cambodia, middle speed diesel is usually used.

Diesel engine is not suitable for large-scale power station because of its small capacity per unit. If it is applied to large-scale power station, so many units need be installed and that cannot enjoy a scale merit. Maximum unit capacity of middle speed diesel is less than about 20 MW and the maximum unit capacity of low speed diesel is about 50 MW.

3.2.3. Conventional Power Plant

Main equipment of conventional power plant are boiler, steam turbine, and generator. Fig.3.2-3 shows system diagram of conventional power plant. Fuel is burnt in boiler using burner, and heats the boiler water in the heat exchanger tubes of boiler. The boiler water is converted to the steam, which is induced into steam turbine and rotates the steam turbine generator.

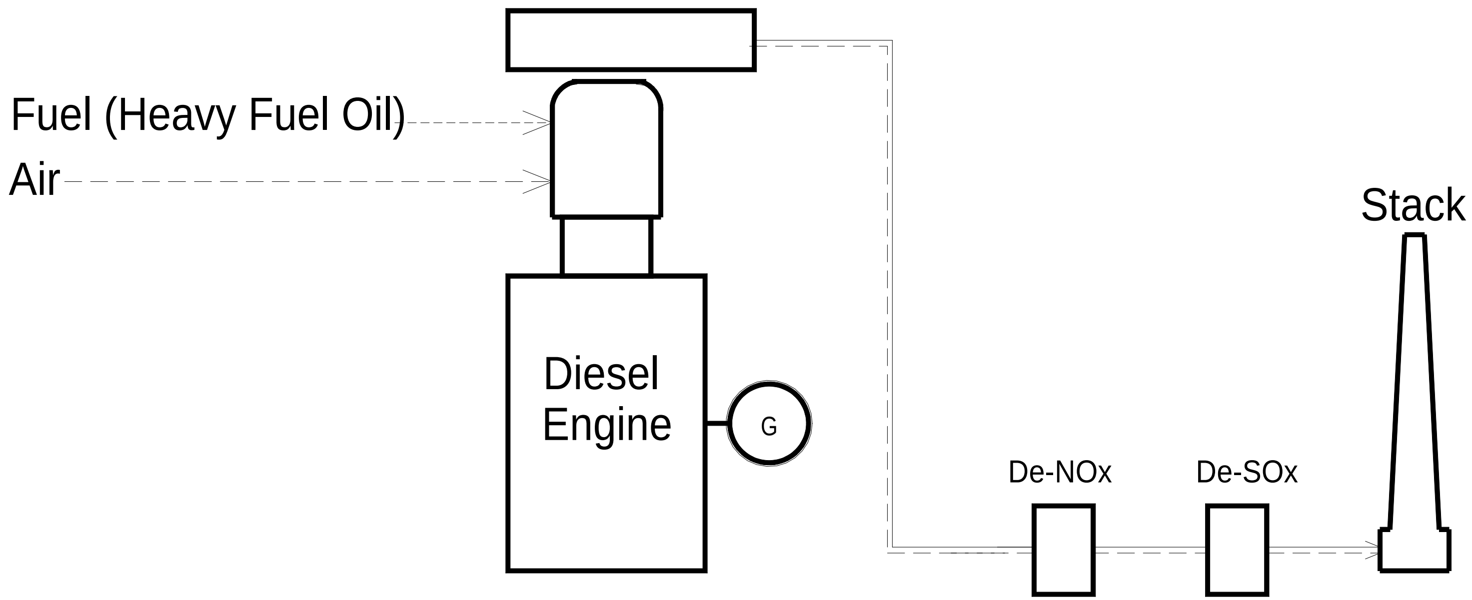


Fig.3.2-2 System Diagram of Diesel Power Plant

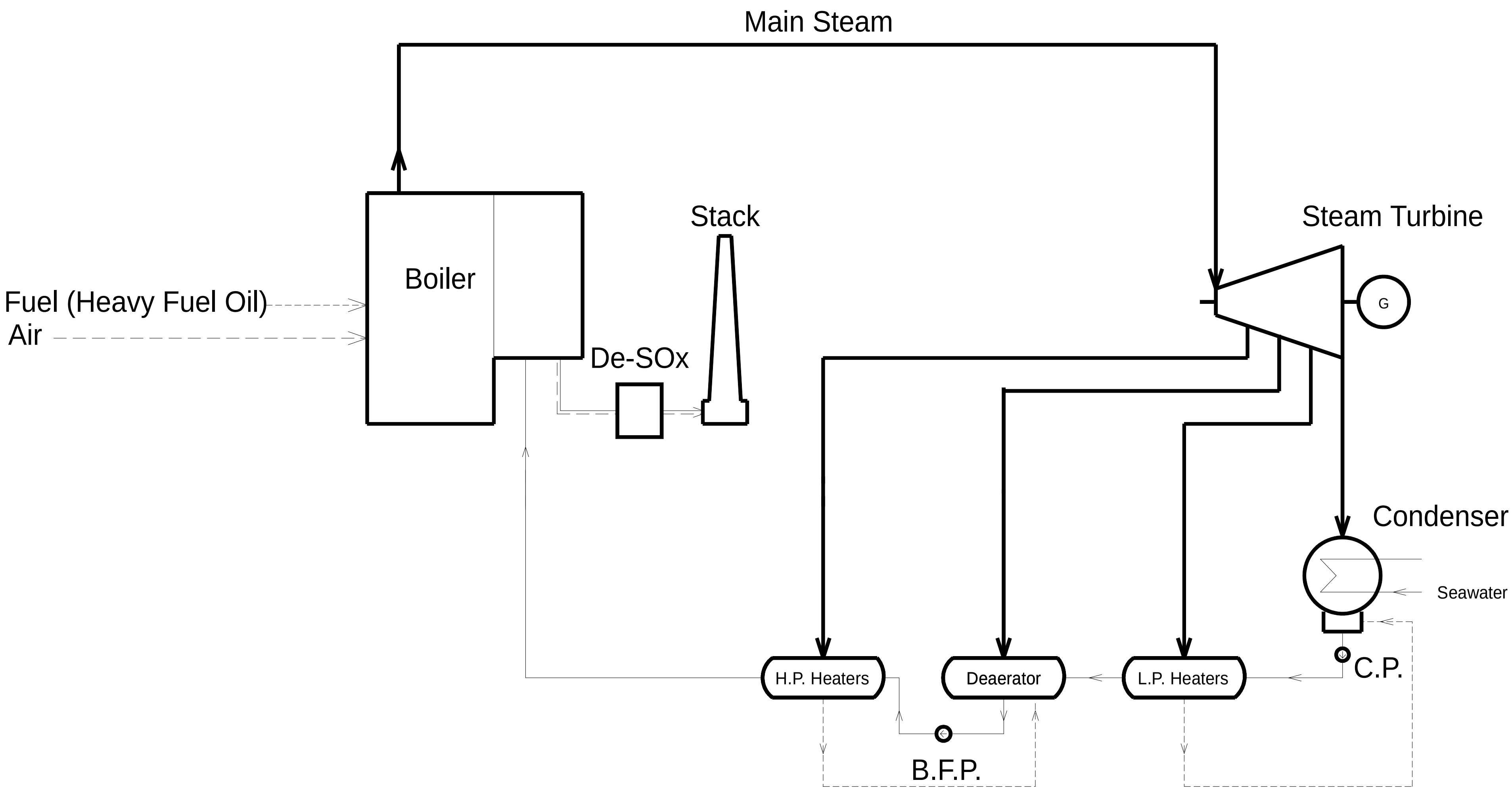


Fig.3.2-3 System Diagram of Conventional Power Plant

3.3. Technical and Environmental Comparison of Power Plant Types

3.3.1. Technical Comparison

Table 3.3-1 shows technical comparison of each power plant type. Details are described as follows:

- Construction Cost

  Construction cost of GTCC is cheapest among these 4 candidates. Middle speed diesel and conventional power plant are relatively cheap, but low speed diesel is most expensive.

- Applicable Fuel

  In rare case, heavy fuel oil is used for gas turbine but it is not recommendable because of some difficulties mentioned below:

  - Complicated pre-treatment of fuel oil is needed.
  - Continuous operation is interrupted by high temperature corrosion of turbine blades and plugging of cooling air hole in turbine blade.

  Therefore natural gas as main fuel and diesel oil as standby fuel are applied to GTCC. Diesel generator and conventional power plant can use both heavy fuel oil and diesel oil, but heavy fuel oil is usually used from economical point of view even if environmental mitigation cost is considered.

- Thermal Efficiency of Generation

  GTCC and low speed diesel have the highest efficiency of about 50% at LHV (Low Heating Value) base among 4 candidates. Middle speed diesel has the second high efficiency of about 43% (LHV), conventional power plant has the lowest efficiency of about 39% (LHV).

- Auxiliary Power Consumption Ratio

  GTCC, middle speed and low speed diesels are low because they have less auxiliary apparatuses. Conventional power plant is almost 2 times higher than GTCC.

- Environmental Mitigation Measures

As for prevention of air pollution, maximum emission levels for pollutant matters are prescribed by Draft Sub-Decree on Control of Air Pollution and Noise in Cambodia. This standard is applied as temporary emission standard of this study. Standard O_2 concentration in the exhaust gas and conditions for gas volume are not prescribed by Draft Sub-Decree, so we tentatively use actual O_2 concentration and gas volume at 760 mm Hg, 0°C for the calculation of air pollution. Table 3.3-2 shows comparison of Cambodian standard and estimated emission level of air pollutant from each type of plant under the conditions described above. As for air pollution, GTCC needs no environmental mitigation measure because emission level of NOx, SOx, and particulates are less than emission standard. Other types of plant need some measures to reduce air pollutant because emission level of air pollutants exceed the standard except NOx level in conventional power plant.

As for hot water discharge, middle and low speed diesel need no cooling seawater so they need no measure. GTCC and conventional power plant need measures to reduce influence of hot water discharge. GTCC uses less quantity of seawater than conventional power plant, so it needs less expensive cost.

- Ease of Operation

Diesel power plant seems easy to operate. GTCC and conventional power plant are relatively easy to operate except star-up and shut-down operation because, in normal operation, they are operated with sophisticated automation system.

- Reliability

GTCC, diesel power plant, and conventional power plant are widely used in the world, all of them show good reliability. Diesel power plant probably has higher reliability because it consists of simple equipment.

As for maintenance of gas turbine, engineers in Cambodia has to acquire new technical knowledge of gas turbine because they have no experience of operation and maintenance on gas turbine. However gas turbine usually does not need so frequent maintenance as diesel engine. Diesel power plant may have fewer problems in maintenance for Cambodian operator because many diesel generators are used in Cambodia at present, but it may needs more frequent maintenance and higher expense.

- Total Evaluation in Technical and Construction Cost Aspects

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 power plant has no advantage compared to others. However, the final decision of plant type should be made after considering environmental and economic comparisons.

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.

3.3.2. Environmental Comparison

Table 3.3-3 shows annual expected quantities of air pollutant discharged from each 180 MW power plant. Table 3.3-4 shows calculation of discharge quantity. Table 3.3-5 and Table 3.3-6 show composition of fuels used for calculation. Data of composition of diesel oil, heavy fuel oil and natural gas in Cambodia which we have obtained are very limited, so general data is used for calculation.

Emission level of NOx, SOx from diesel power plant and NOx from conventional power plant surpass Cambodian draft standard, so De-NOx and De-SOx systems are supposed to be installed to those power plant to reduce emission level less than Cambodian draft standard (NO_2 < 1,000 mg/Nm^3 (487 ppm), SO_2 < 500 mg/Nm^3 (175 ppm)). Quantity of air pollutant discharged from each power plant is calculated using concentration of NOx and SOx after De-NOx and De-SOx system.

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

GTCC is superior to diesel power plant at the comparison of environmental aspect as same as technical comparison. In GTCC, emission level of NOx is low because of low concentration of NOx at combustion and SOx is not produced because of no sulfur in natural gas.

As for emission of CO_2, GTCC is the lowest among 4 candidates. GTCC consumes less fuel for generation compared to others because of high efficiency.

Compared to diesel power plant using heavy fuel oil, GTCC using natural gas can reduce emission of air pollutant. CO_2 is also reduced, that will contribute to preventing greenhouse effect in the earth.

Table 3.3-4 Calculation of Air Pollutant Discharged from Each Power Plant

Quantity of Exhaust Gas — $e = a \times b \times c \times d$

	a	b	c	d	e
	Sending-Out Energy	Heat Rate	Unit Gas Volume	Specific Gravity	Quantity of Gas
	GWh/year	kcal/kWh	$Nm^3/10^6kcal$	kg/Nm^3	ton/year
GTCC	827	1,772	3,240.74	1.302	6.183E+06
Diesel (middle speed)	827	2,084	3,425.56	1.310	7.734E+06
Diesel (low speed)	827	1,845	3,425.56	1.310	6.847E+06
Oil-fired Conventional	827	2,358	1,091.01	1.360	2.893E+06

Emission of NOx — $g = e \times f \times 10^{-6}$

	f	g
	Concentration of NOx	Quantity of NO_2
	PPM	ton/year
GTCC	150	**928**
Diesel (middle speed)	487 *	**3,766**
Diesel (low speed)	487 *	**3,335**
Oil-fired Conventional	300	**868**

* : after DeNOx system

Emission of SOx — $l = e \times h \times 10^{-6}$

	h	l
	Concentration of SOx	Quantity of SO_2
	PPM	ton/year
GTCC	0	**0**
Diesel (middle speed)	175 *	**1,353**
Diesel (low speed)	175 *	**1,198**
Oil-fired Conventional	175 *	**506**

* : after DeSOx system

Emission of CO_2 — $k = e \times j \times 10^{-6}$

	j	k
	Concentration of CO_2	Quantity of CO_2
	Vol.%	ton/year
GTCC	5.55	**3.432E+05**
Diesel (middle speed)	6.81	**5.267E+05**
Diesel (low speed)	6.81	**4.663E+05**
Oil-fired Conventional	20.61	**5.963E+05**

Table 3.3-5 Composition of Fuel Oil

(Unit : wt.%)

Components	Diesel Oil	Heavy Fuel Oil
Carbon	86.22	85.70
Hydrogen	13.10	10.30
Oxigen	0.10	0.10
Nitrogen	0.08	0.30
Sulfur	0.20	3.50
Water & Sediment	0.00	0.10
Ash	0.00	0.00

Table 3.3-6 Composition of Typical Natural Gas

(Unit : vol.%)

Components	Natural Gas
CO_2	1.65
N_2	1.92
CH_4	95.49
C_2H_6	0.72
C_3H_8	0.07
C_4H_{10}	0.02
C_5H_{12}	0.10

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. The economic justification for the implementation of a power plant is also carried out in Chapter 10.

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).

(1) Net Present Value of Total Cost

The net present value of the total cost, consisting of construction cost, maintenance & operation cost during the service period, is derived from the conversion to the present value with a discount rate. A power plant type with the lowest net present value (least cost) against the same benefit is regarded as an economic type. The net present value is derived from the following formula and converted to the year of commencement of plant operation.

$$\mathrm{NPV} = \sum_{i=-1}^{n} \frac{Cost(i)}{(1+r)^{i}}$$

Where	i	:	years
	n	:	Construction period + Service period (= 2 years + 20 years)
	r	:	Discount rate (= 10%)[1]
	Cost (i)	:	Cost in year i

[1] A Discount rate of 10 % ~ 12 % is well applied to Power Sectors in South-east Asia. A discount rate of 10 % is used here.

(2) Levelised Production Cost at Sending-out

Calculation of the production cost follows the calculation method of International Energy Agency, which is called the levelised production cost. A power plant type with the lowest production cost is regarded as an economic type. The levelised production cost is derived from the following formula.

$$\text{Levelised Production Cost} = \frac{\sum \text{NPV(Cost)}}{\sum \text{NPV(Production Energy)}}$$

Where, ΣNPV (Cost) : Accumulation of net present value of the cost (construction & operation) converted with a discount rate.

ΣNPV (Production Energy) : Accumulation of net present value of production energy at sending-out converted with a discount rate.

The levelised production cost calculated in this section is used as one of the indices to make the economic priorities among the candidates. Financial levelised production cost is also calculated in Chapter 10.

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, maintenance & operation cost, fuel type, fuel cost, rate of station use, forced outage rate and scheduled maintenance days are shown in Table 3.4-1. The construction cost concerning the diesel power plant and conventional power plant includes the equipment cost related to reducing the air pollution because heavy fuel will be used.

3.4.4. Prices in Economic Comparison

The economic prices are used in the economic comparison because the evaluation of the project is carried out from the viewpoint of the national economy. The market prices are determined with the relationship between demands and supply ideally. However, provided that the market prices are distorted by the government's interferences with the market, the market prices removed the above distortion are called as the economic prices (shadow prices). Tax, duty and subsidy are one of the examples[2] of the government's interferences. In the economic comparison, tax and subsidy are excluded and the following prices are applied concretely.

(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, as mentioned in Section 3.1.2, are applied.

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) Other Operation & Maintenance Cost

Other operation and maintenance costs estimated in US$ term are used as the border prices at the moment.

[2] An exchange rate controlled by a government is also one of the examples.

3.4.5. Annual Capacity Factor

Annual capacity factors are referred to the results of optimum power development program in Section 2.2.

From the year 7th (2012) onwards, the annual capacity factors are set at 50 % based on the estimated capacity factors from the 7th year (2012) to 13th year (2018).

3.4.6. Results of Economic Comparison

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

Table 3.4-4 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, low speed diesel and oil-fired 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 3.4-2 Calculation for Equivalent Installed Capacity and Generation Energy

Year			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Capacity Factor			71%	75%	55%	63%	67%	70%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Stage1	90 MW																							
Stage 2	90 MW																							

1 Combined Cycle (Natural Gas-fired)

Installed Capacity (90 MW x 2 stages)	180	MW																						
Scheduled Maintenance Days	49	days																						
Forced Outage Rate	8.0%																							
Station Use	2.8%																							
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
Sending-out Energy		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

2 Diesel (Middle Speed)

Scheduled Maintenance Days	28	days																						
Forced Outage Rate	20.0%																							
Station Use	4.6%																							
kW Adjustment Factor	1.099																							
kWh Adjustment Factor	1.019																							
Equivalent Installed Capacity	197.8																							
Equivalent 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

3 Diesel (Low Speed)

Scheduled Maintenance Days	28	days																						
Forced Outage Rate	20.0%																							
Station Use	4.6%																							
kW Adjustment Factor	1.099																							
kWh Adjustment Factor	1.019																							
Equivalent Installed Capacity	197.8																							
Equivqlent 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

4 Oil-fired Conventional

Scheduled Maintenance Days	53	days																						
Forced Outage Rate	8.0%																							
Station Use	6.7%																							
kW Adjustment Factor	1.055																							
kWh Adjustment Factor	1.042																							
Equivalent Installed Capacity	189.9																							
Equivalent 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

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

		-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Sum
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

		-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Sum
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

		-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Sum
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

		-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	Sum
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

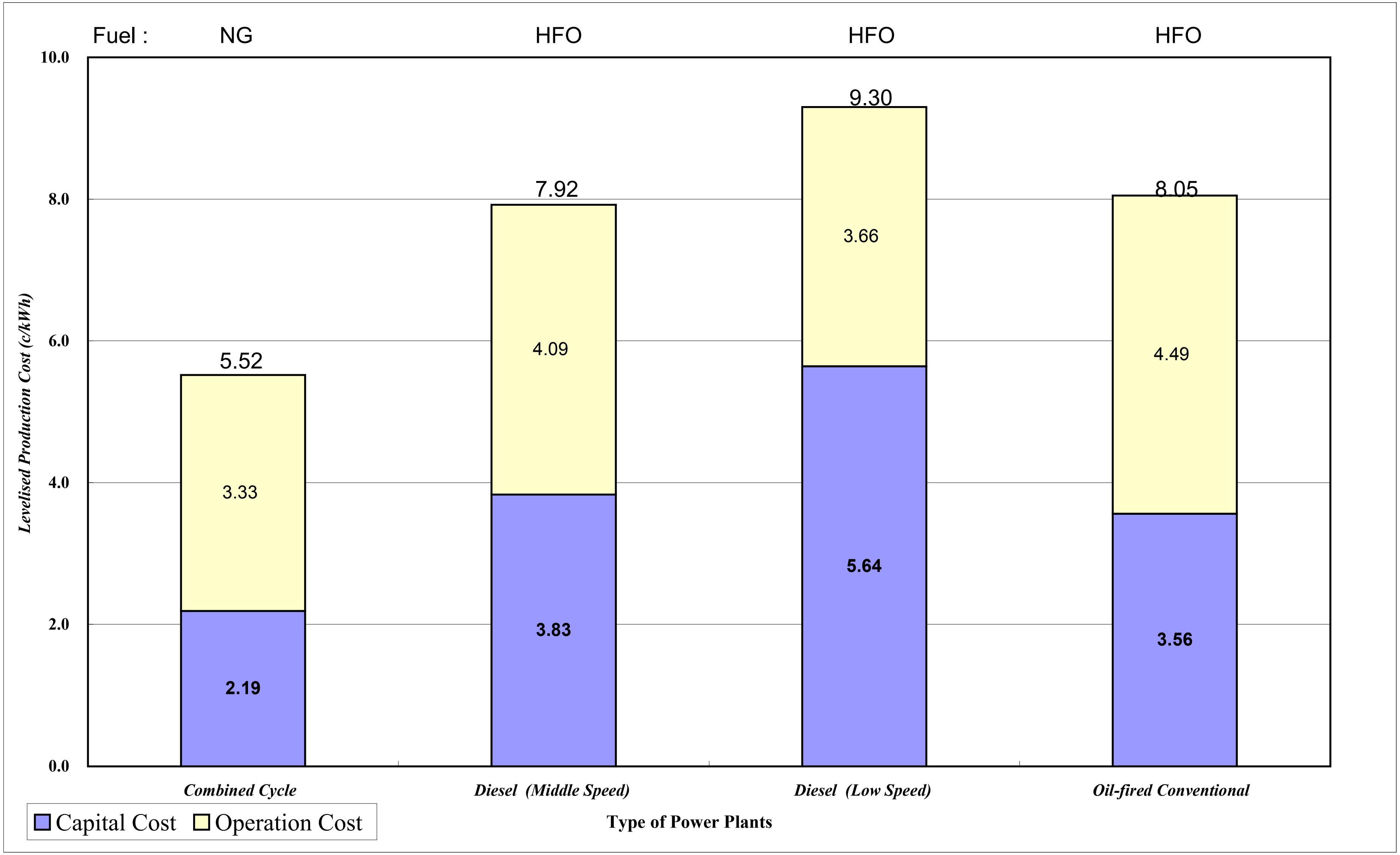


Fig. 3.4-1 Comparison of Production Cost Components at Plant excluding Taxes imposed on Fuel (10%Discount Rate)

3.5. <u>Conclusion</u>

3.5.1. Technical and Environmental Aspect

Combined cycle power plant 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 for operation and maintenance, combined cycle power plant is some difficult for Cambodia to operate or maintain compared to diesel generator because gas turbine needs new technological knowledge for operation and maintenance but they have no experience. However, gas turbine and gas turbine combined cycle technologies are very popular throughout the world. And a gas turbine has been used since 1960's and combined cycle is used since 1980's even in neighboring countries in Southeast Asia such as Indonesia and Bangladesh. Thus introduction of 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.

It is expected that electrical demand will further increase and large-scale power plant will be needed in Cambodia from now on. Introduction of combined cycle power plant, which is suitable for large-scale power plant, will contribute to the development of large-scale power source in future Cambodia.

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 the most suitable for Cambodia.

On the other hand, since EDC has no operation experience concerning the gas turbine combined 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.