

Economic Evaluation of Deferent Generating Systems, Environmental Cost  
and Carbon Tax Simulations

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## 1. Economic Evaluation of Different Generating Systems

This study examined perspectives of different generating systems (nuclear, LNG, coal, oil thermal power) in economics terms, by estimating their generating costs at the plants commissioned in fiscal 1992 and those in fiscal 2000 from current and likely levels of unit construction cost, fuel price, and other conditions.

### 1.1 Estimation method

In this study, the generating cost was estimated in terms of life-long annually equalized cost for the power plants newly commissioned in the target years. This can be obtained by first converting the life-long cost incurred in newly-built plants into present values, then dividing the outcome by their life-long generated output.

This method, considered desirable enough to provide a fairly even basis for evaluating capital-intensive generating sources at the initial stage, like nuclear, and fuel cost-dominated sources, such as thermal power, is commonly in use internationally, including such evaluations made by the OECD/NEA.

Major preconditions employed in the estimation are listed below. No estimation was made for the oil-fired thermal power plant commissioned in fiscal 2000, because none of such plant construction is planned from fiscal 1989 and on.

- (1) Target years: FY1992, FY2000
- (2) Target power resources: Nuclear, LNG, coal, oil (FY1992 alone)
- (3) Price declaration: 1992 price in real terms
- (4) Exchange rate: ¥127/\$ (kept constant in the future)

Meanwhile, the service life specified in the tax law (16 years for nuclear power plants, and 15 years for thermal power plants) was taken in making the estimations.

## 1.2 Preconditions of generating cost estimation

### 1.2.1 Unit cost of power plant construction

Source-by-source unit construction costs of the power plants commissioned in fiscal 1992 and those in fiscal 2000 were obtained as follows: First, plant-by-plant unit construction costs were extracted, from the FY1992 Generating Capacity Installation Plan, by referring to actual and planned figures for a total of seven years, namely three years before and after the base year each; Subsequently, resultant unit costs were adjusted by commodity price as well as the unit number; Then, averaging the outcome, unit construction costs were produced for the model plants onstream in fiscal 1992 and those in fiscal 2000.

#### (a) Commodity price-based adjustment

The unit construction costs extracted from the Generating Capacity Installation Plan were adjusted by commodity price to put them in FY1992 prices. Commodity price-based adjustment was made by taking the Bank of Japan's wholesale price index as the base. For the portion up to fiscal 1992, per-annum average actual records (an April-December average in the FY1992 case) were taken, while a 1.0% rise a year is assumed for the portion from fiscal 1993 and on. Coefficients used in the adjustment are shown in Table 1-1.

#### (b) Unit number-based adjustment

Even if built in the same site and given the same specifications, construction costs of the first unit and the subsequent ones considerably vary in general. This is because the cost to construct the No. 1 unit often includes land cost, land reclamation cost, and the cost of such installations as port facilities put to common use with subsequent units. The other reason is that construction of the No. 2 and subsequent units tend to cost less, thanks to the effect of standardization enabled by copying, the effect of getting skilled, and such other effects as a shortened period of land reclamation. Given these factors, they must properly be adjusted in order to produce correctly estimated unit construction costs for the model plants.

Table 1 - 1 Commodity Price-Based Adjustment Coefficients

F Y	Base	W P I	CPA coefficient
1989		99.0	0.98
90		100.1	0.97
91		98.9	0.98
92	#	97.2	1.00
93		98.2	0.99
94		99.2	0.98
95		100.1	0.97
96		101.1	0.96
97		102.2	0.95
98		103.2	0.94
99		104.2	0.93
2000		105.3	0.92
01		106.3	0.91
02		107.4	0.90
03		108.4	0.89

(Source) Bank of Japan wholesale price index, 1990=100

The FY1992 figure is an average in the April-December period.

From FY1993 and on, assumed is a 1% rise per annum.

In this study, unit construction costs of the model plants were adjusted by taking an approach to average commodity price-adjusted unit construction costs of all the units commissioned in a relatively short period in a single site, based on which coefficients of unit number-based adjustment were calculated for the No. 1 unit as well as the No.2 and subsequent units.

Resultant coefficients are presented in Table 1-2.

Table 1 - 2 Unit No. - Based Adjustment Coefficients

Source	NO. 1 Unit	No. 2 & subsequent units
Nuclear	0.79	1.23
L N G	0.76	1.41
Coal	0.80	1.35
O i l	0.72	1.63

Table 1-3 contains unit construction costs of the model plants, some commissioned in fiscal 1992 and others in fiscal 2000, which were obtained as described above.

Table 1 - 3 Unit Prices of Model Plant Construction by Year of Commissioned  
(¥1,000/KW)

Commissioned in	FY1992	FY1993
Nuclear	341	316
L N G	228	233
Coal	275	293
O i l	209	—

Table 1 - 4 Nuclear Fuel Price Scenarios

(a) Uranium concentrate

F Y	Price in dollar (\$/1bU <sub>3</sub> O <sub>8</sub> )	Exchange rate (¥/\$)	Price in yen (¥/1bU <sub>3</sub> O <sub>8</sub> )
1990	29.39	142	4,173
91	29.39	133	4,173
92	29.39	127	4,173
2000	↑	↑	↑
15	34.12	↑	4,333

(b) UF<sub>6</sub> Conversion

F Y	Price in dollar (\$/1bU <sub>3</sub> O <sub>8</sub> )	Exchange rate (¥/\$)	Price in yen (¥/1bU <sub>3</sub> O <sub>8</sub> )
1990	6.5	142	923
91	6.5	133	865
92	6.5	127	826
2000	↑	↑	↑
15	↑	↑	↑

(c) Uranium enrichment

F Y	DOE (\$/kgSWU)	EURODIF (\$/kgSWU)	Service ratio (DOE / EURODIF)	Exchange rate (¥/\$)	Price in yen (¥/kgSWU)
1990	118	100	4/1	142	16,245
91	118	100	↑	133	15,215
92	125	100	↑	127	15,240
2000	↑	↑	↑	↑	↑
15	↑	↑	↑	↑	↑

(d) Fabrication

F Y	Price (¥/kgU)
1991	88,000
1992	↑
2015	↑

(e) Spent fuel transport

F Y	Price (¥/kgU)
1991	33,800
2000	↑
2020	↑

(f) Reprocessing

F Y	Price (¥/kgU)
2000	192,000
2025	↑

1.2.2 Fuel price scenarios

(1) Nuclear fuel price

For every stage from front to back ends, the nuclear fuel price scenario is assumed as follows.

(a) Uranium concentrate

Due to a slowdown in nuclear development these years, uranium concentrate supply/demand is slack for the present. Accordingly, it is assumed the price remains virtually flat in fiscal 1992-2000. From fiscal 2001 and on, it is assumed to grow 1.0% annually given likely uranium supply/demand developments and potential reserves.

(b) UF<sub>6</sub> conversion

Considering that this process enters a mature stage in technical terms, the conversion cost is assumed to be flat effectively from fiscal 1992 and afterward.

(c) Uranium enrichment

The enrichment cost was produced by averaging the prices of enrichment offered by the DOE (U.S. Department of Energy) and the EURODIF by their shares in enrichment service. Given technical maturity, their enrichment prices both are assumed to virtually level off from fiscal 1992 and on.

(d) Fabrication

Given technical maturity, the fabrication cost is assumed to remain virtually flat from fiscal 1992 and on.

(e) Spent fuel transport

From fiscal 1992 and on, the transport cost is assumed to remain virtually flat.

(f) Spent fuel reprocessing

The spent fuel reprocessing price is assumed to remain virtually flat from fiscal 2000 and on.

Specifics of the nuclear fuel price scenario above are shown in Table

1-4.

(2) Fossil fuel prices

Fossil fuel prices are likely to go upward in the long run. As for oil, coal and LNG, high and low price cases were also assumed in addition to the base case.

a) Oil

In fiscal 1992, the crude oil (CIF) price, having started from the \$18/bbl level, has stayed at the \$20/bbl level these days. In this study, given that the price has stayed at the \$20/bbl level since the second quarter, the crude oil price in fiscal 1992 is put at \$20/bbl. The future price was assumed, by referring to projections made by the IEA and other oil-related organizations, at \$26/bbl for fiscal 2000 and \$31/bbl for fiscal 2010 in the base case, \$21 and \$26/bbl each in the low price case, and \$31 and \$36/bbl respectively in the high price case.

While referring to the formula employed by Tokyo Electric and Japan Oil in their FY1992 contract, the pre-burner price of oil was obtained by calculating the prices of domestically refined C heavy fuel oil, imported C heavy fuel oil, desulfurized product, and crude oil burning, and taking weighted average price of the outcome. The formula was assumed to remain unchanged in the future.

(b) LNG

The past trend shows that the LNG price is highly correlated to the crude oil price. Accordingly, estimated from the past data was the correlation function between the crude oil and LNG prices, based on which the LNG (CIF) price in the future was assumed. The one corresponding to the crude oil price base case was taken as LNG base case, and those to the high and low cases as LNG high and low cases. The pre-burner price of LNG was obtained by adding domestically incurred expenses (¥1,020/t) to the LNG price obtained as described above.

(c) Coal (steaming coal)

Just like the LNG price, the coal price was assumed to link to the crude oil price. The pre-burner price of coal was calculated by adding domestically incurred expenses (¥1,700/t) to the coal CIF price.

Specific results of these fossil fuel price scenarios are shown in Table 1-5.

Table 1 - 5 Fossil Fuel Price Scenarios

## (a) Oil

## ① Base Case

F Y	Crude oil C I F (\$/bbl)	Imported C heavy fuel oil (\$/bbl)	Exchange rate (¥/\$)	Domestically refined C heavy fuel oil (¥/kl)	Imported C heavy fuel oil (¥/bbl)	Desulfurized Product (¥/kl)	Synthetic Price (¥/kl)	Crude oil burning (¥/kl)	Pre- burner Price (¥/kl)
1992	20.0	18.0	127	24,050	23,474	25,180	24,332	22,201	23,266
95	23.0	21.0	↑	26,502	25,911	27,637	26,783	24,653	25,718
2000	26.0	24.0	↑	28,954	28,348	30,094	29,235	27,105	28,170
05	28.5	26.5	↑	30,997	30,379	32,141	31,279	29,148	30,213
10	31.0	29.0	↑	33,041	32,410	34,188	33,322	31,192	32,257

## (b) LNG Price

## ① Base Case

F Y	LNGCIF (\$/t)	Exchange rate (¥/\$)	Expenses (¥/t)	Pre - burner Price (¥/t)
1992	188.9	127	1,020	25,010
95	208.1	↑	↑	27,449
2000	227.3	↑	↑	29,887
05	243.3	↑	↑	31,919
10	259.3	↑	↑	33,951
15	275.3	↑	↑	35,983

## ② High Price Case

F Y	LNGCIF (\$/t)	Exchange rate (¥/\$)	Expenses (¥/t)	Pre - burner Price (¥/t)
1992	188.9	127	1,020	25,010
95	224.1	↑	↑	29,481
2000	259.3	↑	↑	33,951
05	275.3	↑	↑	35,983
10	291.3	↑	↑	38,015
15	307.3	↑	↑	40,047

③ Low Price Case

F Y	LNGCIF (\$/t)	Exchange rate (¥/\$)	Expenses (¥/t)	Pre - burner Price (¥/t)
1992	188.9	127	1,020	25,010
95	192.0	↑	↑	25,417
2000	195.3	↑	↑	25,823
05	211.3	↑	↑	27,855
10	227.3	↑	↑	29,887
15	243.3	↑	↑	31,919

(c) Coal Price

① Base case

F Y	Steaming Coal CIF (\$/t)	Exchange rate (¥/\$)	Expenses (¥/t)	Pre - burner Price (¥/t)
1992	48.5	127	1,700	7,856
95	50.8	↑	↑	8,157
2000	53.2	↑	↑	8,458
05	55.2	↑	↑	8,708
10	57.2	↑	↑	8,959
15	59.1	↑	↑	9,210

② High Price case

F Y	Steaming Coal CIF (\$/t)	Exchange rate (¥/\$)	Expenses (¥/t)	Pre - burner Price (¥/t)
1992	48.5	127	1,700	7,856
95	52.8	↑	↑	8,408
2000	57.2	↑	↑	8,959
05	59.1	↑	↑	9,210
10	61.1	↑	↑	9,461
15	63.1	↑	↑	9,712

③ Low Price case

F Y	Steaming Coal CIF (\$/t)	Exchange rate (¥/\$)	Expenses (¥/t)	Pre - burner Price (¥/t)
1992	48.8	127	1,700	7,856
95	48.9	↑	↑	7,906
2000	49.3	↑	↑	7,956
05	51.2	↑	↑	8,207
10	53.2	↑	↑	8,458
15	55.2	↑	↑	8,708

1.2.3 Reactor decommission cost

The cost to decommission reactor installations was calculated based on the estimation (¥30 billion for a 1.1 GW-class plant) made by the Advisory Committee for Energy's Nuclear Session in its interim report released in 1985. The decommission cost was assumed to be spent in a lump sum after the full service life (16 years).

1.2.4 Other preconditions

Other preconditions employed in generating cost estimation are shown in Table 1-6.

Gross heat efficiency of LNG thermal power generation was put at 44% for the plant commissioned in fiscal 2000 on the assumption that combined cycle type, characterized by outstanding heat efficiency, could be introduced by that time.

1.3 Estimation results

Estimation results are presented in Table 2-7. For the plants commissioned in fiscal 1992, only the base case of fossil fuel scenario was assumed, while the base, high and low cases of fossil fuel scenario were prepared for those commissioned in fiscal 2000. In making the estimation, utilization factor was set at 70%.

### 1.3.1 Plants commissioned in fiscal 1992

Among the plants commissioned in fiscal 1992, nuclear power generation proved least expensive as it costed ¥10.14/kWh, compared with ¥10.64/kWh LNG thermal power, ¥10.94/kWh of coal thermal power, and ¥11.51/kWh of oil thermal power. Also, the results showed LNG had better economics than any other thermal power generating systems.

Focusing on the gaps among the generating sources, the most inexpensive nuclear was 12% cheaper than the most expensive oil thermal power. With oil thermal power excluded, gaps among the alternatives are limited within the range from 5% (LNG thermal power) to 7% (coal thermal power).

The cost to decommission nuclear installations amounted to ¥0.18/kWh. This cost was included in capital cost shown in the table.

Meanwhile, the cost estimation this time did not allow for the high-level waste disposal cost incurred in the back end of nuclear fuel cycle, because specific methods of disposal and cost calculation both were still under consideration, though it was already mapped out as the basic policy that "high-level wastes be confined in glass, then disposed of deep underground."

### 1.3.2 Plants commissioned in fiscal 2000

Among the plants commissioned in fiscal 2000, nuclear power generation would cost ¥9.52/kWh, LNG thermal power ¥10.77/kWh in the fossil fuel base case, and coal thermal power ¥11.62/kWh. Thus, the gaps between nuclear and thermal power generation would widen to 12-18%.

Moreover, in the fossil fuel high price case, nuclear would cost ¥9.52/kWh, compared with ¥11.40/kWh of LNG thermal power and ¥11.80/kWh of coal thermal power. As a result, the already widened gaps would further spread, making nuclear 16-19% cheaper than the alternatives.

Table 2 - 6 Other Preconditions

Depreciation	15 years (16 years for nuclear)
Rate of residual value	10% (percentage on diminishing value)
Return on investment	7.2%
Rate of property tax	1.4%
In-Plant rate	Nuclear 4.0% LNG 3.6% Coal 8.4% Oil 3.5%
Utilization factor	Nuclear 4.0% LNG 3.6% Coal 4.8% Oil 3.9%
Long-term discount rate	6%
Heat value of fuels	LNG 13,000 kcal/kg Coal 6,200 kcal/kg C heavy 9,800 kcal/kg fuel oil
Gross heat efficiency	LNG 39% (44% when commissioned in FY2000) Coal 39% Oil 39%

Table 1 - 7 Results of Generating Cost Estimations  
(Equalized Cost, Gross, Utilization Factor 70%)

(1) Plants commissioned in FY1992

(¥/kWh)

	Nuclear	T h e r m a l		
		L N G	Coal	O i l
Capital cost	6.36	4.22	5.37	3.86
Operating cost	2.32	1.39	2.35	1.38
Fuel cost	1.47	5.03	3.22	6.26
T o t a l	10.14	10.64	10.94	11.51

(2) Plants commissioned in FY2000

(¥/kWh)

	Nuclear	T h e r m a l					
		L N G			C o a l		
		Low	Base	High	Low	Base	High
Capital cost	5.91	4.31			5.72		
Operating cost	2.15	1.42			2.50		
Fuel cost	1.47	4.40	5.03	5.67	3.20	3.40	3.59
T o t a l	9.52	10.13	10.77	11.40	11.43	11.62	11.82

(Notes)

The reactor decommission cost (¥0.18/kWh) is included in capital cost.  
The high-level waste disposal cost is not included.

"Low," "Base" and "High" in the table represent low, base and high price cases of given fossil fuels.

(3) Breakdown of nuclear fuel cycle cost

(¥/kWh)

	Nuclear fuel cost
Uranium concentrate	0.32
UF6 conversion	0.03
Enrichment	0.35
Fabrication	0.32
SF transport	0.08
Reprocessing	0.37
T o t a l	1.47

On the other hand, in the fossil fuel low price case, where fuel prices would rise little until fiscal 2000, nuclear would cost ¥9.52/kWh, compared with ¥10.13/kWh of LNG thermal power and ¥11.43/kWh of coal thermal power. Although the gaps between nuclear and thermal power generation would be narrowed to 6-17%, nuclear's economic superiority remains unshaken.

This is attributable to falling generating costs of nuclear, thanks to lower construction cost than required for the plant onstream in FY1992 plus flat fuel cost at one hand. At the other, thermal power generating costs would be up due to rising fossil fuel prices. These consequently would precipitate wider relative economics between the two.

Among thermal power generation, despite rising fuel prices, the fuel cost of LNG thermal power would be flat in the fossil fuel base case, and some 10% lower in the low price case, thanks to gross heat efficiency assumed high. On the other hand, in reflection to a pair of rising fuel prices and growing construction cost, coal thermal power would result in the ¥11/kWh level in all the three cases.

#### 1.4 Sensitivity analysis

Generating costs of different generating sources are affected by different factors. Fig. 1-1 illustrates how much generating costs can

increase when utilization factor, unit construction cost, exchange rate, and pre-burner price of fuel each fluctuates 20% from the base case. The chart shows nuclear is sensitive to fluctuations in utilization factor and unit construction cost, thus confirming nuclear is "capital-intensive." On the other hand, LNG thermal power is severely affected by fluctuations in fuel price, exchange rate and fuel cost, proving that it is "fuel cost-dominated."

Of these factors, utilization factor, construction cost (unit cost) and exchange rate are discussed in detail below.

Meanwhile, to make calculations in this analysis, the same preconditions were taken as in the fossil fuel base case, which were applied to the plants commissioned in fiscal 1992 and those in fiscal 2000.

#### 1.4.1 Utilization factor

Fig. 1-2 shows generating costs by utilization factor.

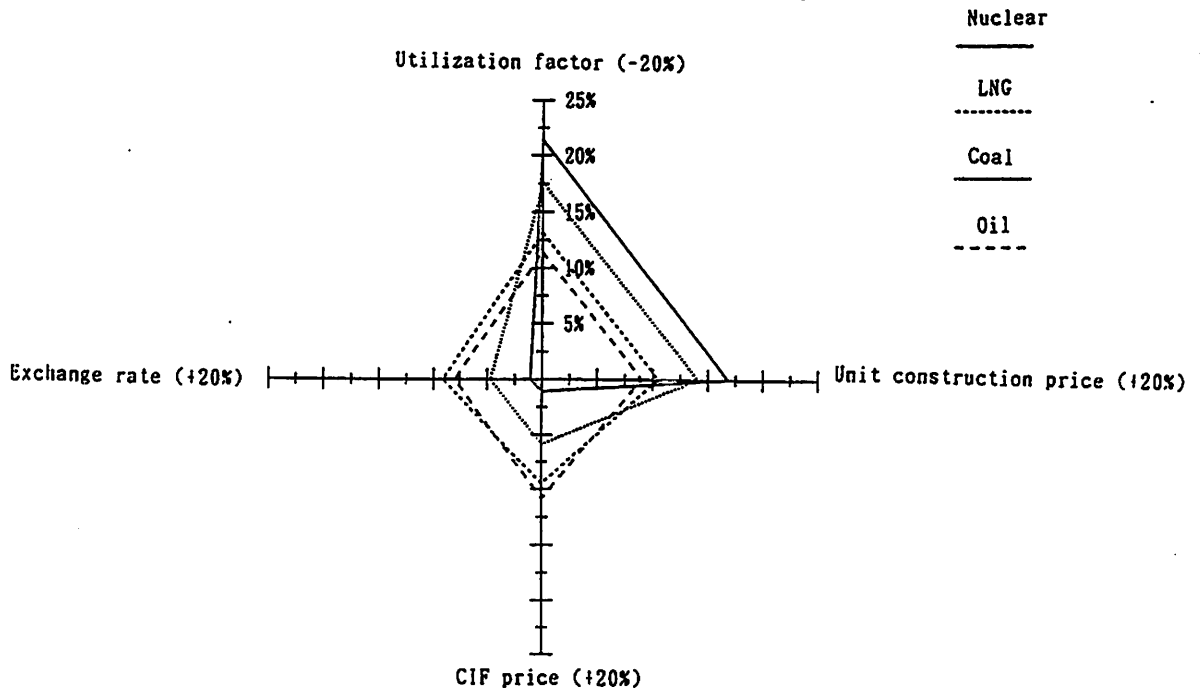
Among the plants commissioned in fiscal 1992, relative economics of nuclear would outrun that of oil thermal power when its utilization factor stands at 50%, and LNG thermal power at 60%. Then, with its utilization factor becoming higher, nuclear's economic superiority would increase.

The plants onstream in fiscal 2000 would show similar trends, though the gap between nuclear and thermal power generation would widen and nuclear would become the least expensive generating source in the domain of utilization factor higher than 45%.

As discussed above, nuclear is the cheapest among the plants onstream in fiscal 1992 when running at 60% or higher, and among those in fiscal 2000 when kept at 45% or higher. Moreover, it is shown that the higher utilization factor would result in the better relative economics.

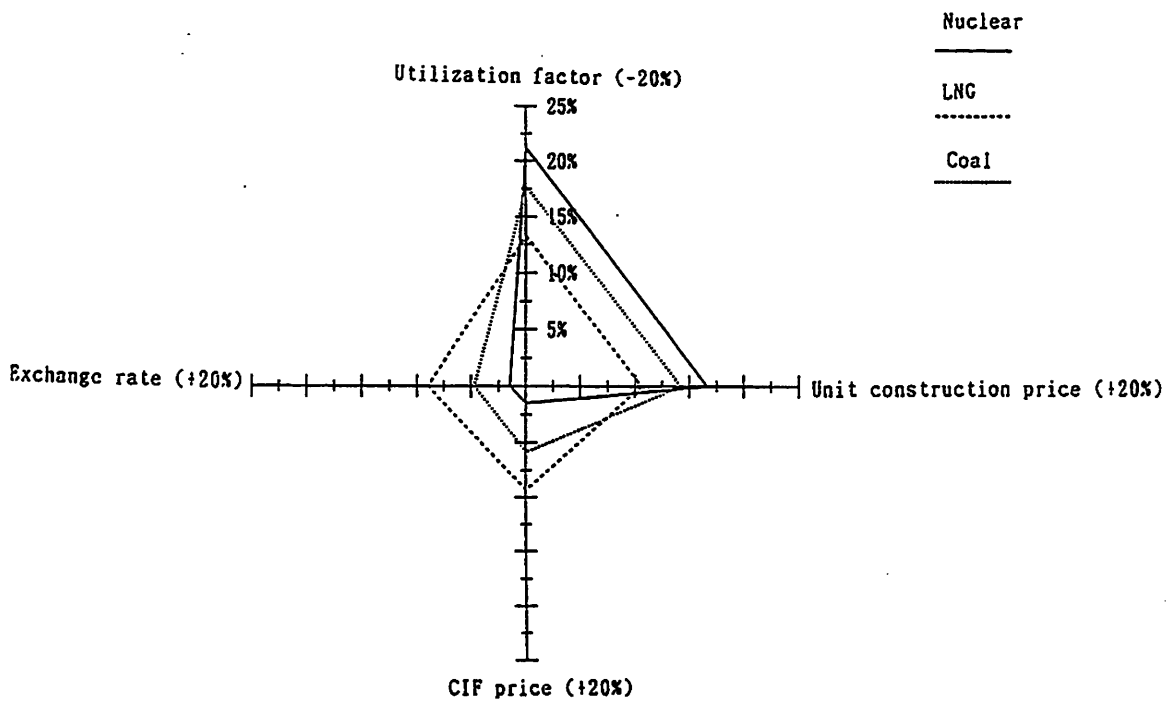
Fig. 1-1 Sensitivity Analyses of Generating Cost

(When commissioned in FY1992)



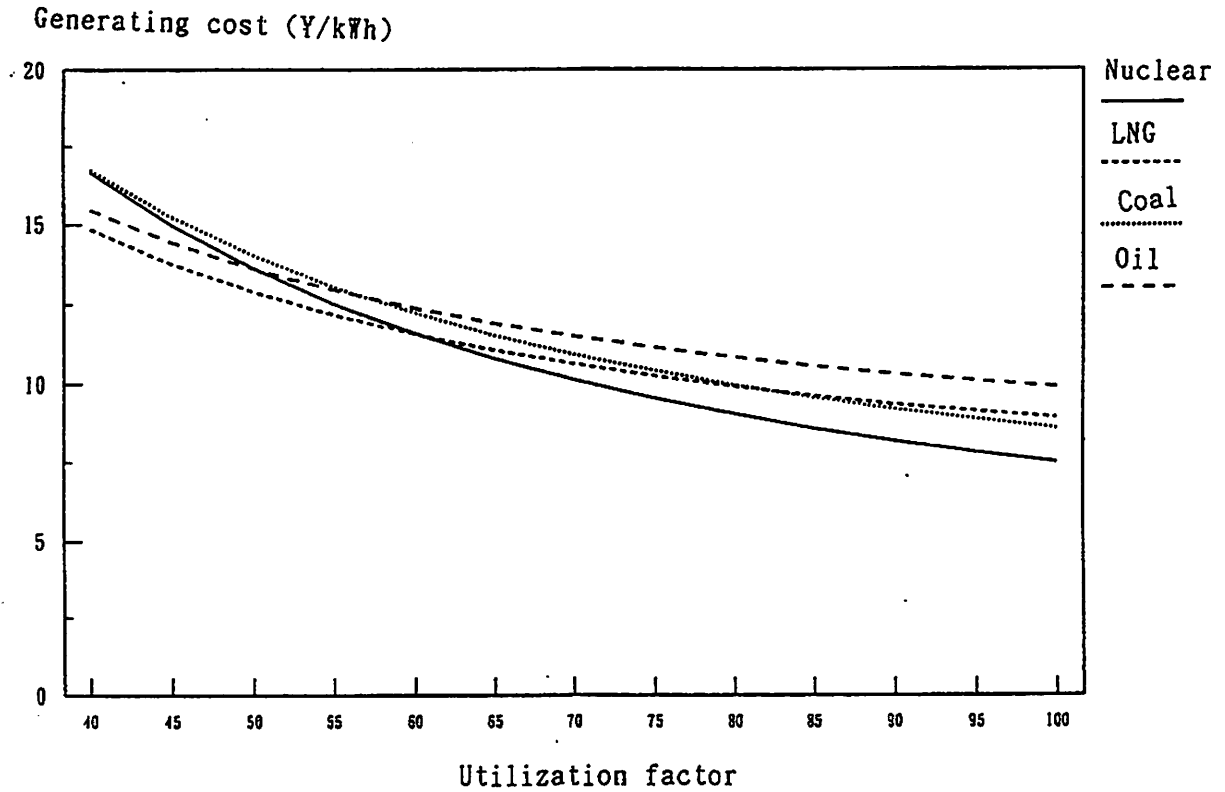
\* Up/down in generating cost when these parameters fluctuate by 20% each.

(When commissioned in FY2000)

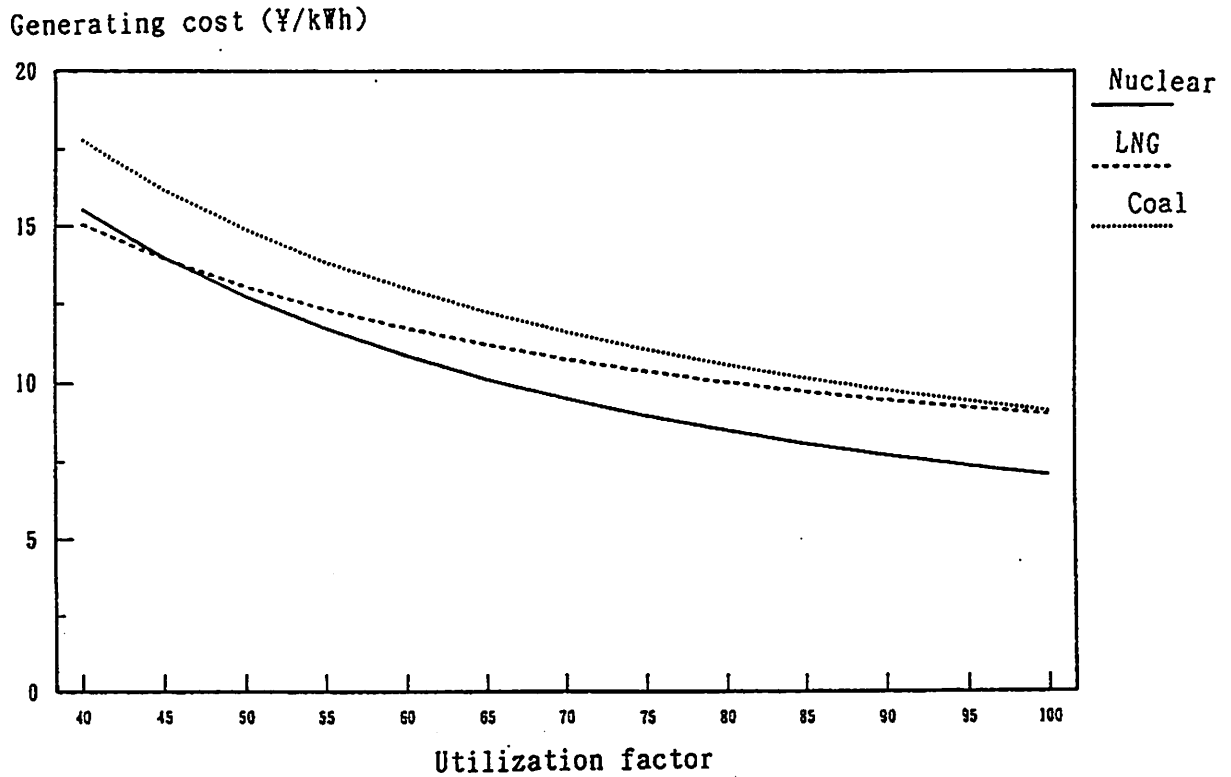


\* Up/down in generating cost when these parameters fluctuate by 20% each.

Fig. 1-2 Generating Costs by Utilization Factor  
 (When commissioned in FY1992)



(When commissioned in FY2000)



#### 1.4.2 Unit construction cost

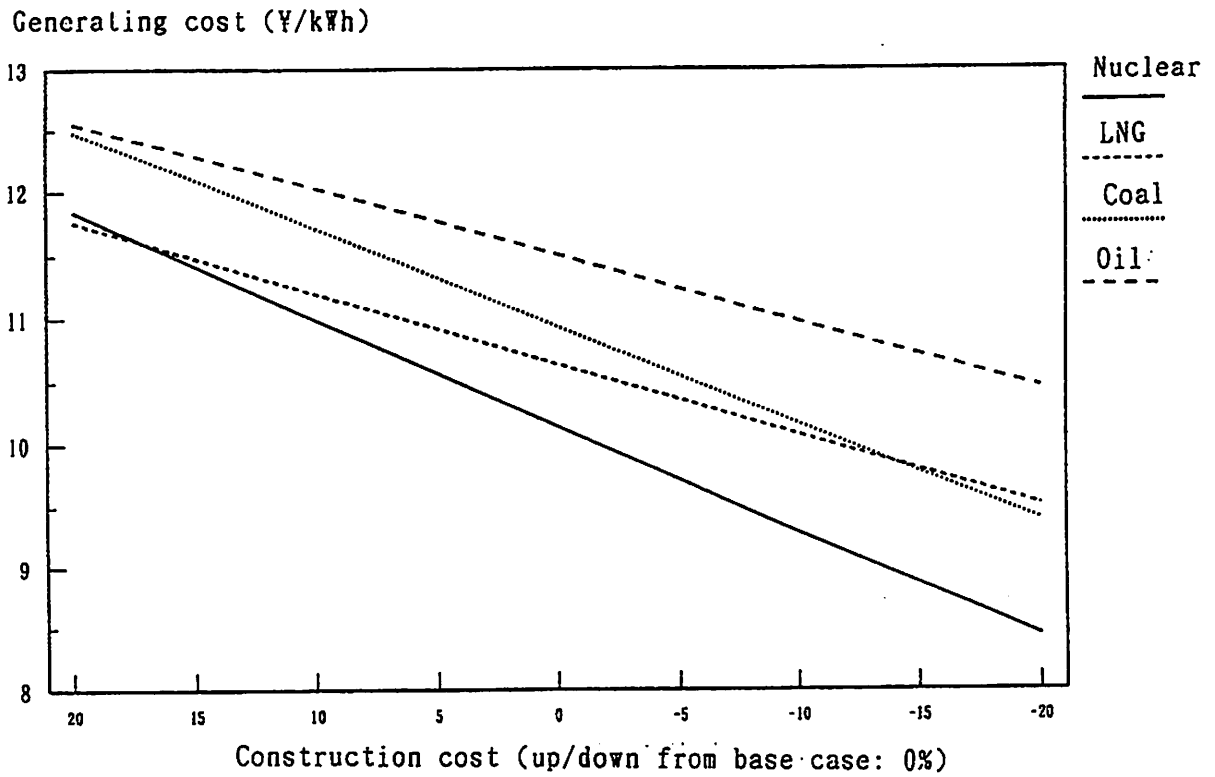
Fig. 1-3 shows generating costs resulting when unit construction costs fluctuate from the base case.

Among the target generating sources, "capital-intensive" nuclear is sensitive to fluctuations in construction cost. A fluctuation in generating cost, which could result from a 1% fluctuation in unit construction cost, would amount to the range of ¥0.085/kWh (FY1992) - ¥0.079/kWh (FY2000) in nuclear case, compared with LNG thermal power's the ¥0.056 - ¥0.057/kWh range, and coal thermal power's the ¥0.077 - ¥0.078/kWh range. In the meantime, when commissioned in fiscal 1992, nuclear and LNG thermal power plants could compete with each other if their unit construction costs increase by around 15% each (¥392,000/kW for nuclear, and ¥262,000 for LNG thermal power).

Cuts in nuclear construction cost are projected in the long run (see Table 1-3). And, the fall in its unit construction cost would form a crucial factor to back economic superiority of nuclear in the future. However, the projection would not necessarily become real. Therefore, assuming that the thermal power plants commissioned in fiscal 2000 would show no fluctuations in their unit construction cost, calculations were made to learn to what extent unit construction cost of nuclear could rise before challenged by thermal power generation in economics terms. The results are shown in Fig. 1-4.

The results show nuclear would be challenged by LNG thermal power when its unit construction cost stands at ¥366,000/kW, and by coal thermal power at ¥400,000/kW. This means that nuclear would be challenged by LNG thermal power when its unit construction cost stays 7% above the present level (at the plants commissioned in fiscal 1992), and 16% above the projected level (for the plants commissioned in fiscal 2000). Likewise, it would be challenged by coal thermal power if the unit cost is 17% and 27% higher than the present and projected levels, respectively.

Fig. 1-3 Generating Costs by Construction Cost  
 (When commissioned in FY1992)



(When commissioned in FY2000)

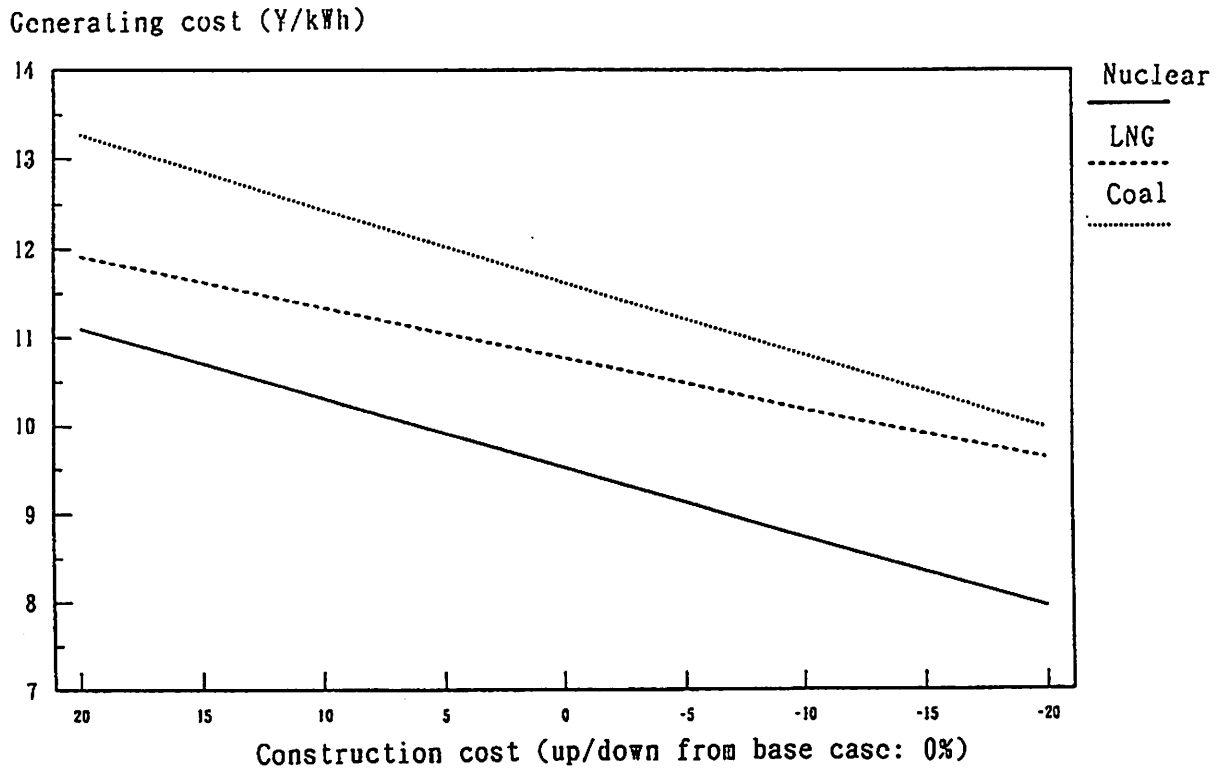
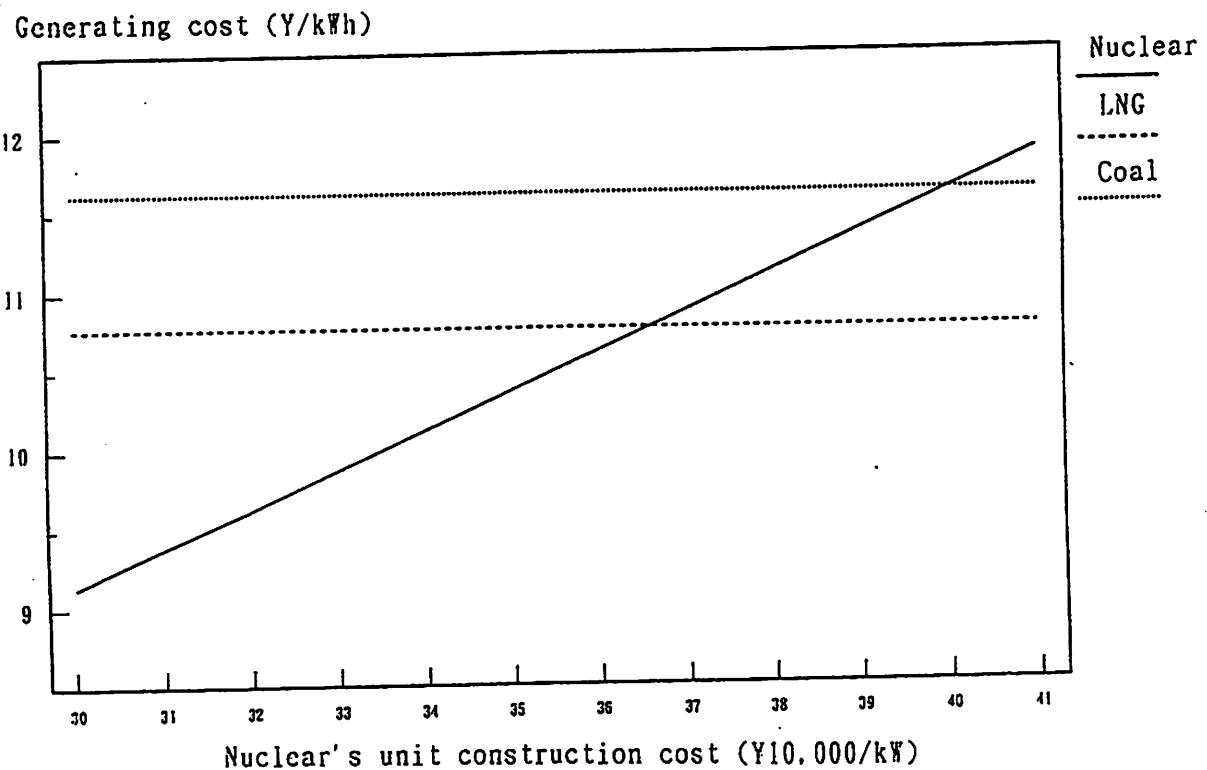


Fig. 1-4 Competitive Prices between Nuclear and Thermal Power Generation  
 (by construction cost)  
 (When commissioned in FY2000)



#### 1.4.3 Exchange rate

The exchange rate, assumed at ¥127/\$ when estimating the generating costs, is floated here to the range of ¥107-147/\$. It should be noted, however, each of the resultant exchange rates in this range is assumed to remain constant at its level. The results are shown in Fig. 1-4.

Among the target generating systems, thermal power generation heavily weighted by fuel cost is sensitive to exchange rate fluctuations. In a striking contrast, nuclear is affected little by such fluctuations. Every ¥1/\$ fluctuation in the exchange rate causes nuclear generating cost to fluctuate as scant as ¥0.004/kWh (FY1992) - ¥0.005/kWh (FY2000), compared with ¥0.38/kWh in LNG thermal power generating cost, and ¥0.020/kWh (FY1922) - 0.022/kWh (FY2000) in coal thermal power. As for the plants commissioned in fiscal 1992, nuclear and LNG thermal power generation can

compete with each other when the exchange rate stands at ¥112/\$.

In this way, compared with alternative generating sources, nuclear is influenced very little by exchange rate fluctuations. In the short run, it is not allowed to enjoy this advantage in the face of such fluctuations as cementing the underlyingly trend of the strong yen these days. On the other hand, however, this suggests that nuclear can provide a stable generating source in the long run against fluctuating exchange rates.

#### 1.4.4 Summary

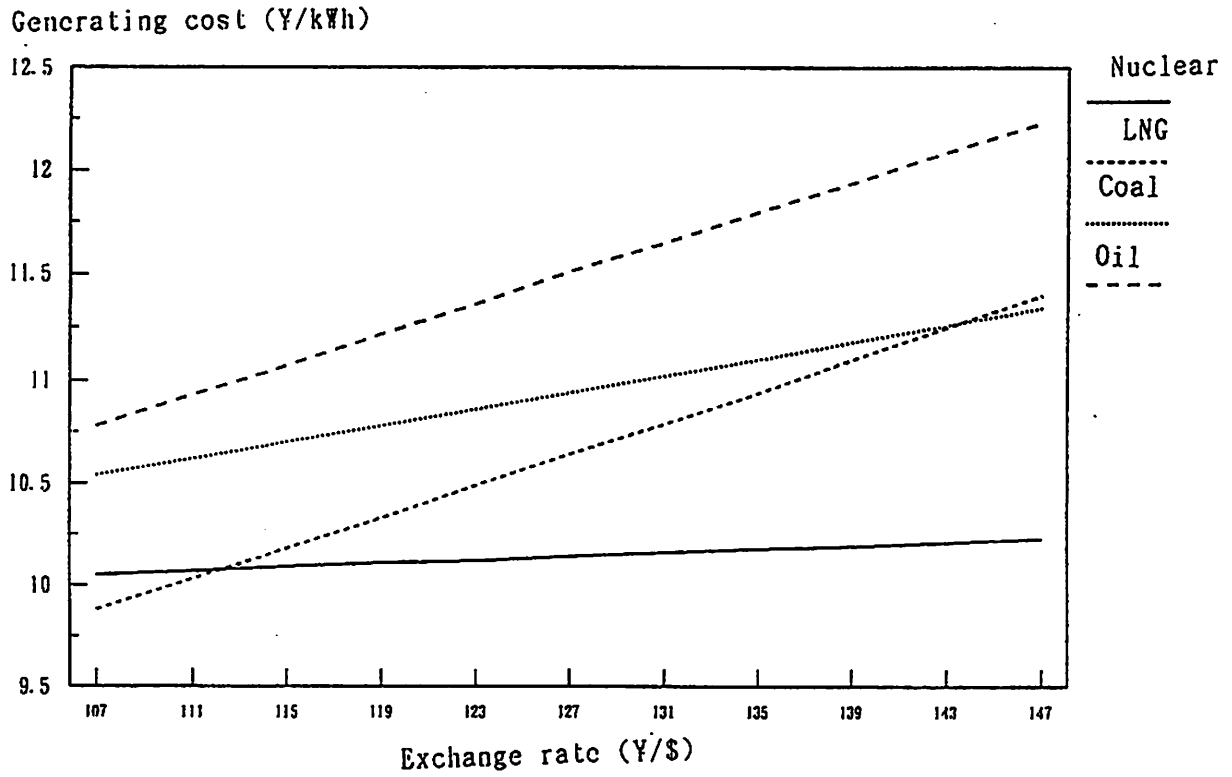
As discussed so far, relative economics among different generating sources depend on fluctuations in such elements as utilization factor, construction cost and exchange rate, with their sensitivity varying too.

Among them, nuclear demonstrates excellent economics in the domain of high utilization factor. It also serves as a stable generating source against sharp exchange rate fluctuations which reflect international economic trends, etc. On the other hand, nuclear is more sensitive to rising construction cost than any other alternatives.

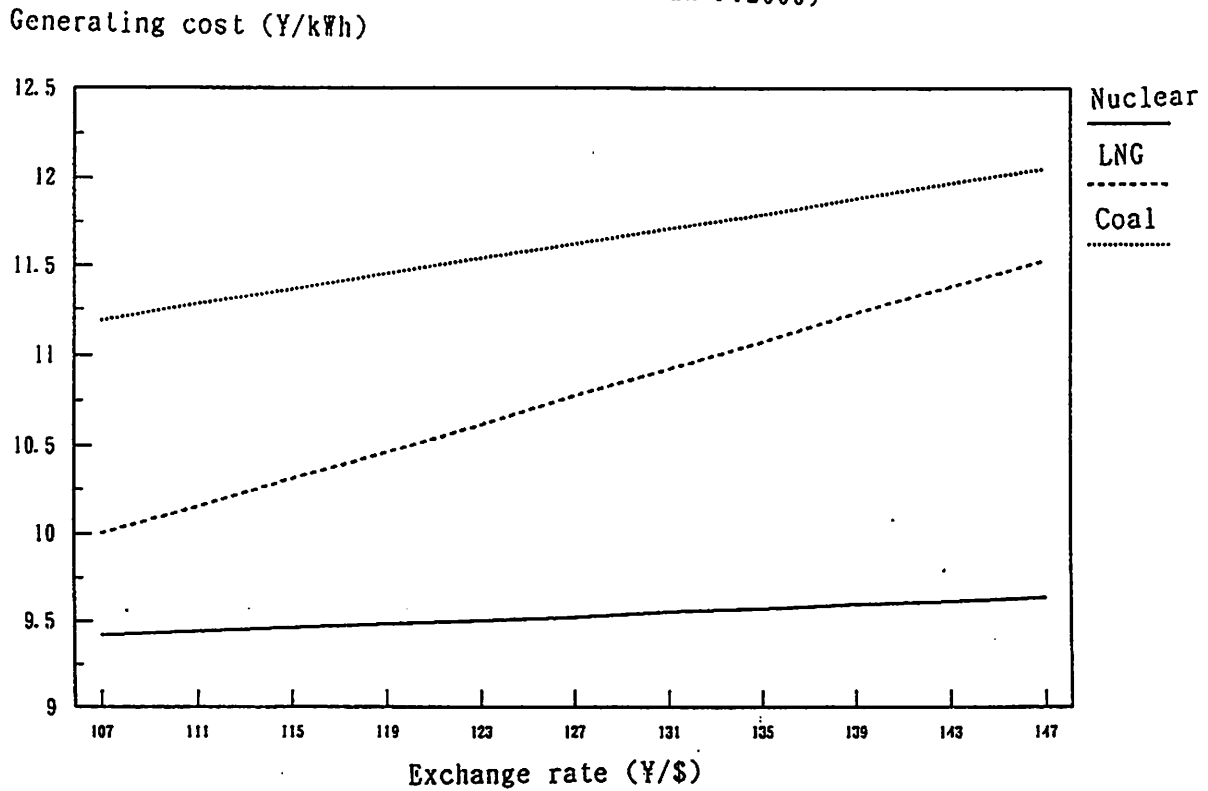
The construction cost, having massive impacts on nuclear generating cost, is projected now to go downward in the long run. If this cost is up, instead of being slashed, and stays some 10% above the present level (at the plants commissioned in fiscal 1992), economics of nuclear would eventually be outrun by that of thermal power generation.

Therefore, it can be said that, as far as its construction cost remains as projected today, nuclear is hardly affected by such external factors as the exchange rate, and can demonstrate better economics when running high, an outstanding feature crucial to a base load source. Therefore, in cost terms, too, nuclear can provide an advantageous and stable generating source in the long run. In other words, to keep its cost superiority inevitably requires strenuous, continuous efforts to slash the construction cost.

Fig. 1-5 Generating Costs by Exchange Rate  
 (When commissioned in FY1992)



(When commissioned in FY2000)



## 2. Environmental control cost

In conventional generating cost estimation, environmental control cost has been implicitly included in the cost to build equipment. Here, spendings in SO<sub>x</sub>, NO<sub>x</sub> and CO<sub>2</sub> control are grouped together in environmental cost, and distincted from the generating cost incurred prior to any environmental control measures taken, in an attempt to show clearly how much extra cost is needed in the capacity of environmental cost.

In case of nuclear power generation, environmental cost required for SO<sub>x</sub>, NO<sub>x</sub> and CO<sub>2</sub> control is nil, and it becomes by far advantageous in generating cost terms.

Meanwhile, environmental control cost is discussed here while referring to the estimations made by Messrs. Motofuji and Uchiyama of the CRIEPI (Central Research Institute of Electric Power Industry).

### 2-1. Environmental control cost incurred in thermal (coal, LNG-fired) power generation

In planning generating schemes for newly-built 1,000MW thermal power plants, one fired by coal, and the other by LNG, three cases can be considered in respect to flue gas from boilers. They are:

- ① No control, with flue gas discharged into the atmosphere as it is.
- ② SO<sub>x</sub> and NO<sub>x</sub> control given.
- ③ CO<sub>2</sub> control (two processes examined) on top of SO<sub>x</sub> and NO<sub>x</sub> control.

SO<sub>x</sub> and NO<sub>x</sub> control technologies assumed in making the estimations are coal-gypsum process (SO<sub>x</sub>) and ammonia catalyst contact reduction process (NO<sub>x</sub>), the both currently in use in Japan. As for CO<sub>2</sub> recovery, estimations are made for two technical options. One is amine process, of which commercialization is likely soon. The other is a future technology called pure oxygen combustion process (PSA process). Recovered CO<sub>2</sub> in a liquid state is to be transported in specialized carriers to 3,000km offshore, then confined in 3,000m-deep waters.

### 2-2. Assumptions

Assumptions of construction and fuel costs, among others, are crucial

to cost estimations. It is also necessary to specify the scope of environmental control. Table 2-1 contains equipment/fuel costs (in 1991 price).

## 2-3. Generating cost at newly-built 1,000MW thermal power plants

### (1) Generating efficiency and generating cost

Generating efficiency at coal-fired thermal power plant goes down, from 38.84% in no control case, and from 39.52% in no SOx/NOx control case, to 37.95%. With CO2 control added, it goes down further to 25.88-29.14%. Reversely, generating cost goes up, from ¥8.11/kWh in no control case, to ¥10.71/kWh in SOx/NOx control case. With CO2 control added, the cost reaches the ¥18.0-22.5/kWh range.

At LNG-fired plant, generating efficiency changes little from 39.52% in no control case to 39.44% in NOx control case. But, with CO2 control taken, the efficiency deteriorates considerably to 31.68-32.62%. Generating cost amounts to ¥9.29/kWh in no control case, which rises to ¥9.67/kWh in NOx control case, and further to ¥15.0-15.9/kWh with CO2 control added. (See Figs. 2-1 & 2-2.)

## 2-4. Environmental cost and total environmental control cost

As shown in Fig. 2-3, Fig. 2-4 and Table 2-2, environmental control requires huge costs.

## 2-5. Environmental cost and limits of public burden

Tougher environmental standards, if introduced, would leave few choices but to incorporate the environmental cost into electricity rates. In this case, nuclear would become by far advantageous. Also, LNG thermal power could remain fully competitive within the scope of SOx/NOx control. But, if total CO2 emission control standards (ex. CO2/kW stabilization) are introduced, fossil fuel-fired thermal power could no longer rival nuclear, nor be organized as economically feasible power resources. If it is allowed to incorporate the environmental cost into rates, introduction of total CO2 emission control would also become possible. But, given

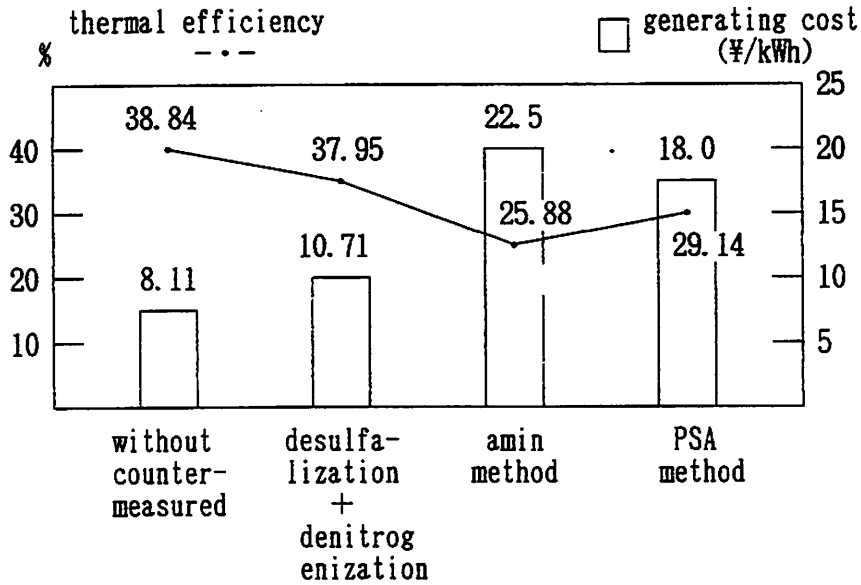
nature of global warming, it is more realistic to consider how to check it in an ultra-long time span. Moreover, because the environmental cost incurred in total CO2 emission control standards should cause formidable burden to the public, such a short-range target as one by 2000 is nothing but unrealistic.

Table 2 - 1. Cost of construction, operation, etc

		coal-fired	LNG-fired
Boiler/Turbine Generating Facility	construction cost (10 <sup>8</sup> ¥)	1955	2040
	unit price of fuel (¥/t)	8,320	23,983
	levelized ratio of expenditure (%)	15.28	15.28
Desulfalization facility	construction cost (10 <sup>8</sup> ¥)	345	
	operating cost (10 <sup>6</sup> ¥/Y)	701	
	Annual rate of expenditure	21.56	
Denitrogenization facility	construction cost (10 <sup>8</sup> ¥)	100	60
	operating cost (10 <sup>6</sup> ¥/Y)	3,206	877
	levelized ratio of expenditure (%)	21.65	21.56
Decarbonization (Amin method) + storage in sea	construction cost (10 <sup>8</sup> ¥)	1010	647
	decreased operating cost (10 <sup>6</sup> ¥/Y)	-4 35	-2 19
	levelized ratio of expenditure (%)	21.56	21.56
Decarbonization (PSA method) + storage in sea	construction cost (10 <sup>8</sup> ¥)	1017	818
	decreased operating cost (10 <sup>6</sup> ¥/Y)	-319 35	-19 19
	decreased levelized ratio of expenditure (%)	-32 21.56	-9 21.56

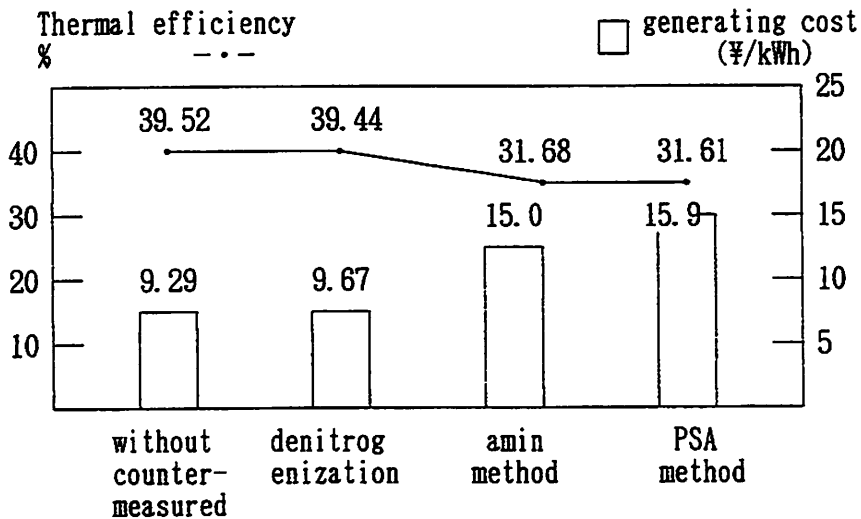
Source: Motofuji & Uchiyama, Economic of Electric Power, CRIEPI

Fig 2 - 1 Economics of enviromental counter-measure technology thermal efficiency and generating cost of coal-fired plant( $10^3$ MW)



Source: same as Table 1

Fig 2 - 2 Thermal efficiency and generating cost of LNG-fired plant( $10^3$ MW)



Source: same as Table 1

Fig. 2 - 3 Environmental cost of coal fired generating plant (10<sup>3</sup>MW)

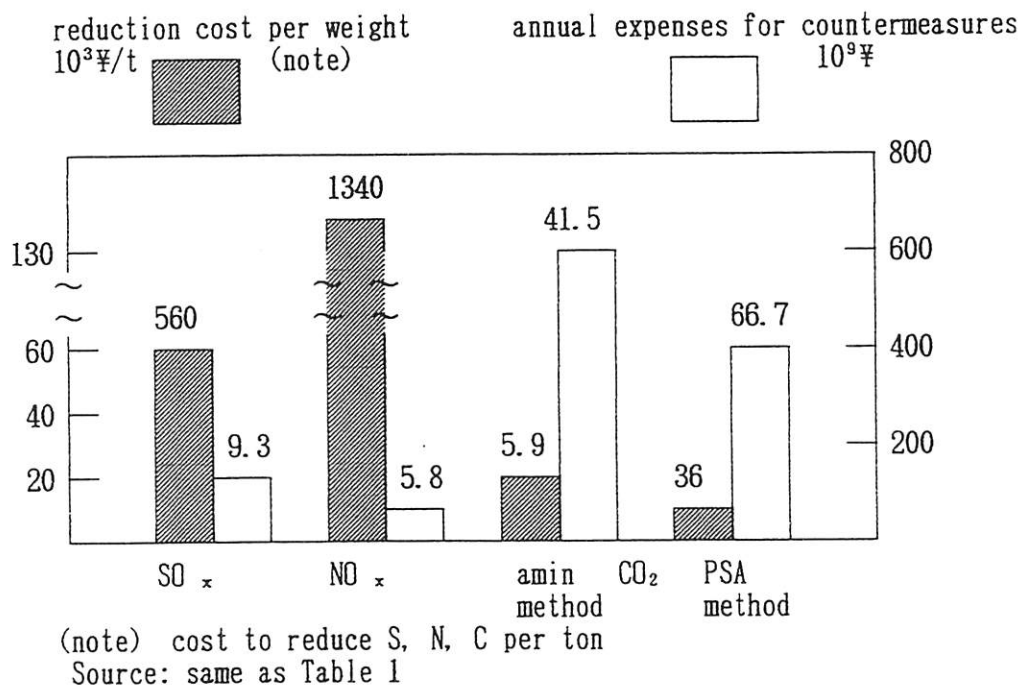
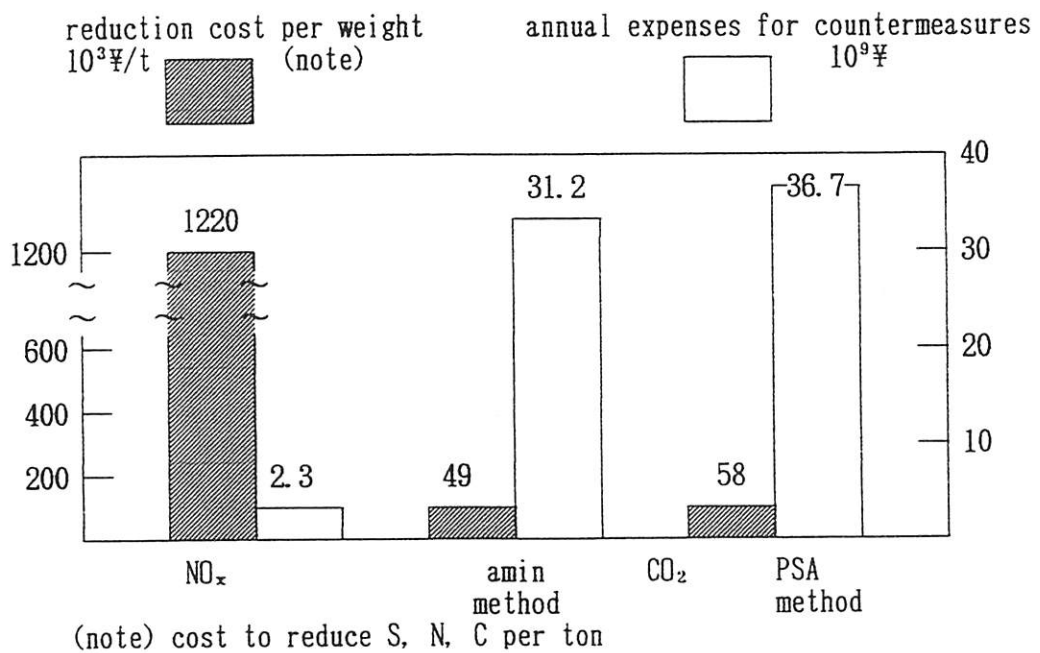


Fig. 2 - 4 Environmental cost of LNG fired generating plant (10<sup>3</sup>MW)



### 3. Carbon tax to stabilize CO2 emissions

Japan's Action Program to Arrest Global Warming (Oct. 1990) set a target that per capita CO2 emissions from 2000 and on be stabilized generally at 1990 levels. What will be the size of a carbon tax, if it is introduced as the only one instrument to attain the target?

Fig. 3-1 shows major options to stabilize per capita CO2 emissions.

With such models as shown in Fig. 6-1 in use, necessary carbon tax amounts are estimated. The results are shown in Table 3-1.

The carbon tax required to stabilize CO2 emissions would amount to ¥46,200/kl or \$70/bbl (\$1=¥105) by 2000, and to ¥57,100/kl or \$100/bbl (\$1=¥90) by 2010.\*1) The GNP growth would be down to 2.6%/year in 2000 from 3.7% in base case, and down to 2.0%/year in 2010 from 2.6%/year in base case. The growth of final energy consumption would slow down to 0.9%/year in 2000 from 2.7%/year in base case, and to 0.4%/year in 2010 from 1.2%/year in base case. This means GNP losses of as much as some ¥60 trillion (\$56 million) in 2000, and of about ¥116 trillion (\$1.2 trillion) in 2010. These suggest how huge will be the cost to stabilize CO2 emissions. It is nearly impossible to solve the issue in the short run. To eliminate this problem worldwide, including developing countries, ultra-long-range efforts are needed by getting 2050 and afterward in perspectives.

#### \*1) How to return carbon tax revenues, and results

- The whole amount (100%) is to be returned, 25% each for lowering personal income tax, cutting corporate income tax, raising government spendings (12.5% for government final consumption spendings, 12.5% for public capital formation), increasing subsidies.
  - The rise in subsidies "Was considered in order to analyze strengthening of energy conservation investment later.
  - Either of these ways of reflux, if taken, results in a lower economic growth than in the base case.
- Depressed consumption by rising general prices can cause the real

economy to shrink.

- Full amount of government tax receipts can hardly be refluxed due to inevitable losses on the way of individual channels.
- Given the purport of carbon taxation, it is hard to practise a reflux which produces particularly massive ripple effects.

\*2) Model-Based simulation of Carbon Tax Needed to Stabilize CO<sub>2</sub> Emissions

Objectives/aims of the simulation

- To examine size of carbon tax needed to stabilize CO<sub>2</sub> emissions.
- To examine economic impacts of carbon tax needed for CO<sub>2</sub> stabilization.
- To examine how individual functions of carbon tax work on.
- To modify an "Energy Econometric Analysis Model" developed by the IEE, and use it in the simulation.
- To back energy amounts, crude oil imports, etc. to macro economic terms and energy prices, then analyze interactions between the economy and energy
- To make exogenous variables endogenous as much as possible.

\*3) How to impose carbon tax

- To start taxing from 1993 and on by increasing the tax amount every year at a certain pace per carbon ton.
- In size, the carbon tax must be heavy enough to stabilize per capita CO<sub>2</sub> emissions in 2000 and afterward virtually at 1990 levels.
- Different energy sources are taxed by multiplying a per carbon ton tax amount by specific carbon emission coefficients to them, with resultant tax amounts added on their energy prices.
- Electricity and town gas are taxed by producing average carbon tax amounts by dividing total carbon tax amounts incurring in fossil fuel inputs, with resultant tax amounts added on electricity/Town gas rates.

Fig 3-1 A Menu of CO<sub>2</sub> Stabilization Measures

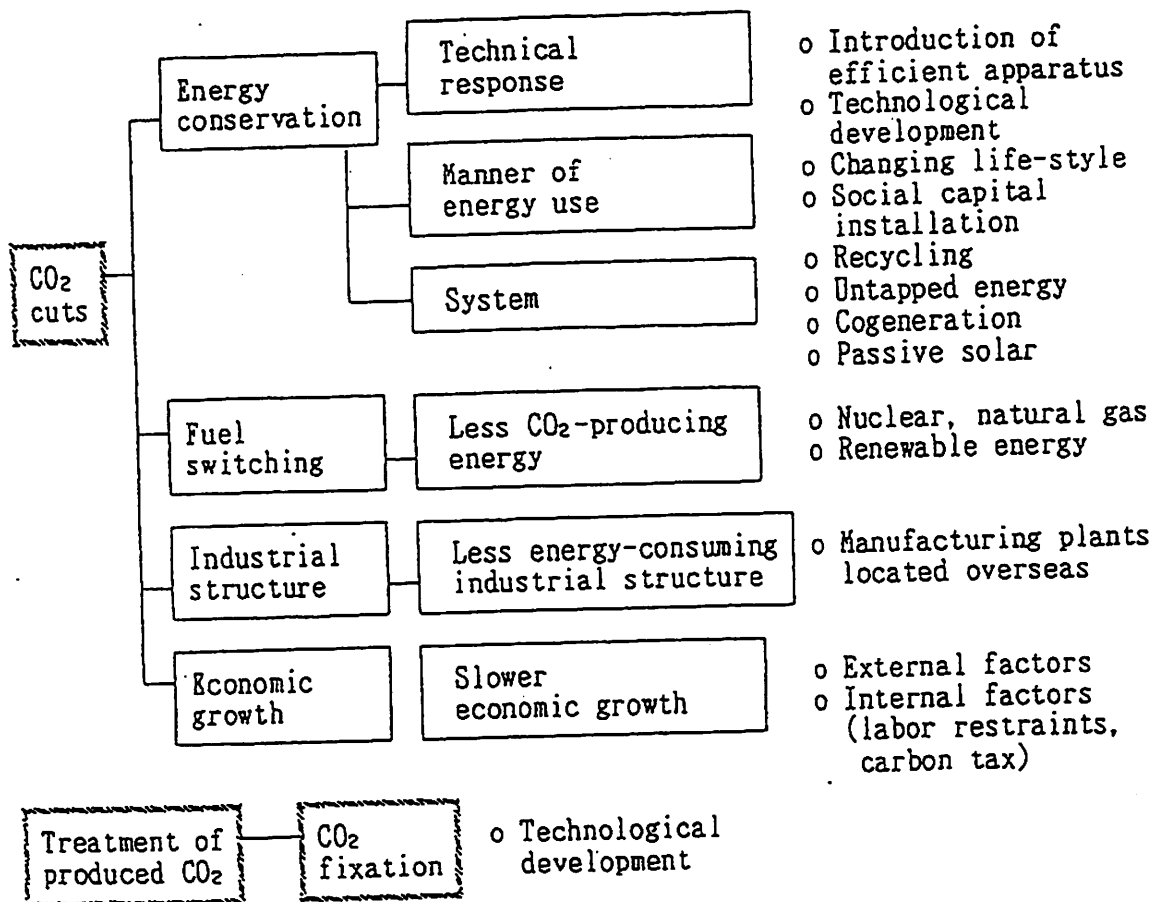


Fig 3-2 Overall Structure of Energy Econometric Analysis Model

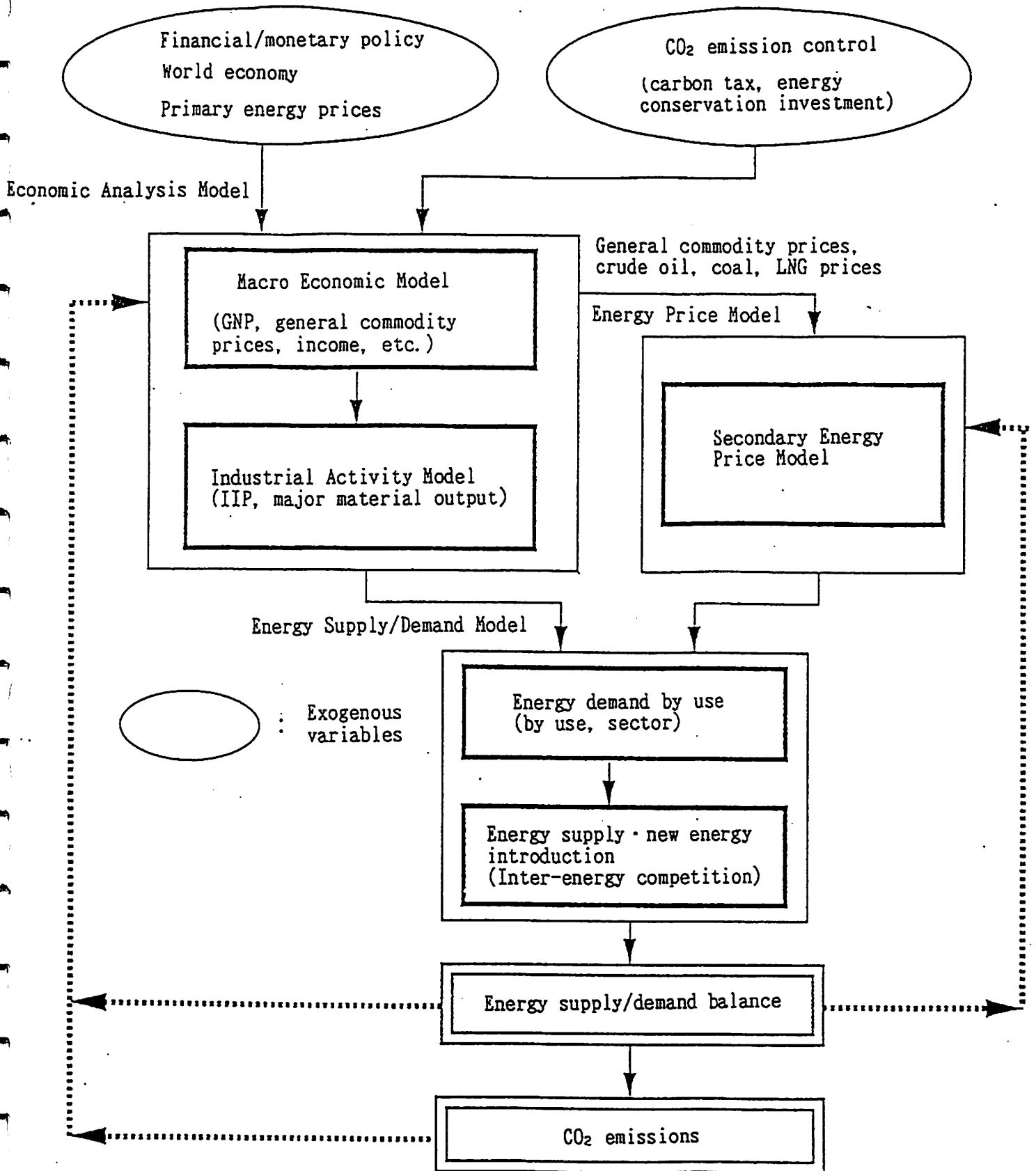
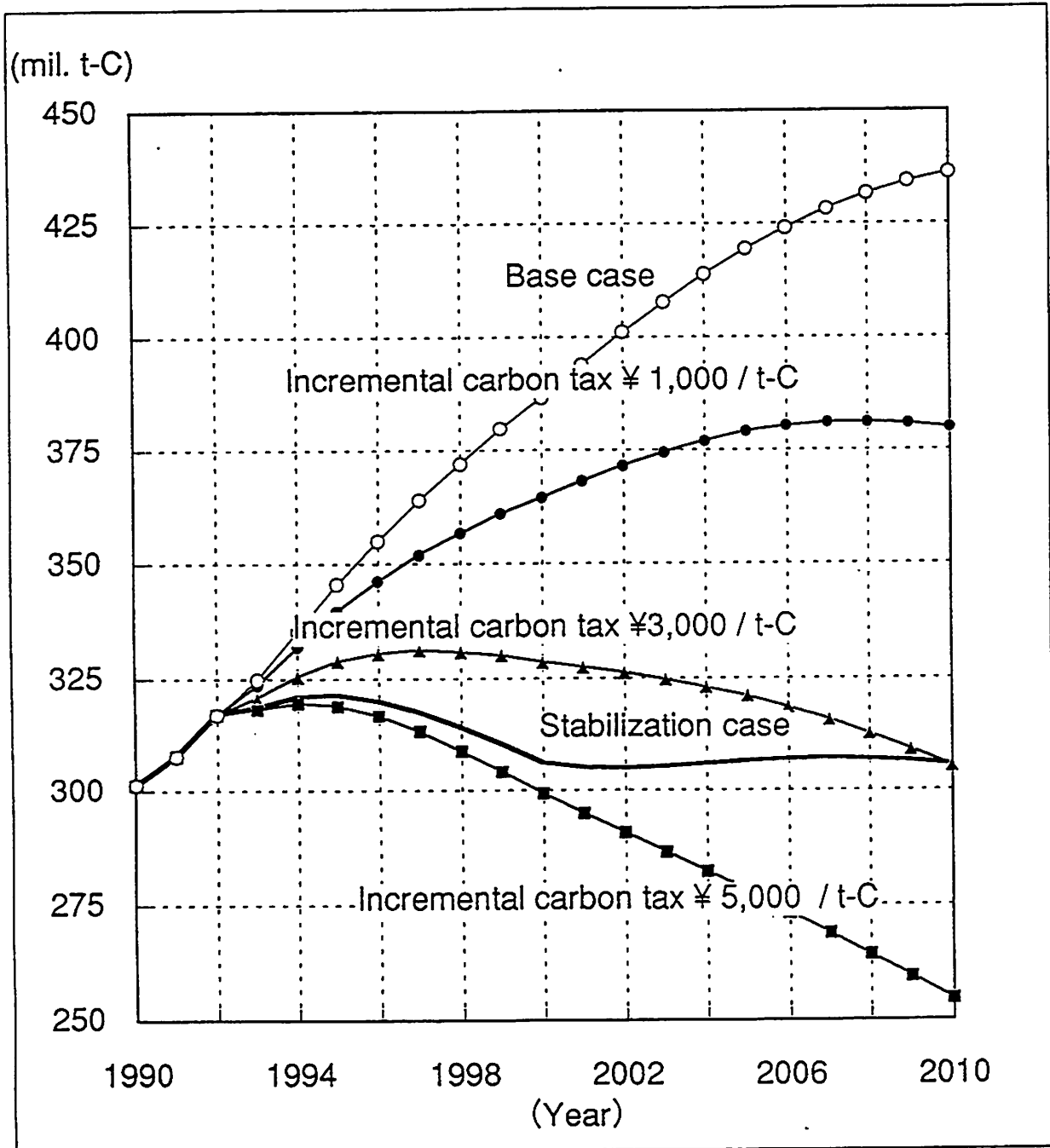


Fig 3-3

Size of Carbon Tax Required to Control and Stabilize CO2 Emissions  
Tax Revenues Transferred Overseas Case (Without Reflux to Home)



Carbon tax needed to stabilize CO2 emissions

1993~2000 Incremental portion ¥4,500 / t-C Carbon tax in 2000 ¥36,000 / t-C

2000~2010 Incremental portion ¥1,000 / t-C Carbon tax in 2010 ¥46,000 / t-C

Table 3-1 A Summary of Stabilization Case with Carbon Tax

Item		Unit	Actual	simulated results		Growth (%)		
			1990	2000	2010	00/90	10/00	10/90
Base Case	Real G N P	tri. yen	409.2	587.5	759.8	3.7	2.6	3.1
	Real private final consumption expenditure	tri. yen	234.1	306.7	357.1	2.7	1.5	2.1
	I I P	(1985=100)	127.2	175.5	226.9	3.3	2.6	2.9
	W P I	(1985=100)	91.0	103.2	116.9	1.3	1.3	1.3
	Crude oil prices	¥1000 / kl	20.8	27.0	42.7	2.6	4.7	3.7
	Energy consumption	mil. toe	466.3	607.4	687.3	2.7	1.2	2.0
	C O <sub>2</sub> emissions	mil. t-C	301.3	386.7	436.1	2.5	1.2	1.9
	Per head CO <sub>2</sub> emissions	t-C / head	2.44	3.04	3.38	2.3	1.0	1.6
Stabilization Case	Carbon tax needed for stabilization	¥1000 / t-C	0.0	<u>64.0</u>	<u>79.0</u>	—	2.1	—
	Carbon tax on crude oil	¥1000/ kl	0.0	<u>46.2</u>	<u>57.1</u>	—	2.1	—
	Energy consumption	mil.toe	466.3	511.1	531.4	0.9	0.4	0.7
	C O <sub>2</sub> emissions	mil.t-C	301.3	306.4	307.5	0.2	0.0	0.1
	Per head CO <sub>2</sub> emissions	t-C /head	2.44	<u>2.41</u>	<u>2.38</u>	-0.1	-0.1	-0.1
	Real G N P	bie/yen	409.2	528.3	644.0	<u>2.6</u>	<u>2.0</u>	2.3
	Real private final consumption expenditure	tri.yen	234.1	277.2	309.8	1.7	1.1	1.4
	I I P	(1985=100)	127.2	166.5	212.0	2.7	2.4	2.6
W P I	(1985=100)	91.0	107.8	121.5	1.7	1.2	1.5	

Table 3-2 Energy Demand and CO<sub>2</sub> Emissions with Carbon Tax

Item			Actual	Sumulted results		Growth (%)		
				1990	2000	2010	00/90	10/00
Base Case	Energy consumption	mil.toe	466.3	607.4	687.3	2.7	1.2	2.0
	Industrial	mil.toe	160.9	185.8	200.5	1.4	0.8	1.1
	Residential/commercial	mil.toe	78.9	112.1	124.1	3.6	1.0	2.3
	Transport	mil.toe	74.4	97.4	109.9	2.7	1.2	2.0
	Conversion/others	mil.toe	152.1	212.2	252.9	3.4	1.8	2.6
	C O <sub>2</sub> emissions	mil.t-C	301.3	386.7	436.1	2.5	1.2	1.9
	Energy intensity	kg-oe / ¥	1.14	1.03	0.90	-1.0	-1.3	-1.1
	CO <sub>2</sub> emissions/toe	t-C / toe	0.65	0.64	0.63	-0.1	0.0	-0.1
Stabilization Case	Energy consumption	mil.toe	466.3	511.1	531.4	0.9	0.4	0.7
	Industrial	mil.toe	160.9	163.2	165.7	0.1	0.2	0.1
	Residential/commercial	mil.toe	78.9	84.0	82.9	0.6	-0.1	0.2
	Transport	mil.toe	74.4	85.2	89.9	1.4	0.5	1.0
	Conversion/others	mil.toe	152.1	178.7	192.9	1.6	0.8	1.2
	C O <sub>2</sub> emissions	mil.t-C	301.3	306.4	307.5	0.2	0.0	0.1
	Energy intensity	kg-oe / ¥	1.14	0.97	0.83	-1.0	-1.5	-1.3
	CO <sub>2</sub> emissions/toe	t-C / toe	0.65	0.60	0.58	-0.7	-0.4	-0.6