5.2 The Rehabilitation Improvement Effect

Among the equipment selected for rehabilitation in this report, the rehabilitation improvement effect expected after rehabilitation work implementation of the equipment considered as Rank A is estimated as shown in Table 5.2-1.

Table 5.2-1 The Rehabilitation Improvement Effect for the Equipment (Rank A)

Rehabilitation improvement item	Rehabilitation improvement effect（MTug／year）
(1) Reduction of auxiliary power ratio	693.6
(2) Recovery of condenser vacuum	170.3
(3) Saving heavy oil fuel consumption	164.3
(4) Increase of the plant availability	10,749.4
Total	11,777.6

Details of each rehabilitation improvement item are given below.

5.2.1 Reduction of Auxiliary Power Ratio

Through the loans (phase-I) from the Japanese government from 1996 - 1999, coal combustion equipment of boiler No. 1 – boiler No. 4 was converted to the direct combustion system. The auxiliary power ratio is reduced by rehabilitation of the equipment, such as Mill and PGF. The changes in the auxiliary power ratio from 1995 - 2000 are shown in Fig. 5.2-1.

Through the loans from the Japanese government scheduled for 2001 - 2005 (Phase-II), the same rehabilitation as that of Phase-I is due to be implemented for boiler No. 5 – boiler No. 8 Reduction with the same auxiliary power ratio is expected.

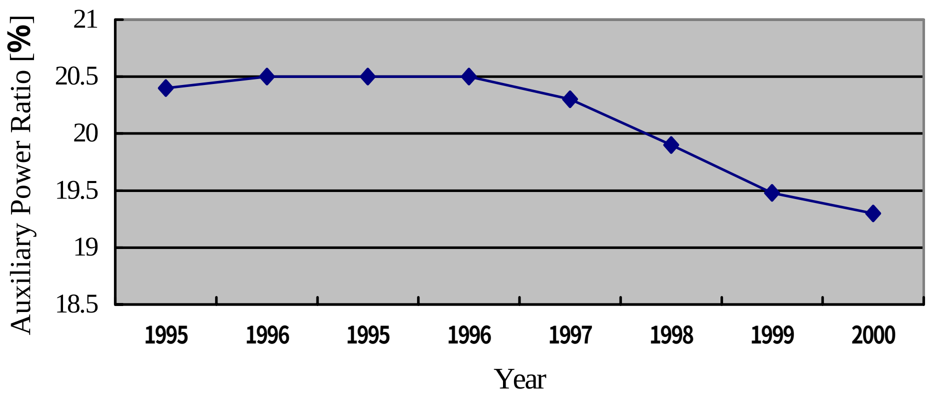

Fig. 5.2-1 The Changes in the Auxiliary Power Ratio

In addition to the above-mentioned improvement effect, a big reduction in the auxiliary power ratio is expected by inverterization of feed water pump motor No. 1 - No. 8. Now, the feed pump is operated by fixed rotation irrespective of the boiler load. The feed water control valve adjusts the water flow.

When feed water pump operation is changed into variable rotation control by the inverter, the power required becomes reducible in proportion to the cube of rotations (the amount of water flow).

The energy saving rate is calculated by the following formula:

Energy saving rate [%] = $(1- (\text{average load }[\%]/100)^3) \times 100$

Here, in the water quantity of the feed pump: Q[m^3/min], exhaust pressure: H[m], pump efficiency: η [%] and axial power of the pump is calculated by the following formula:

Pump axis power $P = 16.3 \times Q \times H/\eta$

$= 16.3 \times 420 \times 1{,}600/78$

$= 2{,}340$[kW]

The reduction amount of the auxiliary power of each boiler is calculated by the following formula from the rate of energy saving, and annual operation hours:

The reduction amount of auxiliary power [kWh]

= 2,340[kW]×(Energy saving rate [%/100]×Operation hours [h]/1,000

The reduction of auxiliary power ratio by inverterization of the feed water pump motor is shown in Table 5.2-2.

Table 5.2-2 The Reduction of the Auxiliary Power Ratio

(Based on the Year 2000 Boiler Operation Record)

From the boiler operation record in 2000, the reduction of the auxiliary power ratio is calculated per boiler.

	unit	1u	2u	3u	4u	5u	6u	7u	8u	Total
Steam production	kt	1,538	1,278	1,187	1,961	1,027	1,611	407	1,630	10,639
Operation hrs	h	4,466	3,675	3,363	5,904	2,991	4,771	1,376	4,910	
Average load	t/h	344	348	353	332	343	338	295	332	
	%	82	83	84	79	82	80	70	79	
Energy saving rate	%	45	43	41	51	45	48	65	51	
Auxiliary power reduction	MWh	4,692	3,717	3,205	6,988	3,177	5,359	2,099	5,820	35,057

Therefore, when the feed water pump motor is of inverter control and the average load is per the year 2000 base, the amount of auxiliary power consumption will be set to 367.7-35.1=332.6 GWh. The auxiliary power ratio is cut by 1.9%.

	(Year 2000 TES4 record)		(After inverterization)
Electric generation amount	1,910 GWh		1,910 GWh
Auxiliary power consumption amount	367.7 GWh	⇒	332.6 GWh
Auxiliary power ratio	19.3 %		17.4%
	(From Table 4.1-1)		

Cutting part of the auxiliary power leads to an increase in selling electric energy. Since the electric energy selling unit price of TES4 in 2000 is 19.76 Tug/kWh from Table 4.1-1, the rehabilitation improvement effect is:

35.1 GWh×19.76 Tug/kWh＝693.6 MTug

Moreover, the feed water pump, when not required to run as intended, is usually put into standby operation as a backup service. If the reliability of equipment improves by replacement of the feed water pump/motor, the number of pumps can be reduced in the proper number, and a further reduction of the auxiliary power ratio can be expected.

5.2.2 Recovery of Condenser Vacuum

The condenser vacuum has gradually deteriorated every year since 1993. In TES4, the recovery of the condenser vacuum is one of the most important items of the annual action plan, and a workgroup centering on the Engineering Department including the Operation Department and the turbine section has been formed, so cause investigation and measures are being implemented. However, neither cause investigation nor its measures are sufficient. The changes of the condenser vacuum over the past 11 years in TES4 are shown in Fig.5.2-2.

Table 6.2-8 of "Chapter 6, Administration of the plant equipment in 6.2.3, Administration of the engineering" describes the current status of cause investigation and its measures. Major causes of condenser vacuum decline are that since planning and implementation of the necessary repairs have not been fully conducted, the suction portion of the air leak has increased by the superannuated equipment. And also, there is clogging of the condenser tube inlet by foreign substances, and a shortage of the cooling water flow resulting from non-collection of the bearing cooling water.

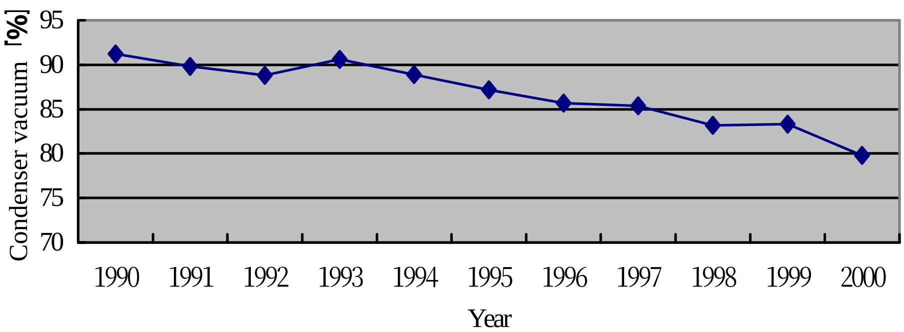

Fig.5.2-2 The Changes of the Condenser Vacuum

By replacing and repairing Rank A equipment, the recovery of the condenser vacuum can be expected to produce a design value (92% : 650 mmHg). Consequently, a reduction in the amount of annual fuel losses of 170.3 MTug can be aimed at by improvement of the condenser vacuum. The calculation basis of the amount of annual fuel losses by the decline of the condenser vacuum is shown in Table 5.2-3 and Fig.5.2-3.

Table 5.2-3 The Amount of Annual Fuel Losses by the Degree of Decline of the Condenser Vacuum

<table>
<tr><td colspan="2">Current Status</td><td colspan="2">Design</td></tr>
<tr><td>Turbine inlet steam condition
130ata, 555°C
⇒ 3,487 kJ/kg</td><td>Heat drop
3,211 kJ/kg</td><td>Turbine inlet steam condition
130ata, 555°C
⇒ 3,487 kJ/kg</td><td>Heat drop
3,263 kJ/kg</td></tr>
<tr><td colspan="2">Condenser vacuum -563.59 mmHg
Saturated steam temp. 66°C
⇒ 276 kJ/kg</td><td colspan="2">Condenser vacuum -650 mmHg
Saturated steam temp. 53°C
⇒ 224 kJ/kg</td></tr>
<tr><td colspan="4">1. Calculation of the rate of turbine heat loss
(Present state) From the turbine inlet steam condition, this enthalpy is 3487 kJ/kg .. (a).
From the condenser vacuum, saturated steam temp. is obtained. From saturated steam temp. and wetness (=1.0), the condenser outlet enthalpy is given as 276 kJ/kg........................... (b).
Thus, the turbine heat drop is given by (a) – (b) 3,211 kJ/kg .... (c).

(Design) From the turbine inlet steam condition, this enthalpy is the same as in (a.)
From the condenser vacuum, saturated steam temp. is obtained. From saturated steam temp. and wetness (=1.0), the condenser outlet entropy is given as 224 kJ/kg .... (d)
Thus, the turbine heat drop is given by (a) – (d) 3,263 kJ/kg .... (e)
From the above data, the heat loss per turbine obtained is: (e) - (c), 52 kJ/kg........... (f)
The rate of turbine heat loss to the design heat drop is: (f) ÷ (e), 1.6% .... (g)
In conclusion, the fuel consumption for this rate increases.

2. Calculation of the amount of annual fuel losses
From the data of TES4, the amount of specific fuel consumption for electricity generated in the year 2000 is 388.9 g/kWh (coal calorie 7000 kcal/kg base).
Since the annual electric power production is 1,910G Wh, annual consumption fuel (for electricity) is: 388.9 g/kWh×1,910 GWh=742,799 tons .... (h)
The amount of fuel losses by the decline of the condenser vacuum is:
From (g) × (h), 11,885 tons

3. Calculation of the rehabilitation improvement effect
Since the fuel unit price of Baganuur coal in the year 2000 is 7,000 Tug/t and 3,420 kcal/kg, the amount of annual coal losses becomes:
7,000 Tug/t × 11,885 t × 7,000 kcal/kg ÷ 3,420 kcal/kg
=170.3 MTug</td></tr>
</table>

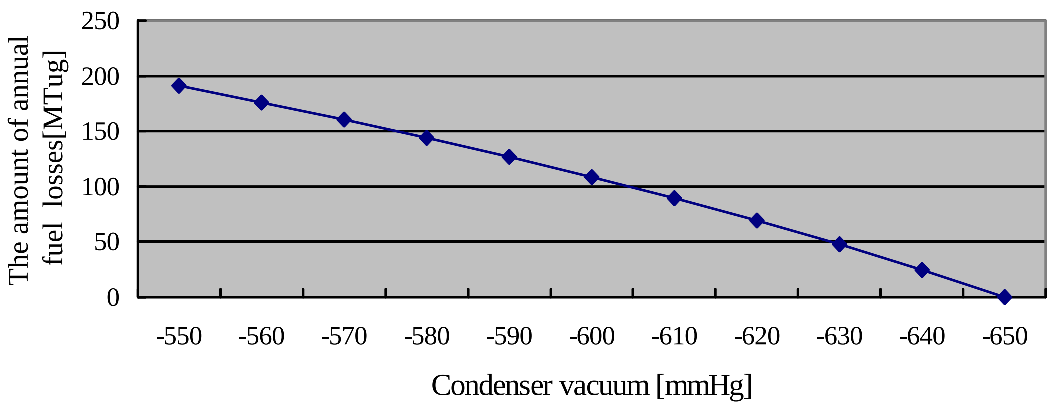

Fig. 5.2-3 The Amount of Annual Fuel Losses by the Decline of the Condenser Vacuum

5.2.3 Saving Heavy Oil Fuel Consumption

Through the loans (Phase-I) from the Japanese government from 1996 - 1999, pulverized coal combustion equipment from boiler No. 1 – boiler No. 4 was converted to the direct combustion system. As a result, the amount of heavy oil consumption has been cut sharply through fewer failures of the pulverized coal combustion equipment. It is also considered that as the number boiler start-ups decreased, this factor led to a drastic reduction in the amount of heavy oil consumption by the decrease in the number of times of critical failure. The changes in the amount of heavy oil consumption and purchasing cost in 1997 - 2000 are shown in Fig.5.2-4.

However, since the heavy oil unit price has soared in recent years, the heavy oil purchase cost increased from 1999 to 2000. TES4 is aiming at a further reduction in the amount of heavy oil to be used.

On the other hand, the disadvantage is that the method, in which the start-up time tends to be shortened, cuts the amount of heavy oil to be used by force, which reduces the life of the equipment etc. An operation standard should be observed and forced starting should be avoided. Rather, in order to decrease shutdown caused by accidents or failures, the maintenance of equipment based on preventive maintenance should be managed and performed.

Reduction of the amount of heavy oil used, therefore, is possible by reducing the number of start-ups. Maintenance of the worn out parts of the pulverized coal combustion equipment updated by Phase-I is especially important. When proper maintenance is not managed and performed, the failure rate increases over several years, raising concern over the increase in the amount of heavy oil consumption.

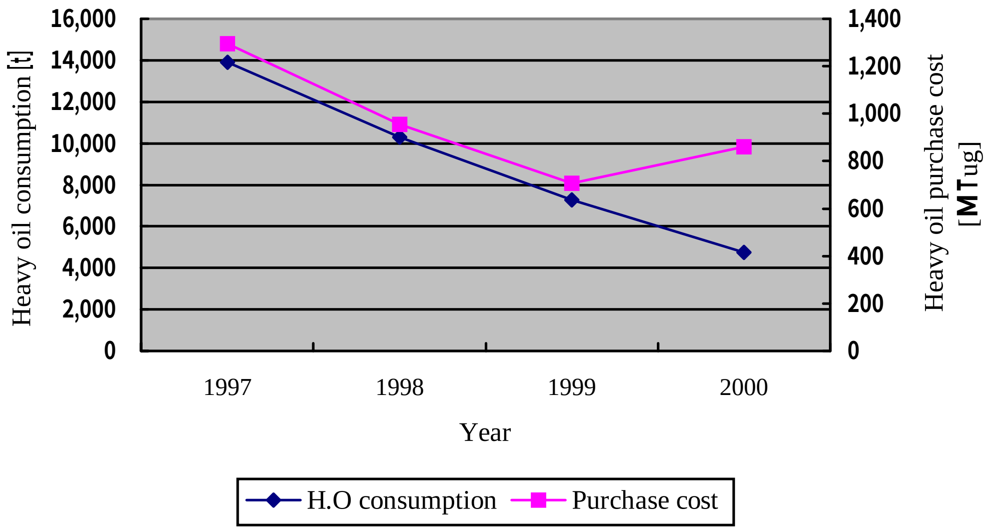

Fig. 5.2-4 The Changes in the Amount of Heavy Oil Consumption and Purchase Cost

The amount of heavy oil consumption changes with differences in conditions such as hot start-up, cold start-up and open-air temperature. Provided that the amount of heavy oil consumption per start-up in the year 2000 year is averaged, it is 26.4 tons at cold start-up and 6.0 tons at hot start-up. The number of start-ups and the amount of heavy oil consumption of each boiler in the year 2000 are shown in Table 5.2-4.

Table 5.2-4 The Number of Start-Ups and Heavy Oil Consumption of Each Boiler in the Year 2000

Boiler No.	1u	2u	3u	4u	5u	6u	7u	8u	Total	Heavy oil consumption [t]	Ave.[t]
Hot start-up	16	23	15	20	10	21	6	16	127	762	6.0
Cold start-up	12	15	13	10	17	13	7	13	100	2642	26.4
Total	28	38	28	30	27	34	13	29	227	3404	15.0

Through the loans (Phase-II) from the Japanese government scheduled for 2001 - 2005, the same rehabilitation as that in Phase-I is scheduled to be carried out for boiler No.5 - boiler No.8. Subsequently, the same reduction in the amount of heavy oil consumption is expected. The prediction of the rehabilitation improvement effect after Phase-II rehabilitation work is shown in Table 5.2-5 concerning the amount of heavy oil consumption in the year 2000 on the basis of the results of an investigation by the Operation Department.

The amount of heavy oil consumption uniformly enabled a reduction of 65.9% based on the Phase-I actual result ([year 2000 actual result 4,739 t] / [1997 actual result 13,897 t]=0.341). (Since old equipment was removed, 0 was used for heavy oil consumption previously required for a blocked separator cyclone.)

Table 5.2-5 Start-Ups of Each Boiler in the Year 2000 and Predicted Amount of Heavy Oil Consumption

The reason for heavy oil consumption	Year 2000 H.O. consumption [t]	H.O. consumption After Phase-II [t]	Predicted H.O. consumption reduction after Phase-II [t]
Hot start-up	737	251	486
Cold start-up	2,409	821	1,588
Boiler shutdown	57	19	38
Failure of boiler pulverized coal combustion equipment	55	19	36
Failure of mill	735	251	481
Poor coal quality	167	57	110
Blocked coal shooter	150	51	99
Blocked separate cyclone	17	0	17
Failure of boiler aux. equipment	159	54	105
Firing assist at low load	36	12	24
Obstruction of instrument	11	4	7
Electrical failure	43	15	28
Others	217	74	143
The sum of heavy oil consumption	4,739	1,628	3,111

The number of boiler shutdowns per cause of each failure in the year 2000 is shown in Table 5.2-6. The number of shutdowns by failure of turbine equipment and electric equipment is 23 times and 54 times, respectively.

The equipment selected for rehabilitation in this report is mainly turbine and electric equipment. By rehabilitating Rank A equipment, the number of cases of each annual failure is presupposed to decrease to 10% or 2 times and 5 times. Consequently,
15 t×(21+49) =1,050 [t] reduction amount of heavy oil consumption is expected.

The heavy oil unit price in the year 2000 is 156,494 Tug/t. When the heavy oil purchase unit price is constant, reduction in the amount of heavy oil consumption becomes:
1,050 t×156,494 Tug/t =164.3 MTug.

Table 5.2-6 The Number of Boiler Shutdowns according to Failure Cause in the Year 2000

Equipment	Boiler	Turbine	C & I	Electric	Fuel	Maintenance
2000 year	131	23	6	54	2	1

5.2.4 Increase of the Plant Availability

(1) The Increase in the Amount of Selling Electric Energy

Table 5.2-7 shows the actual result of turbine/generator operation in the year 2000. The total failure repair hours of the turbine/generator increased to an annual 16,264 hours. Therefore, the availability (operation hour base) was only an average of 54.5%. Especially, the availability of the 80 MW turbine/generator was as low as about 40% or less, and it was hardly in operation because of frequent repair works.

Table 5.2-7 The Actual Result of Turbine/Generator Operation in the Year 2000

.	Unit	1u	2u	3u	4u	5u	6u	Total
Rated load	MW	80	100	100	100	80	80	540
Electric energy production	MWH	170,339	346,946	567,950	550,915	143,985	129,515	1,909,651
	%	8.9	18.2	29.7	28.8	7.5	6.8	100
Average load	MW	49	81	79	78	40	43	370
	%	61	81	79	78	50	54	69
Operation	hour	3,498	4,306	7,228	7,069	3,600	3,021	28,722
Standby	hour	213	276	685	879	942	575	3,570
Planned repair	hour	0	4,101	0	0	0	0	4,101
Failure repair	hour	5,064	99	860	820	4,239	5,182	16,264
Fault shutdown	hour	9	2	11	16	3	6	47
Availability	%	39.8	49.0	82.3	80.5	41.0	34.4	54.5

The following is assumed when examining the availability of the turbine/generator in 2011 after the rehabilitation of Rank A equipment.

1) Each of the 100 MW and 80 MW turbine/generators will stop requiring a major overhaul for an annual 4,200 hours (about six months).
2) One of the turbine/generators will stop requiring a middle overhaul for an annual 2,100 hours (about three months).
3) The average load of each turbine/generator will go up to 80%, respectively.
4) The failure repair hours will decrease to as low as 90% that of the year 2000 record.
5) Standby hours will not change with the actual result in the year 2000.

   (All the failure repair time reductions will contribute to the plant availability.)

The examination result is shown in Table 5.2-8. And the changes of plant availability of each turbine/generator are shown in Fig 5.2-5.

Table 5.2-8 Predicted Availability of the Turbine/Generator in 2011

	Unit	1u	2u	3u	4u	5u	6u	Total
Rated load	MW	80	100	100	100	80	80	540
Electric energy production	MWh	246,784	343,680	640,160	456,560	474,816	491,840	2653,840
	%	9.3	13.0	24.1	17.2	17.9	18.5	100
Average load	MW	64	80	80	80	64	64	432
	%	80	80	80	80	80	80	80
Operation	hour	3,856	4,296	8,002	5,707	7,419	7,685	36,965
Standby	hour	213	276	685	879	942	575	3,570
Planned repair	hour	4,200	4,200	0	2,100	0	0	10,500
Failure repair	hour	506	10	86	82	420	518	1,622
Fault shutdown	hour	9	2	11	16	3	6	47
Availability	%	43.9	48.9	91.1	65.0	84.5	87.5	70.1

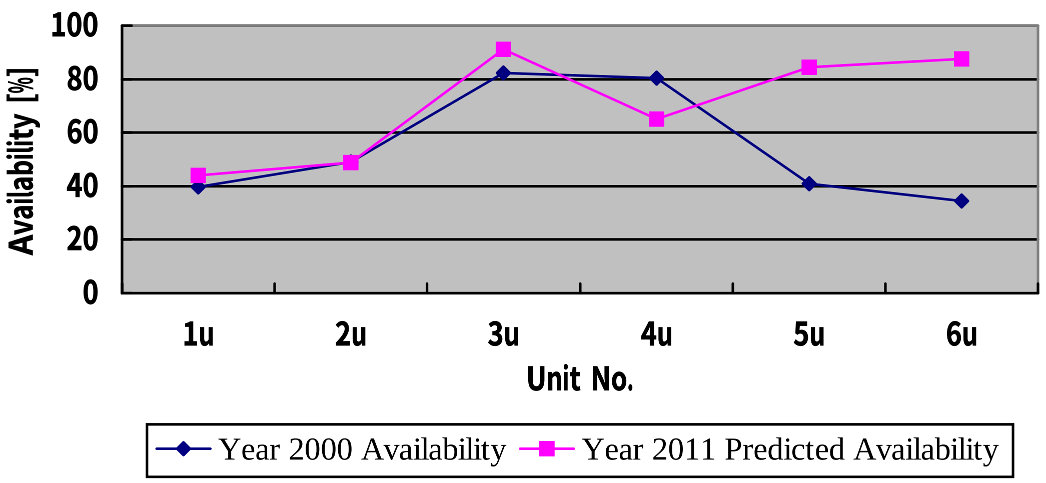

Fig 5.2-5 The Changes of Availability of Each Turbine/Generator

Since a large decrease in failure repair hours is expected, availability (operation time base) of turbine/generator No.3, 5 and 6, which are not scheduled for a major overhaul or middle overhaul, increases to 80% or more, and an average of about 70% becomes possible. Additionally, electric energy production increases in 744 GWh. Since electric energy sales in the year 2000 (a portion of which is deducted as auxiliary power) are 1,526 GWh from Table 4.1-1, the amount of TES4 annual electric energy sales increases to 2,270 GWh in 2011 after the rehabilitation of Rank A equipment.

Availability of the turbine/generator depends on the growth of electric power demand. In order to relate the increase in turbine/generator availability with the increase in sales income, an increased part of TES4 selling electric energy must replace import electric energy. (Refer to Table 3.2-2 (1),(2) Forecast on electric power demand)

Since the capability of annual electric energy sales after Phase-II rehabilitation becomes 1,726 GWh, the amount of increase in selling electric energy by the rehabilitation effect of Rank A equipment is: 744 GWh－(1,726 GWh－1,526GWh) =544 GWh.

If the electric energy selling unit price considers the year 2000 as a base, since it is 19.76 Tug/kWh, the increase in the sales income by the increase in turbine/generator availability becomes: 19.76 Tug/kWh×544 GWh=10,749.4 MTug.

(2) The increase in the Amount of Selling Heat Supply

Table 5.2-9 shows the actual result of boiler operation in the year 2000. The total failure repair hours of boilers increased to an annual 22,269 hours. Therefore, the availability (operation hour base) was only an average of 45.0%, and only half of the rated operation hours were worked in one year. Especially, boiler No. 7 was shutdown for about ten months as a planned repair and boiler No.2, 3 and 5 had failed. As a result, availability was much less than 50%.

Table 5.2-9 The Actual Result of Boiler Operation in the Year 2000

	Unit	1u	2u	3u	4u	5u	6u	7u	8u	Total
Rated load	t/h	420	420	420	420	420	420	420	420	3,360
Steam production	kt	1,538	1,278	1,187	1,961	1,027	1,611	407	1,630	10,639
	%	14.5	12.0	11.2	18.4	9.7	15.1	3.8	15.3	100
Average load	t/h	344	348	353	332	343	338	295	332	2,685
	%	82	83	84	79	82	80	70	79	80
Operation	h	4,466	3,675	3,363	5,904	2,991	4,771	1,376	4,910	31,456
Standby	h	356	483	1,242	1,450	507	1,178	162	1,305	6,683
Planned repair	h	0	376	0	0	2,055	0	7,035	0	9,466
Failure repair	h	3,949	4,223	4,169	1,113	3,227	2,822	208	2,558	22,269
Fault shutdown	h	13	27	10	17	4	13	3	11	98
Availability	%	50.8	41.8	38.3	69.6	34.1	54.3	15.7	55.9	45.0

The following is assumed when examining the availability of the boiler in 2011 after the rehabilitation of Rank A equipment.

1) Two boilers will stop requiring a major overhaul for an annual 4,200 hours (about six months).
2) Two boilers will stop requiring a middle overhaul for an annual 2,100 hours (about three months).
3) The average load of each boiler will go up to 90%, respectively.
4) Failure repair hours will decrease to as low as 90% that of the year 2000 record.
5) Standby hours will not change with the actual result in the year 2000.

(All the failure repair time reductions will contribute to the plant availability.)

The examination result is shown in Table 5.2-10. And the changes of availability of each boiler are shown in Fig 5.2-6.

Table 5.2-10 Predicted Availability of the Boiler in 2011

	Unit	1u	2u	3u	4u	5u	6u	7u	8u	Total
Rated load	t/h	420	420	420	420	420	420	420	420	3360
Steam production	kt	3032	1380	2689	2724	1418	2764	2456	1932	18,395
	%	16.5	7.5	14.6	14.8	7.7	15.0	13.4	10.5	100
Average load	t/h	378	378	378	378	378	378	378	378	3024
	%	90	90	90	90	90	90	90	90	90
Operation	h	8020	3652	7115	7206	3750	7311	6498	5112	48,664
Standby	h	356	483	1242	1450	507	1178	162	1305	6,683
Planned repair	h	0	4200	0	0	4200	0	2100	2100	12,600
Failure repair	h	395	422	417	111	323	282	21	256	2,227
Fault shutdown	h	13	27	10	17	4	13	3	11	98
Availability	%	91.3	41.6	81.0	82.0	42.7	83.2	74.0	58.2	69.3

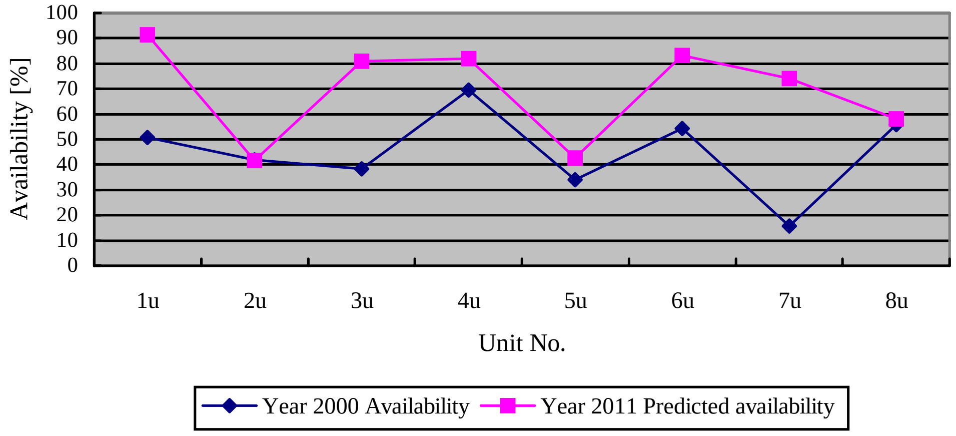

Fig 5.2-6 The Changes of Availability of Each Boiler

Since a large decrease in failure repair hours is expected, availability (operation time base) of boiler No.1, 3, 4 and 6, which are not scheduled for a major or middle overhaul, increases to 80% or more, and an average of about 70% becomes possible. Additionally, steam production increases to 7,756 kt. Even if the increased part of the electric energy production is deducted from the increased steam production, the increased portion in the market capability of annual heat supply becomes 2,475 Tcal (Refer to the calculation basis on the next page).

Boiler availability depends on the growth of heat demand. In order to relate the increase in the boiler availability with the increase in heat sales income, the growth in the heating demand must surpass the forecasted heating growth. (Refer to Table 3.3-1 (1), (2) Forecast on heating demand.)

Since the market capability of the annual heat supply after Phase-II rehabilitation becomes 6,100 Tcal, the rehabilitation effect of the Rank A equipment will appear in 2018 and beyond.

(Calculation basis)

(1) The increase in the steam production

Steam production increases by the rise in availability.

The forecasted production in 2011－Production in the year 2000

=18,395－10,639=7,756 kt ....**1)**

(2) The amount of steam required for an increase in the electric energy production

The amount of steam required for an increase in the electric energy production is:

The increased amount of electric energy production×3600 kJ/kWh÷Boiler outlet steam enthalpy ÷ Turbine efficiency

=744 GWh×3,600 kJ/kWh ÷ 3,490 kJ/kg ÷ 0.42=1,828 kt ....**2)**

(3) Calculation of the amount of steam usable for heat supply

The increased amount of heat supply＝The increased amount of steam production－The amount of steam required for the increase in the electric energy production

=1)–2)=5,928 kt..**3)**

(4) Calculation of heat use efficiency

From the actual result in the year 2000, the heat use efficiency of the boiler outlet steam:

The steam amount used for heat supply = Annual steam production - The steam amount required for electric power production

=10,639 kt－1,910 GWh × 3,600 kJ/kWh÷3,490 kJ/kg÷0.42

=10,639 kt－4,691 kt

=5,948 kt

As enthalpy of the boiler outlet (560°C, 140 atg) is 3490 kJ/kg = 834.9 kcal, the converted quantity of heat is:

5,948 kt × 834.9 kcal/kg=4,967 Tcal

Since the selling quantity of heat in the year 2000 is 2,523 Tcal, heat use efficiency is:

2,523÷ 4,967=0.5..**4)**

(5) The increase in the market capability of the annual heat supply

The increase in the market capability of the annual heat supply is:

3)×834.9 kcal/kg×**4)**

=5,928 kt×834.9 kcal/kg×0.5=2,475 Tcal

5.2.5 The Rehabilitation Improvement Effect of Others

Regarding the rehabilitation improvement effect of others, which is expected after rehabilitation work implementation of the Rank A equipment, there has been a reduction in the amount of boiler water blows, a reduction in the amount of steam leaks and a reduction of air pollutants in exhaust gas. These effects are described below.

(1) Reduction in the Amount of Boiler Water Blows

The amount of losses of steam and water to the supply water in 1995 - 2000 is shown in Fig. 5.2-7. It changes by about 14.6 - 15.4%. Among these, about 80% is the inevitable loss through drum water blow, evaporator drain, steam converter drain, etc., and the remaining 20% loss is for the leakage of steam and water from piping etc. because planning and implementation of the necessary repair has not been fully conducted.

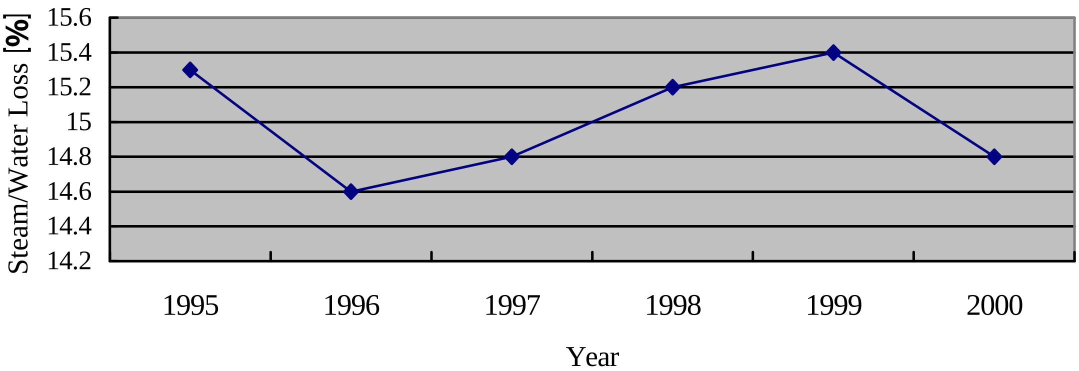

Fig. 5.2-7 Steam/Water Loss

In order to keep the concentration of solvent solids (hardness ingredients, such as silica causing scaling) of boiler water at a normal level and to prevent the generation of obstacles, blow corresponding to that maintaining boiler water quality at less than the limited value is indispensable. TES4 is operating with a 12% rate of blows now. The amount of blows is reduced in cases of boiler make-up water shortages by the increase in plant start-up/shutdown. The amount of blows, on the other hand, is increased through the aggravation caused by the quality of the boiler make-up water.

The following effects are expected as a result of the rehabilitation work of Rank A equipment.

1) Boiler operation hours are increased by higher availability. As start-up, which requires a lot of make-up water, decreases sharply, the amount of annual blows is reduced and, as a result, shortages in the amount of boiler make-up water are solved.

2) The boiler make-up water quality is improved by the installation of automatic control and supervisory instruments for water treatment equipment, and the constant rate of blow can be observed.

Cost losses to the amount of blows are shown in Fig.5.2-8 and Table 5.2-11. The losses by water blows are not only water loss but also heat loss. This shows that the amount of losses is quite large.

In TES4, these losses cost an annual 905.7 GTug. Implementation of an improvement plan towards reducing the amount of blows is proposed, as described below:

1) By switching to the chemical management of high sludge diffusion effect etc, the blow rate is gradually cut by supervising the water quality.

2) By installing continuous blowing equipment, heat exchange of the feed water and the blow water is carried out, and the thermal energies of blow water are collected in the feed water.

When the amount of blows can be cut down to half that of the actual result, the amount of losses becomes 450 GTug, and drastic reduction can be expected.

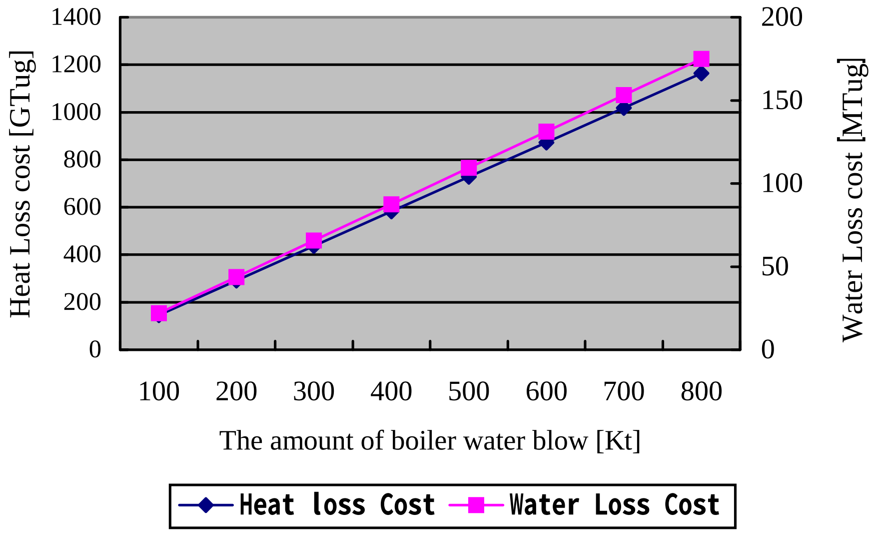

Fig. 5.2-8 The Cost Losses to the Amount of Boiler Water

Table 5.2-11 Relation between the amount of Blows, and the Cost Losses

Blow	kt	100	200	300	400	500	600	700	800
Heat loss cost	GTug	143.9	287.9	431.8	575.8	719.7	863.7	1007.6	1151.6
Water loss cost	MTug	21.9	43.8	65.6	87.5	109.4	131.3	153.2	175.0

Drum blow water conditions

160 kg/cm^2, 346°C, enthalpy of blow water:
2,598 kJ/kg ⇒ 621.5 kcal/kg

(1) Calculation of the heat unit cost of blow water

The heat unit cost of drum blow water Qb [Tug/t] is calculated by the following formulas:

$$Qb = \frac{1{,}000(ib - iw) \times a}{f/100 \times C}$$

ib: Enthalpy of blow water [kcal/kg]
iw: Enthalpy of feed water [kcal/kg]
f: Boiler efficiency ［%］
C: Calorific value of fuel [kcal/kg]
a: Fuel unit price [Tug/kg]

Therefore, the heat unit cost of drum blow water Qb [Tug/t] is calculated as:

Qb=1,439,442 [Tug/t]

(2) Boiler make-up water unit cost

Boiler make-up water unit cost is 218.8 [Tug/t] according to the year 2000 operation report by chemical section.

(3) Calculation of the blow loss cost

When the amount of drum blows for every boiler is 20 [t/h], as the annual operation of all boilers is 31,456 h,

Annual blow amount is: 20 [t/h]×31,456 [h]=629.12[kt]
Heat loss cost is: 1,439,442 [Tug/t]×629.12 [kt]=905.58 [GTug]
Water loss cost is: 218.8[Tug/t]×629.12 [kt] =137.65 [MTug]

(2) Reduction in the Amount of Steam Leaks

In TES4, water and steam are always leaking from various parts (welding, grand, gaskets). (The leakage situation of the feed water control valve is shown in Fig. 5.2-9.) This leakage is not an inevitable loss as it is in the boiler water blow mentioned in (1) but a loss caused by inadequate maintenance, and this becomes 3% of the boiler make-up water.

Fig. 5.2-9 The Leakage Situation of the Feed Water Valve

The parts where leakage is especially remarkable are found in the auxiliary steam supply equipment. Since this is equipment common to all boilers, these can only be repaired during total boiler shutdown, and the amount of leaks, therefore, is also increasing. As an example, the cost losses incurred due to the leakage from a bore diameter in a 16-k auxiliary steam header is calculated, and is shown in Fig.5.2-10 and Table 5.2-12.

In the losses by steam leakage and blows, heat loss is much larger than water loss. For example, when there is steam leakage from a bore diameter (1mm) in the 16-k auxiliary steam header, the annual amount of losses becomes 89.7GTug.

Although the auxiliary steam temp. and press reducing control valves for plant start up are mentioned as Rank A equipment, reduction in the amount of auxiliary steam leaks is expected by this replacement. The steam leak parts, which need to be repaired immediately, are seen everywhere in the power plant. Since these steam leak repairs not only lead to a reduction in the loss of heat and water, but also suppress the influence on the surrounding equipment (less failure parts), this leads to an improvement in hazard areas. TES4 is, therefore, expected to take positive measures.

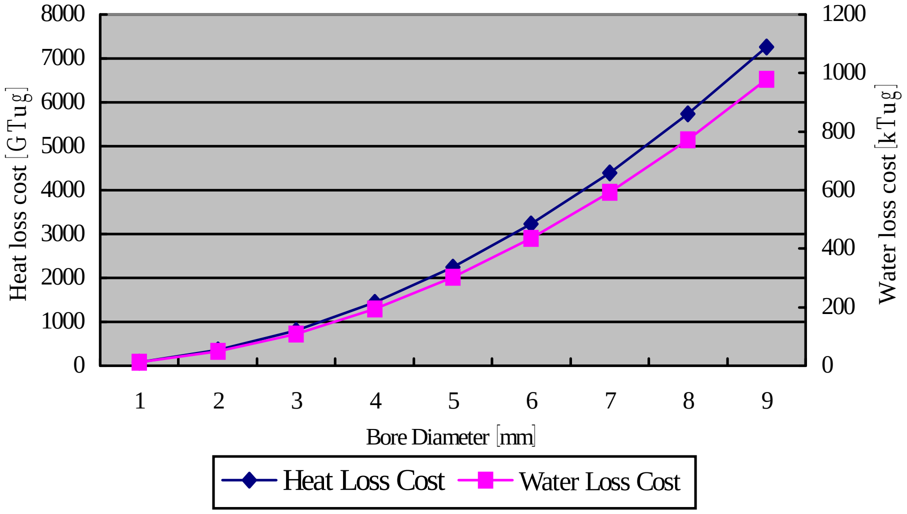

Fig. 5.2-10 Relation Between Bore Diameter and the Cost Losses

Table 5.2-12 Relation Between Bore Diameter and the Cost Losses

Bore diameter	mm	1	2	3	4	5	6	7	8	9
Steam leak	t/h	0.01	0.03	0.06	0.10	0.16	0.23	0.31	0.40	0.51
Heat loss cost	GTug	90	359	807	1435	2242	3229	4395	5740	7265
Water loss cost	kTug	12	48	109	193	302	435	592	773	978

(Calculation basis)

Steam conditions of the auxiliary steam header are: 16 kg/cm^2, 250°C
Steam enthalpy is: 2,921 kJ/kg = 698.8 kcal/kg

(1) The heat unit cost of auxiliary steam

The heat unit cost of auxiliary steam (Qs) [Tug/t] is calculated by the following formulas:

$Qs = (1{,}000(is - iw) \times a)/(f/100 \times C)$

is: steam enthalpy [kcal/kg]
iw: feed water enthalpy [kcal/kg]
f: boiler efficiency [%]
C: Calorific value of fuel [kcal/kg]
a: fuel unit cost [Tug/kg]

There fore, the heat unit cost of auxiliary steam Qs [Tug/t] is calculated as:

Qs=1,624,594 [Tug/t]

(2) Boiler make-up water unit cost

Boiler make-up water unit cost is:
218.8 [Tug/t] according to the year 2000 operation report by the chemical section.

(3) Amount of steam leaks

The amount of steam leaks from small holes (Gs) [t] is calculated by the following formulas:

$Gs = 0.5626 \times D^2 \times ((p+1)/v)^{1/2}$

Gs: dry saturated steam [kg/h]
D: bore diameter [mm]
p: steam pressure [kg/cm^2]
v: dry saturated steam specific volume [m^3/kg]

(3) Reduction of the Air Pollutants in Exhaust Gas

1) NOx, SO_2 emission situation

During the Phase-I rehabilitation work, plant operation was started on September 23, 1998 after boiler No.3 rehabilitation work. The remaining boiler No.1, No.2 and No.4 subject to rehabilitation were put into operation during the year 2000 following boiler No.3. Since the measurement equipment broke down, TES4 has not been able to perform exhaust gas measurement since 1999. For this reason, the data of SO_2 and NOx of the repaired unit is limited to only the data of boiler No.3 from 1998.

The exhaust gas measurement result on October 26, 1998 is shown in Table 5.2-13. The measurement was taken by the Central Laboratory for Nature and the Environment at the request of TES4 and the measurement equipment used was NOS-7000 and PU-8808 made in Japan.

Table 5.2-13 Exhaust Gas Measurement Result

（ESP outlet on average, 6% O_2 conversion result）

	Boiler No.3	Boiler No.5	Boiler No.6
NOx (ppm)	142.0	404.2	438.7
SO_2 (ppm)	463.0	529.6	457.9

From the above exhaust gas measurement result, the NOx concentration value of the repaired boiler No.3 is lower compared with other units, and the NOx reduction effect by the rehabilitation work is obvious.

By replacement of the coal burner and air / fuel flow control equipment, the amount of NOx emission was considered to be reduced.

However, it is necessary to check this NOx reduction effect through long-term and periodical investigation of the exhaust gas including the remaining to be repaired boiler No.1, 4 and 5.

2) CO_2 emission situation

The situation of the amount of CO_2 emission accompanying the electric power generation and heat supply of TES4 in 1998 and afterwards is shown in Table 5.3-14.

Although the amount of CO_2 emission is increasing in proportion to the amount of coal consumption, the amount of CO_2 emission of per Net Energy (electric power production + heat production) will be 0.432 t/Gcal in 2000. Compared with 0.467 t/Gcal in 1998, it is has decreased by about 7.5%. Reduction in this amount of CO_2 emission is based on the increase by the repair improvement effect of Phase-I and higher coal calorie.

If the amount of CO_2 emission in 2011 is expected as an effect of the rehabilitation work for Rank A, the amount of CO_2 emission in 2011 will increase to about 56% from the rise of availability compared with 2000. CO_2 / Net Energy value in 2000 is considered to have decreased slightly.

Table 5.3-14 Coal Consumption and Emitted CO_2 at TES4

	Unit	1998	1999	2000	2011
Amount of coal consumption	1000t	2,045.0	2,075.5	2,190.4	3,407.8
Electric power production*1	10^3 Gcal	3,546.5	3,736.9	3,911.0	5,436.3
Steam production*2	10^3 Gcal	4,391.2	4,614.2	5,046.2	8,558.2
Amount of CO_2 emission	1000t	3,710.8	3,683.9	3,872.1	6,024.21
CO_2/Net Energy*3	t/G cal	0.467	0.441	0.432	0.430

**1 ∴kWh ×860kcal/kWh／Turbine efficiency 0.42*
**2 ∴Heat supply amount／Heat use rate 0.5*
**3 ∴Net Electric Energy + Net Heat Energy*

		1998	1999	2000
Baganuur coal	Amount of coal consumption (t)	19,82,300	1,787,400	1,792,200
	Calorific value (kcal/kg)	3,344	3,401	3,420
	Moisture (%)	32.13	33	33
	Carbon (%)	73.2	73.2	73.2
Shivee-Ovoo coal	Amount of coal consumption (t)	62,700	288,100	398,200
	Calorific value (kcal/kg)	2,870	3,018	3,020
	Moisture (%)	40.47	39	39
	Carbon (%)	72.89	72.89	72.89

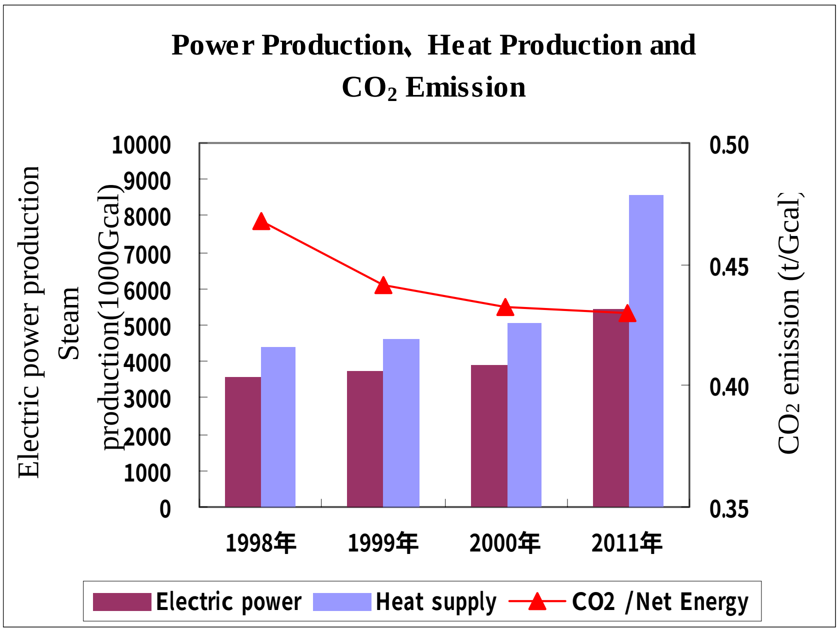

Fig.5.2-11 Coal Consumption and emitted CO_2 at TES4

Amount of coal consumption, the amount of CO_2 emission, etc. in 1998 - 2000

(1) Heat conversion of the electric power production
Electric power production × 860 kcal/kWh ÷ Turbine Efficiency 0.42

(2) The amount of CO_2 emission
All the carbon of coal was assumed to change to CO_2.
Consumed Coal Amount (Dry Coal) × Carbon % / 100 × CO_2/C
= Consumed Coal Amount (Dry Coal) × Carbon % / 100 × 44/12

(3) CO_2/Net Energy
The amount of CO_2 emission/(Heat value converted by the electric power production+Steam production)

Calculation of the amount of coal consumption, amount of CO_2 emission at the time of 2011 operation.

(1) Consumed coal amount [kt] required for heat supply in 2000
Heat Supply Amount 2,523.1Tcal ÷ Heat use rate 0.5 ÷ (Coal kcal/kg × Boiler Efficiency)
= 5,046.2 Tcal ÷ (Coal kcal/kg × Boiler Efficiency) ....A

(2) Consumed coal amount required for electric power production in 2000
Electric Power Production 1,910 GWh × 860 kcal/kWh ÷ Turbine Efficiency 0.42
÷ (Coal kcal/kg × Boiler Efficiency)
= 3,911.0 Tcal ÷ (Coal kcal/kg × Boiler Efficiency) ....B

(3) The ratio (A/B) of the heat production / electric power production in the amount of consumed coal in 2000 is:
A/B = 5,046.2/3,910.952 = 0.563/0.437.

(4) Consumed coal amount in 2011
1) Consumed coal amount kt required for heat supply
(Amount of heat supply in 2011 will increase from 1,756Tcal to 2,523.1Tcal in 2000.)
Amount of consumed coal in 2000 × 0.563 × (2,523.1+1756)/2,523.1
= 2,190.4 kt × 0.563 1.70 = 2,096.4 kt
2) Consumed coal amount required for electric power production (2654 GWh)
(The electric power production in 2011 increases from 744 GWh to 1,910 GWh in the year 2000 and 1.6% of turbine heat losses is recovered.)
Amount of consumed coal in 2000 × 0.437 × (1,910+744)/1,910 × (1 - 0.016)
= 2,190.4 kt × 0.437 × 1.37 = 1,311.4 kt

(5) Amount of steam production in 2011 = (2,523.1+1,756)/Heat supply rate 0.5=8,558.2 Tcal

(6) Heat value conversion of electric power production 2,654 GWh in 2011
Heat value converted by the electric power production in 2000 × (1,910+744)/1910
=3,911.0 Gcal × 1.39=5,436.3 Gcal

(7) The amount of CO_2 emission in 2011
1) The amount of CO_2 emission due to steam production
Total amount of CO_2 emission in 2000: 3,872.1 kt × 0.563 × 1.70= 3,706.0 kt
2) The amount of CO_2 emission due to electric power production
Total amount of CO_2 emission in 2000: 3,872.1 kt × 0.437 × 1.37= 2,318.2 kt
1)＋2)=3,706.0+2318.2=6,024.2 kt