A Vision of Energy Structure for Integrated Steel Works of Future*

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I. Introduction

The 4th Middle East War that broke out in 1973 and the OPEC's petroleum strategy that was taken subsequently had shaken from its foundations the Japanese economy, which was then growing at a high rate supported by unlimited and inexpensive oil. We call this the First Oil Crisis or the First Oil Shock. At that time, Japan had been dependent on oil for 77 % of the primary energy, and 99.8 % of oil was imports. Therefore, a price rise in oil directly meant another price rise in all the other energies, coal, electricity, gas, and any other.

All the industries that operated on energy had to face the energy saving. Save petroleum, save electric power, save coal—any and sundry energies were the target for the economization movement. Instead of the labor saving of the high rate growth time, the energy saving came to the fore.

By nature, the iron- and steel-making is an industry that bases itself on coal. Therefore, its dependence on oil had traditionally been low—about 20 % at most. Yet, the quantity it used to consume was huge: it was 13.5 million k ℓ , or as much as 15.5 million k ℓ with kerosene and LPG included, in the FY* 1973. When reckoned in terms of the total energy with coal and electric power taken into account, the iron and steel industry was consuming some 18 % of the national total, the indubitable leader in the mining and manufacturing industries sector.

To overcome the First Oil Shock, every steel firm had started tackling the energy saving problems by establishing an organization that centrally controls energies, and by determining the control indexes and saving targets. It was an allout effort at anything that might lead to energy saving. Through the FYs 1974 to 1978, it was mostly technical improvements done at the operation ends, yet 8 to 9 % reduction was gained in the overall rate as the steel industry as a whole. We call this the First Round Energy Saving.

Then, the Second Oil Shock due to Iranian Revolution struck to bring about further price rise and uncertainty of supply. The price leapt up from slightly over 12 \$/bbl to 26 to 30, a 2.5-fold increase, which, even though it was smaller percentagewise than that of the 1st Oil Shock of 4-fold, was far greater in the absolute amount. Saving of energies, especially that

of oil, had to be reinvigorated.

At that time, there was this to think about: even after the oil became quite expensive by the 1st Oil Shock, the coking coal was actually more expensive than the oil, but the 2nd Oil Shock brought about a reversal in the matter. That is, the price ratio of oil to coal (as coke), when reckoned in terms of calorific value, was enlarged to 2 to 2.5 times. This meant that, even though more had to be spent in coal or coke—even though contrary to the ideal of energy saving—more could be saved in cost.

One typical result was the curtailment of the oil for blast furnace (BF) injection. This movement started early with small and medium size BFs and spread gradually to large BFs to become the all coke, or the no oil, operation that is now quite universal.* Although maintenance of high tapping rate (TR) and occurrence of operational difficulties were yet to be feared, every steel firm had gone almost entirely into the all coke practice by the spring of 1981.

As the all coke operation spread, more coke came to be needed, and that much more of coke oven gas (COG) came to be had in hand. Traditionally, in an integrated iron and steel works, besides the COG, various byproduct gases like BFG (blast furnace gas) and LDG (LD converter gas) have been utilized as fuels not only for hot stoves, coke ovens, and sintering, but at the down stream apparatuses like reheating furnaces and heat treatment furnaces (mainly COG) as well as for boilers (mainly BFG and LDG). This was a reason, when assisted by the energy saving techniques developed specifically for those apparatuses and by the improved gas recovery, of the great saving of fuel oil actually achieved. This state of affairs is shown in Table 1 and exemplified in Fig. 1.

And so, a new era in energy saving, that evolved out of sheer reduction of per tonnage crude steel energy rate into a higher order energy policy making, a policy that considers future supply/demand relationships by the species (for example, for kerosene and for light oil individually) as well as the total energy balance (for example, what to do with excess BFG), has dawned. This we call the Second Round of energy saving.

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† The Japanese Fiscal Year starts on April 1 and ends on March 31.

†† Though there were (still are) instances of tar injection, tar is a coal-derivative fuel.

- a few years of time, and
- 2) the Target (TGT) Bases, which are the ones either considered to be today's technological limit or presumed to be achievable only if further measures or new equipment (be it already available if yet uncommon or expected to become practical in the near future) were provided for.

It is believed that the Model Steel Works presented herein is generalized well enough so that the cases of real works should readily be indentified for quantitative comparison.

II. Designing of the Model Steel Works

To see the effects of energy saving measures and of operation variations to be taken by individual sectors on the overall energy structure of integrated iron and steel works, a hypothetical steel works of an yearly production capacity of 8 million t crude steel has been designed as a model. The figurative and numerical grounds were decided upon by consulting the IISI's "A Technological Study on Energy in the Steel Industry" (Committee on Technology, 1976) and JISF's "Research and Development of Total System—Study of Waste Heat Utilization Technology System" (1979).

In view of the actual operation of recent years, the capacity usage ratio (CUR) was set at 80 %, and the continuous casting rate (CCR) at 70 %.* There will be a coke oven plant, two 5 000 m³ BF's, a lime calcination plant, three 300 t/ch basic oxygen (or LD) furnaces (BOF) working on two-by-three principle, three slab CC machines, a bloom CC machine, an ingotmaking plant, and rolling lines, both hot and cold, appropriately equipped with mills and furnaces. The products are, from the hot rolling plant, hot coils, medium thickness sheets (the pickled sheet steels), plates, bars and rods, and seamless pipes, while out of the cold rolling plant, cold strips, cold rolled sheets, galvanized sheets, and tinned sheets. This is shown in the material flow diagram of Fig. 2.

The major operation rates and parameters shown in Table 2 were decided upon on the basis of actual records attained by the member firms in FY 1978. Therefore, this Model with its oil injection at BF and relatively low CCR is to represent the state of affairs when the First Round Energy Saving was completed.

III. Establishment of STD and TGT Rates for Individual Sectors

1. The Cokemaking Sector

The coke ovens have become, in accordance with the marked enlargement and sophistication of BF's, larger, better automated, and better adaptable to changes in quality of coal. Besides, such large scale energy saving technologies as coke dry quenching (CDQ) or preheating of coal have spread widely. Yet, factors of coking operation, *e.g.*, grade of coal, chemical composition including moisture, oven structure, and state of heating and combustion, remain to

Table 2. Major operation rates and parameters of the model steel works.

Sector	Operation parameters and rates	
Cokemaking	Coal calorific value	7 700 kcal/kg-dry
	Coal volatile matter	27 %
	Coke oven CUR	100 %
	Coke gross yield	75 %
	Coke lump yield	65 %
	Coke breeze ratio	10 %
Ironmaking	Sinter yield	98 %
	Sinter lump yield	76.5 %
	Sinter fines ratio (Return sinter)	23.5 %
	BF coke rate	415 kg/t-pig
	BF oil rate	35 kg/t-pig
	BF sinter ratio	80 %
Steelmaking	BF pellet ratio	10 %
	Hot metal rate	0.92
	Lime rate	40 kg/t-steel
Ingotmaking	CC rate	70 %
	Killed steel ratio in the slab ingots	12.5 %
Rolling	Killed steel ratio in the billet ingots	61 %
	Plate mill HCR	30 %
Rolling	Hot strip mill HDR	20 kt/month
	Hot strip mill HCR	19 %
	Bar mill HCR	50 %

be as complex and mutually interactive as ever, so that no comprehensive theoretical analysis method is available.

Therefore, the rates, oven dimensions, and such were determined by taking statistical average of reported results. As for the Chemical Division, on the other hand, as the process itself differs greatly from a firm to another, several representative cases were selected and their average was adopted.

1. The Chemical Division

The chemical process was limited to the refining of COG as shown in Fig. 3. The STD rates are the values that appeared to be the best among the reported achievements. Further, as no remarkable accomplishments in energy saving were found, the TGT rates were taken as the same as STD. Those values are listed in Table 3.

2. Determination of STD and TGT Rates and Operation Parameters

(1) Correlations among Operation Parameters

The two great factors of coke oven operation that affect on energy saving are the volatile matter (VM) value of the coking coal and the CUR (capacity usage ratio). As may be seen in Table 4, all the operation parameters were found representable by respective correlation equation of first order when the actual experiences of 12 coke ovens were averaged over and modified by the expected effects of energy saving

* Today it is already 80 % or even more, see Iki, *Tetsu-to-Hagané*, **69** (1983), 7.

Fig. 2. Materials flow diagram for the model 8 million t steel works.

Fig. 3. Process flow of chemical division and examples of popular energy application.

Table 3. STD and TDT rate for chemical division.

	COG (kcal/t-coal)	Power (kWh/t-coal)	Steam (kg/t-coal)
Rates (STD=TGT)	20×10^3	25	60

Table 4. Operation parameters and correlation formulas.

Relations	Correlations	Units
Gross yield vs. VM	$-0.85 \text{ VM} + 99.1$	%
Lump yield vs. VM	$-0.8 \text{ VM} + 86.5$	%
Tar generation vs. VM	$2.8 \text{ VM} - 39.6$	kg/t-coal
COG generation vs. VM	$5.5 \text{ VM} + 159$	Nm ³ /t-coal
Fuel gas CV vs. CUR	$20 \text{ CUR} - 100$	kcal/Nm ³

measures presented in Table 5.

(2) Determination of STD and TGT Rates

The state-of-arts fuel rate (FR) is 650×10^3 kcal/t-coal for a CUR of 120 % and VM of 27 %. For the Model, it is assumed that the VM remains 27 % but the CUR is lowered to 100 %, and that the energy saving measures of Table 6 are all practiced. The results are the STD FR of 576×10^3 kcal/t-coal for a COG CV (calorific value) of 1 000 kcal/Nm³ and a COG generation rate of 312 Nm³/t-coal.

The TGT rates are the same as the STD, except that the steam recovery rate is up by 0.5 t/t-coal thanks to the CDQ line. The state-of-arts values, the STD values and the TGT values are summarized in Table 7 together with values for "New Oven", which

Table 5. Fuel rate Decrements due to operation changes.

	Operation variation	Energy saved (10 ³ kcal/t-coal)
CUR	Increased by 10 %	16.0
Carburization time	Prolonged by 1 hr	17.7
Setting time	Shortened by 1 hr	7.6
Furnace temp.	Held to less than 10 °C	1.3
Calorific value	Lowered by 100 kcal/Nm ³	5.0
Moisture	Lowered by 1 %	16.8

Table 6. Energy saving measures for coke oven towards STD operation.

Energy saving measures	Present status	STD	Energy saved (10 ³ kcal/t-coal)
Lowering of fuel-to-air ratio (m)	1.4	→ 1.2	23
Lowering of coke temp. (°C)*	1 100	→ 1 010	49
Lowering of moisture (%)	9	→ 7	18

* Simultaneously COG temp. lowered from 720 to 680 °C.

will be discussed next.

The energy flow for STD operation is shown in Fig. 4, of which the occurrence of various waste heats and their utilization are shown in Fig. 5 and Table 8.

(3) The Case of New Oven

Here, what can be done when allowed to start all anew, *i.e.*, if freed of old practices and equipment, is examined to estimate a limit. In anticipation of future coal quality, the low temperature mode of coking practice on a coal of VM 30 % and a low CUR of 80 % are assumed. Then, other operation parameters may be computed out using the formulas of Table 4.

In the FR (fuel rate), energy saving measures of (a) 50 % increase of checker area, which should bring about a 20×10^3 kcal/t-coal reduction by lowering the

waste gas temperature from 190 to 140 °C, and (b) the preheating of the charge coal to 200 °C, which produces 90×10^3 kcal/t-coal (the heat needed to do this, 110.5×10^3 kcal/t-coal, is assumed to be recoverable through an appropriate waste heat utilization apparatus), have been taken into account. This gives from the heat balance calculation an FR of 433×10^3 kcal/t-coal, a figure that is improved even over the TGT by about 25 %. On the other hand, as the CUR is lowered, the power rate (PR) is increased by 5 to become 25 kWh/t-coal. The results are shown in Table 7 together with State-of-Arts, STD, and TGT values.

Table 7. Summary of rates and parameters for coke oven.

	Present status	STD	TGT	New furnace
Gross yield (%)	75.0	75.0	75.0	73.6
Lump yield (%)	65.0	65.0	65.0	62.5
CUR (%)	120	100	100	80
Coal CV (kcal/kg)	7 700	7 700	7 700	7 700
Tar generation (kg/t)	36	36	36	44
Crude light oil (kg/t)	7.4	7.4	7.4	7.4
FR (10 ³ kcal/t)	656	576	576	433
PR (kWh/t)	20	20	20	25
Fuel gas CV (kcal/t)	1 200	1 000	1 000	1 000
COG generation (Nm ³ /t)	307	312	312	330
VM (%)	27	27	27	30
Steam (kg/t)	6.7	6.7	6.7	6.7
Compressed air (Nm ³ /t)	3.5	3.5	3.5	3.5
Water (kg/t)	497	500	—	—
Recovered steam (kg/t)	—	—	500	500

2. The Ironmaking Sector

The Ironmaking Sector, which encompasses the Raw Materials, Sintering, BF, and Hot Stove Divisions, is the greatest energy expender in the great energy consumer, the integrated steel works. Therefore, it exerts a great influence on the total energy balance, but because of the absence of generally accepted theory, analysis and determination of technical limits is rather difficult.

Thus, numerical values have been reasonably selected from experiences as shown in Table 2 and Fig. 2. In particular, the coke breeze rate (CBR) was assumed to be 45 kg/t-sinter and the FR 450 kg/t-pig (*i.e.*, FR=CR (coke rate)+OR (oil rate)=415+35) for an SPR (sinter and pellet ratio) of 80+10 % and a TR (tapping rate) of about 1.8 t/m³·day. Other parameters of operation and the materials flow are as given in Fig. 6, where the chemistries of ore, pellet, lump coke, and sinter are the actual figures averaged over the member firms, while the quantity and the

Fig. 4. Energy flow through coke oven in STD operation.

Table 8. Heats wasted from coke oven and their recovery.

Sensible heats	Temp. (°C)	CV (10 ³ kcal/t-coal)	Method of recovery and utilization
Coke	1 010	271.9	As steam or power by CDQ; Steam : 0.5 t-steam/t-coke Power : 65 kWh/t-coal
COG	680	162.5	At the dry main, though no truly recommendable method is available; a 70 % recovery will cover the heat needed for preheating of coal.
Waste gas	190	55.5	Temperature is not high enough ; at the lower limit of 140 °C, recoverable heat is no more than 150×10^3 .

Fig. 5. Recoverable exhaust heats of coke oven.

Fig. 7. Energy flow through sinter division in STD operation.

5 kg/t-sinter and in consideration of the latent heat of moisture evaporation, its effect has been estimated to be 3 kg/t-sinter. Those two bring the TGT rate to 40 kg/t-sinter.

(ii) The Ignitor COG Rate

The STD is related to those rates achieved by ignitors that are practicing pressure control and combustion control. The TGT, 16.5×10^3 kcal/t-sinter, is the value that should be attained by introducing combustion air preheating, an effect of 5×10^3 kcal/t-sinter, on top of STD.

(iii) The Power Rate

When those energy saving measures are taken, power consumption is increased by so much as needed for blowing hot gas both for sinter preheating and for combustion air preheating. This hot gas is the air carrying the heat recovered from the sinter cooler, and for an air temperature of 250 °C, warm airs of 270 Nm³/t-sinter for sinter preheating and 62.5 for combustion air preheating are needed to accomplish the economization quoted above. For a pressure loss of 900 mmAq through the waste heat recovery line, the additional blower power requirement is 2 kWh/t-sinter, which determines the TGT.

3. The STD Rates for Blast Furnace and Hot Stove

(1) Determination of Operation Parameters and Pig Composition

As mentioned earlier, there are two BF's of 5 000 m³ inner volume, tapping pig at a rate of ca. 1.8 t/m³·day at 1 530 °C. They are each equipped with a TRT (top-pressure recovery turbine) power generation plant and four hot stoves, operating in the staggar/parallel mode to produce hot blast of 1 315 °C. A dehumitizer (6 g/Nm³) and a waste heat recovery apparatus (to heat the combustion air to 200 °C) are also provided. The compositions of pig and slag have been computed out by the materials balance assuming the Fe content in the pig to be 950 kg/t-pig.

Table 10. Operation variations examined.

	Cases to be examined	Operation actions*
Oil rate (OR) decreased	OR=17 kg/t or all coke	Decrease TB
Blast temp. (TB) changed	± 10 °C	Change OR
Blast moisture (MB) increased	MB=10 or 15 g/Nm ³	Decrease OR
Sinter & pellet rate (SPR) changed	SPR=75+15 or 70+20	Constant OR
The "oil-less" operations	Injection of COG, tar, or pulverized coal	

* with the Tuyere Front Temp. (TFT) held constant at 2 463 °C

(2) Analysis of BF Operation and Operation Variations

The analysis of STD base BF operation and examination of effects due to the use of oil-alternative fuels, i.e., injection of COG, tar, or pulverized coal for no-oil (or the "oil-less") campaign have been done by conducting the equilibrium calculation for the heat preservation zone (at 1 000 °C) by means of the Rist diagram method.³⁻⁵⁾ Besides those, effects of decreasing the OR, varying the blast temperature and SPR, and increasing the moisture in the blast were considered. The variation conditions are summarized in Table 10.

Other STD's not apparently shown are the shaft efficiency of 96.7 %, utilization of in-furnace CO, the η_{CO} , 51.2 %, tuyere front temperature 2 463 °C (held constant for all the cases), BFG CV 696 kcal/Nm³ (CO₂ 22.7 %, CO 21.6 %, H₂ 1.7 %, balance N₂), top pressure 2.15 kg/cm²G, and top gas temperature 120 °C. The utilization of H₂, η_{H_2} , has been assumed to be the same as η_{CO} . The results are shown in Table 11, and the corresponding energy flow is illustrated in Fig. 8.

Table 11. Changes in the rates and parameters due to BF operation variation (STD base).

Divisions	Rates and parameters	STD	Operation actions taken										
			Oil decreased (TB decreased)		TB varied (OR varied)		MB increased (OR decreased)		SPR varied (OR constant)		“Oil-less” operation (Substitute fuel injection)		
			OR=17 kg/t-pig	All coke	TB up 10 °C	TB down 10 °C	MB=10 g/Nm³	MB=15 g/Nm³	SPR=75 +15 %	SPR=70 +20 %	COG 50.67 Nm³/t-pig	Tar 27.5 kg/ t-pig	Coal*1 55.1 kg
1	PR (kWh/t)	4	4	4	4	4	4	4	4	4	4	4	
2	CBR (kg/t-sinter)	45+3.8	45+3.8	45+3.8	45+3.8	45+3.8	45+3.8	45+3.8	45+3.8	45+3.8	45+3.8	45+3.3	45+3.8
	Igniter COG (10³ kcal/t-sinter)	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5	21.5
	PR (kWh/t-sinter)	44.0	44.0	44.0	44.0	44.0	44.0	44.0	47.2	50.9	44.0	44.0	44.0
3	FR (kg/t-pig)	450.0	460.0	472.0	449.8	450.2	450.9	452.2	452.0	455.0	458.2	453.3	457.9
	CR (kg/t-pig)	415.0	443.0	472.0	417.0	417.0	421.3	429.2	417.0	420.0	433.3	425.8	402.8
	OR <i>etc.</i> (kg/t-pig)	35.0	17.0	0	36.8	33.2	29.6	23.1	35.0	35.0	24.9	27.5	55.1
	Blast volume rate (Nm³/t-pig)	1 058	1 095	1 131	1 059	1 056	1 049	1 038	1 065	1 072	1 044	1 056	1 043
	BFG (Nm³/t-pig)	1 545	1 585	1 606	1 547	1 543	1 538	1 531	1 555	1 564	1 559	1 505	1 516
	BFG CV (kcal/Nm³)	696	682	676*2	695	696	698	701	699	701	705	686	694
	η _{CO} (%)	51.2	51.0	50.7	51.2	51.2	51.2	51.2	50.9	50.6	51.1	51.4	51.2
	Blast temp. (°C)	1 315	1 213	1 120	1 325	1 305	1 315	1 315	1 315	1 315	1 315	1 315	1 315
	Blast moisture (g/Nm³)	6	6	6	6	10	15	6	6	6	6	6	6
	TFT*3 (°C)	2 463	2 463	2 462	2 463	2 463	2 463	2 463	2 463	2 464	2 460	2 461	2 463
	Top pressure (kg/cm²)	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15
	Top gas temp. (°C)	120	120	120	120	120	120	120	120	120	120	120	120
	Slag rate (kg/t-pig)	310	314	316	310	311	311	312	300	290	310	310	310
	TRT PS (kWh/t-pig)	35.6	36.6	37.0	35.7	35.6	35.5	35.3	35.9	36.1	35.9	35.9	35.0
4	BFG rate (Nm³/t-pig)	393	460	529	387	397	389	390	396	400	386	393	389
	COG rate (Nm³/t-pig)	47	32	17	49	45	46	46	47	47	46	47	47
	M gas CV (kcal/Nm³)	1 110	938	800	1 129	1 091	1 111	1 111	1 108	1 108	1 114	1 105	1 113

*1 Pulverized coal 55.1 kg/t-pig

*2 The decrease of BFG CV is due to assumption of $\eta_{H_2} = \eta_{CO}$, which applies to other cases also.

*3 Tuyere front temperature

Division : 1 Raw materials; 2 Sinter; 3 BF; 4 Hot stove

Fig. 8.
Energy flow through blast furnace
in STD operation.

Nextly, the effects of those operation variations and the alternative fuel campaign on the total energy balance of the entire ironmaking sector, involving all the coke oven, raw materials, sintering, BF, and hot stove divisions, were computed out. Those are summarized in Table 12 (see p. 872~3) and Fig. 9. It will be seen among others that the all-coke operation will bring about an energy increase of 72×10^3 kcal/t-pig over the STD, and that a change of SPR from the STD 80+10 % to 70+20 will result in a decrease by 60×10^3 kcal/t-pig from STD, though this is due to not assigning any energy value to the pellet.

4. The TGT Rates of Blast Furnace and Hot Stove

(1) Energy Saving Measures for BF and the TGT Rates

(i) Lowering of Fuel Rate

Proper control of burden distribution is known to help improve the gas utilization. As quantitative appreciation of this effect is difficult, however, the TGT was set on an assumption that the shaft efficiency could be raised to 98 % from the STD of 96.7 %. Other TGT rates were computed out on this as shown in Table 13, where an ideal case of shaft efficiency of 100 % is also presented.

(ii) Equalizing-and-Relieving Recovery of Top Pressure

By this practice, the BFG recovery is improved by 0.6 %.

(iii) The Dry Dust Collector

The use of a dry dust collector in place of currently popular wet precipitator will entail a 600 mmAq decrease in the pressure loss to TRT and a raise of TRT inlet temperature to 110 from 50 °C. Those two combined will increase the TRT power output from 35.6 kWh/t-pig to 42.9.

(iv) Heat Recovery from BF Slag

The recovery rate has been set at 60 %. The heat recovered may be utilized either as process steam or electric power depending on the current energy situation of the works.

(2) The Hot Stove

The STD thermal efficiency of 80 % is the average of the actual experiences. Further, by taking measures to prevent localization of gas flow in the hot oven, yet another 2 % gain can be expected. This gives the TGT. The STD and the TGT rates are shown in Table 14, where the following two formulas were used to calculate the thermal efficiency, η_{HS} :

$$\eta_{HS} = \frac{\text{(Wind sensible heat)}}{\text{[(Fuel latent heat) + (Fuel sensible heat) + (Preheated air sensible heat) + (Cold wind sensible heat)]}}$$

$$\text{Dome temperature} = (0.95 \times \text{Flame temperature}) - 150\text{ }^{\circ}\text{C}$$

(3) No-oil Operation Variations for TGT Rates

To examine the current no-oil operation and future gas balance, TGT rates and figures were calculated. Those are shown in Table 15 in comparison with the STD values.

*COG $H_t = 4\,511$ kcal/Nm³
Tar $H_t = 8\,200$ kcal/kg
Pulverized coal $H_t = 7\,211$ kcal/kg (Ash 8 %)
Ironmaking total energy=Raw materials+Coke oven+Sinter+Hot stove+BF—BFG (as generated)—Power generated by TRT (excluding power for blast blower)

Fig. 9. Changes in ironmaking total energy according to variations of operation.

Table 13. Rates and parameters for BF TGT and ideal operations.

	TGT	Ideal*
Shaft efficiency (%)	98.0	100.0
FR (=CR+OR) (kg/t-pig)	446 (=411+35)	440 (=405+35)
Blast temp. (°C)	1 315	1 315
Blast moisture (g/Nm³)	6	6
Blast volume rate (Nm³/t-pig)	1 050	1 037
BFG (Nm³/t-pig)	1 518	1 511
η_{CO} (%)	52.1	53.6
BFG CV (kcal/Nm³)	685	662

* Calculated according to Rist³⁾

Table 14. Rates and parameters for STD and TGT hot stove operations.

	STD $\eta_{HS}=80\%$	TGT $\eta_{HS}=82\%$
BFG (696 kcal/Nm³) (Nm³/t)	393	382
COG (4 600 kcal/Nm³) (Nm³/t)	47	45.6
M gas (kcal/Nm³)	1 110	1 110
Heat rate (10³ kcal/t-pig)	490	475.6

3. The Steelmaking Sector

The energy consumed in the Steelmaking Sector is no more than about 4 % of the total. Seemingly this is quite small, but when the latent and sensible heats of C and Si and others that the hot metal brings in amount to an equivalent of ca. 15 %. Besides, there is the energy, ca. 6 % equivalent, that is needed to prepare the auxiliary raw materials. Therefore, in the Steelmaking Sector, the points of energy saving should be placed, aside from the obvious and straightforward

Table 12. Total energy for ironmaking.

Plants	STD	Oil injection		Blast temp.		Blast moisture		SPR
		17 kg/t	All coke	1 325 °C	1 305 °C	10 g/Nm³	15 g/Nm³	
Coke oven	368.8	402.8	442.2	364.7	369.4	375.3	385.5	369.4
Raw materials	19.1	19.1	19.1	19.1	19.1	19.1	19.1	19.1
Sintering	629.2	629.2	629.2	629.2	629.2	629.2	629.2	629.2
Blast furnace	2 248.6	2 264.7	2 300.1	2 251.9	2 246.8	2 243.0	2 235.7	2 250.8
Coke	2 988.0	3 189.6	3 398.4	2 973.6	3 002.4	3 033.4	3 089.5	3 002.4
Oil, etc.	345.1	167.6	0	362.8	327.4	291.9	227.8	345.1
BFG	−1 075.3	−1 081.0	−1 085.7	−1 075.2	−1 073.9	−1 073.5	−1 073.2	−1 086.9
TRT power	−87.3	−89.6	−90.7	−87.4	−87.2	−86.9	−86.5	−87.9
Power	73.5	73.5	73.5	73.5	73.5	73.5	73.5	73.5
Hot stove	493.6	465.1	440.3	498.3	487.3	487.0	488.9	496.9
BFG	273.5	313.7	357.6	269.0	276.3	271.5	273.4	276.8
COG	215.2	146.5	77.8	224.4	206.1	210.6	210.6	215.2
Power	4.9	4.9	4.9	4.9	4.9	4.9	4.9	4.9
Grand total	3 759.3	3 780.9	3 830.9	3 763.2	3 751.8	3 753.6	3 758.4	3 722.7

Notes: 1. Figures include the power for blower and energy for dehumidizer. 2. A 90 kWh/t-pulverized coal is

Table 15. Changes in the rates and parameters due to BF operation variation (TGT base).

Operation actions	STD	TGT	All coke		Substitute fuel injection					
			STD	TGT	COG		Tar		Pulverized coal	
					STD	TGT	STD	TGT	STD	TGT
Shaft efficiency (%)	96.7	98.0	96.7	98.0	96.7	98.0	96.7	98.0	96.7	98.0
Hot stove efficiency (%)	80.0	82.0	80.0	82.0	80.0	82.0	80.0	82.0	80.0	82.0
Fuel rate (kg/t-pig)	450.0	446.0	472.0	468.2	458.2	454.0	453.3	449.4	457.9	454.0
Coke rate (kg/t-pig)	415.0	411.0	472.0	468.2	433.3	429.1	425.8	421.9	402.8	399.4
Oil (etc.) rate (kg/t-pig)	35.0	35.0	0	0	24.9	24.9	27.5	27.5	55.1	54.6
Blast volume rate (Nm³/t-pig)	1 058	1 050	1 131	1 121	1 044	1 036	1 056	1 047	1 043	1 035
BFG (Nm³/t-pig)	1 545	1 518	1 606	1 591	1 559	1 545	1 505	1 499	1 516	1 503
BFG CV (kcal/Nm³)	696	685	676*	661*	705	693	686	671	694	677
η_{CO} (%)	51.2	52.1	50.7	51.6	51.1	52.0	51.4	52.4	51.2	52.8
Blast temp. (°C)	1 315	1 315	1 120	1 120	1 315	1 315	1 315	1 315	1 315	1 315
Blast moisture (g/Nm³)	6	6	6	6	6	6	6	6	6	6
Tuyere front temp. (°C)	2 463	2 463	2 462	2 462	2 460	2 450	2 461	2 460	2 463	2 463
Top pressure (kg/cm²)	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15
Top gas temp. (°C)	120	120	120	120	120	120	120	120	120	120
Slag rate (kg/t-pig)	310	310	316	313	310	310	310	310	310	310
TRT power (kWh/t-pig)	35.6	42.7	37.0	44.8	35.9	43.5	34.9	42.2	35.0	42.3
BFG rate (Nm³/t-pig)	393	375	529	499	386	366	393	371	389	364
COG rate (Nm³/t-pig)	47.0	46.7	17.0	19.8	46.0	46.0	47.0	48.1	47.0	47.4
M gas CV (kcal/Nm³)	1 110	1 116	800	811	1 114	1 129	1 105	1 122	1 113	1 129

* The decrease of BFG CV is due to the assumption of $\eta_{H_2} = \eta_{CO}$, which applies to other cases also.

cutting down on the direct energy consumption, on how to reduce the auxiliary materials requirement as well as how to efficiently recover the waste energy of converter refining process and the sensible heats of the products.

1. The STD and TGT Rates

The entire rate system of the Steelmaking Sector is examined by five divisions of Lime Calcination, BOF, Ingotmaking, Degassing, Continuous Casting (CC) of Slabs and Blooms, and Grooming* of Continuously

* *Seisei*, or to finely prepare. “Grooming” is here proposed for conventional “finishing”, for, born out of the QC (quality control) movement, this word denotes activities that are more comprehensive than mere finishing. For example, in the CC grooming line, mechanical and metallographic tests are conducted often as a matter of course.

Unit : 10³ kcal/t-pig

varied	Substitute fuel injection		
	COG	Tar	Pulverized coal
70+20 %			
373.5	390.6	381.2	352.6
19.1	19.1	19.1	19.1
629.2	629.2	629.2	629.2
2 262.4	2 242.7	2 252.0	2 254.5
3 024.0	3 119.8	3 065.8	2 900.2
345.1	232.0	225.5	401.0
-1 096.4	-1 099.1	-1 032.4	-1 051.3
-88.4	-88.1	-85.0	-85.7
73.5	73.5	73.5	73.5
500.5	487.6	489.7	490.2
280.4	272.1	269.6	270.0
215.2	210.6	215.2	215.3
4.9	4.9	4.9	4.9
3 699.7	3 769.2	3 771.2	3 745.4

included in the Pulverized coal injection.

Cast Slabs and Blooms. The STD and the TGT rates of those divisions are shown in Table 16 together with the energy saving measures adopted.

The lime calcination furnace is the rotary kiln, which is the most popular among the member firms, whose FR is given as 963×10³ kcal/t-CaO from the actual achievements. As this figure is close enough to the theoretical value of 800 kcal for the CaCO₃ → CaO+CO₂ reaction, the TGT is equated to the STD.

The BOF is of the top blowing type with its OG (off gas) energy to be recovered by a boiler. From the STD oxygen rate of 45 Nm³/t, 1.5 Nm³/t is expected to be curtailed by adding more iron ore. This should become possible by preventing the drop of hot metal temperature by 50 °C (from 180 to 130 °C for the charging temperature of 1 350 °C). Another 0.5 Nm³/t should be taken out by making the blow pattern even more appropriate. Thus, the TGT is set at 43 Nm³/t.

The STD PR is 24 kWh/t, from which 3.5 kWh/t should be curtailable by practicing the revolution control on both the induced draft fan and the dust collector blower, and another 0.5 kWh/t by intensifying the saving of power for cooling water pumps and general illumination.

The STD for LDG recovery is 100 Nm³/t (an ef-

Table 16. The STD and the TGT rates for steelmaking sector.

Plants		Rates	STD	TGT	Energy saving measures	Notes
Lime calcination		COG (Nm ³ /t-CaO)	210	210		Rotary kiln
		Power (kWh/t-CaO)	40	40		
BOF and ironmaking		Oxygen (Nm ³ /t)	45	43	Prevention of cooling of hot metal; improvement of blow pattern	Top blowing with OG recovery and equipped with waste heat recovery boiler.
		Power (kWh/t)	24	20	Control of blower revolution speed]	
					Power saving by pump operation	
		Nitrogen (Nm ³ /t)	12	10	Better management of sealing N gas	
		COG (Nm ³ /t)	3.3	3.3	Equipment of recuperator; rationalization of charging pattern	
		LDG recovery (Nm ³ /t)	100	104	Control of furnace pressure; equipment of fast gas analyzer	
Degassing		Steam recovery (kg/t)		60	Waste heat recovered to gas temp. of 400 °C	RH method; 25 % of the crude steel is to be degassed.
		Steam (kg/t)	35	28	Enlargement of nozzle; rationalization of steam usage pattern	
		Power (kWh/t)	1.2	1.0	Rationalization of cooling pump usage	
		COG (Nm ³ /t)			Intensification of control over drying and warming	
CC	Slab	Power (kWh/t)	5	4	Intensification of pump control	Slab CCR 75 %
		COG (Nm ³ /t)	1.0	0.5	Rationalization of tundish heating pattern	
	Bloom	Power (kWh/t)	5	4	Power saving at pumps by going to CCC	Bloom CCR 50 %
		COG (Nm ³ /t)	1.0	0.5	Rationalization of tundish heating pattern; improvement of insulation	
CC grooming	Slab	Power (kWh/t)	6	4	Improvement of surface quality of the product slabs and blooms	40 % of slabs and 70 % of blooms are to be HCR'd.
		Oxygen (Nm ³ /t)	4	2		
		COG (Nm ³ /t)	0.8	0.5		
	Bloom	Power (kWh/t)	2	1.3		
		Oxygen (Nm ³ /t)	1.5	1.0		
		COG (Nm ³ /t)	0.3	0.2		

fective CO recovery of 78 %) at hot metal rate (HMR) of 92 %. This should be able to improve to an effective CO recovery of 83 % or 104 Nm³/t by improving the precision of the gas analyzer and of furnace pressure control. This gives the TGT, in which the heat of LDG is recovered to a gas temperature of 400 °C by the OG boiler to generate process steam at 60 kg/t.

One quarter of the steel is to be treated in the degassing furnace of RH type. The STD steam rate of 35 kg/t will be reduced by 7 by shortening the processing time, by selecting the immersion nozzle properly, and by correcting the process pattern.

In the CC (slabs and blooms), intensification of coolant pump control and increased productivity by resorting to CCC (continuous continuous casting) are taken into account.

In the CC Grooming, 40 % of the slabs and 70 % of the blooms are to be hot charged. Because of this, as well as of improved surface quality, the slab cooler, the cold scarfers, and such, those equipment that are crowding the grooming line, are dispensed with.

The STD energy flow is shown in Fig. 10. The temperature drop from tapping to degassing or casting, which runs up to as much as 50 to 60 °C, can be cut down by 15 °C by providing a cover to the ladle. This means that the end point of blowing may be lowered by that much, the dephosphorization efficiency increased, quantity of lime reduced, quantity of slag decreased, yield improved, quantity of deoxidizer reduced, and, as a consequence, as much as 10 to 12×10³ kcal/t-crude steel may readily be saved. Besides, pretreatment of molten pig and the combined, or the top-and-bottom, blowing practice for BOF, the two technologies that are spreading rapidly, will result in a decrease of O₂ by improving the decarburization efficiency, decrease of Al due to decreased dissolved O, general improvement of yield, and increase in LDG recovery, all of which will in turn bring about further energy saving of 20 to 30×10³ kcal/t.

2. Variation in the CC Ratio

A case of CCR (continuous casting ratio) of 80 %, an intensification by 10 % over the STD to be directed to slabmaking, is examined to see how much energy can be saved by improving the yield. The result is shown in Table 17, where it will be seen that a 10 % increase in CCR is equivalent to 14.9×10³ kcal/t-slab.

Fig. 10. Energy flow through BOF in STD operation.

Nextly, for a given gross quantity of rolled products, the quantities of necessary molten pig with or without purchased scrap (*i.e.*, the in-house return scrap only) are calculated. Here, the yields across any two processes are assumed to remain unaffected, and the in-house return scrap is computed by (molten steel—products)×0.807. The materials flow is shown in Table 18. It will be seen that no purchased scrap promises an improved yield and resultant substantial decrease of needed molten pig, and that this decrease in pig is equivalent to energy saving of *ca.* 10×10³ kcal/t-crude steel.

4. The Ingotmaking Sector

At the time of data compilation for this study,¹⁾ the ingotmaking was undergoing a great change from the old practice under the impacts of rapid increase of CCR, spreading of hot direct rolling (HDR), popularization of CC bloom reheating furnace, improvements in heating pattern of soaking pit, *etc.* Therefore, the actual achievements of member firms were not on the same level, particularly in the steel mix, production, and track time at the steelmaking sector, so that various rates, especially the FR, differed greatly. Thus, the entire Ingotmaking Sector has been divided into three divisions of the IC (ingot cast) Slab, the IC Billet, and the CC Bloom (bloom to billet), as shown in Fig. 11, and then the steel mix has been determined reasonably though rather arbitrarily.

Table 17. Energy saving due to intensification of CC.

		(A) CCR = 70 %	(B) CCR = 80 %
Production	CC (kt-slab/month)	333.0	382.0
	Ingot (kt-slab/month)	103.0	54.0
CC	Heat (10 ³ kcal/t-slab)	8.6	8.4
	Power (kWh/t-slab)	11	10
	Total (10 ³ kcal/t-slab)	35.6	32.9
Bloom	Heat (10 ³ kcal/t-slab)	66	66
	Power (kWh/t-slab)	34	37
	Steam (kg/t-slab)	7.0	7.7
	Total (10 ³ kcal/t-slab)	154.9	162.9
Grand total: (10 ³ kcal/t-slab)		63.9	49.0
Difference, B—A: (10 ³ kcal/t-slab)		—14.9

Fig. 11. Production and steel mix of ingotmaking sector.

Table 18. Changes in the materials flow due to changes in the HMR. (unit kg/month)

CCR=70% STD			CCR=80% No purchased scrap			CCR=80% With purchased scrap		
Hot metal 529		Scrap steel 46	Hot metal 527.6		Scrap steel 40.5	Hot metal 522.1		Scrap steel 46
Yield 95.4%			Yield 95.4%			Yield 95.4%		
Molten steel 549			Molten steel 542			Molten steel 542		
CC slab 343	Ingot 165	CC billet 41	CC Slab 393	Ingot 108	CC billet 41	CC slab 393	Ingot 108	CC billet 41
97.1%	97.2%	97.1%	97.1%	97.2%	97.1%	97.1%	97.2%	97.1%
Ingot 160			Ingot 105			Ingot 105		
116	44		61	44		61	44	
88.7%	88.7%		88.7%	88.7%		88.7%	88.7%	
333	103	39	382	54	39	382	54	39
Slab	Billet	Bloom	Slab	Billet	Bloom	Slab	Billet	Bloom
Hot metal decreased by :			1.4kt/month			6.9kt/month		
HMR (%) : 92.0			92.9			91.8		

1. The STD and the TGT Rates for IC Slab and IC Billet Divisions

The soaking pit is of a capacity of 250 t/ch, of the top firing type, burning a mixed byproduct gas (M gas) of 2 500 kcal/Nm³ with air preheated to 450 °C. The FR was considered individually by hot ingot and cold ingot, both of the rimmed steel or the killed steel. The STD is related to those actual achievements of the category of “very good”, while the TGT is based on the “best achieved” with further energy saving taken into account. Those values for slab soaking pit are shown in Table 19, and the energy flow in Fig. 12. The PRs have been computed by the following formulas from the production rates:

STD

TGT

Slab; $y = -0.084x + 43,$ $y = -0.084x + 35$

Billet; $y = -0.2x + 69.5,$ $y = -0.2x + 60.0$

where, y : the PR in kWh/t
 x : the production rate in kt/month.

Those rates are all summarized in Table 20, where various rates other than FR and PR are the average of actual achievements both for STD and for TGT.

2. The STD and the TGT Rates for CC Bloom Division

The heating of the CC blooms for reducing to billets is being done either in reheating furnace or in soaking pit, of which the latter is generally thought as more advantageous by its better FR. Nevertheless, the reheating furnace is considered here because of its greater flexibility for adopting energy saving measures and of the large production rate (kt/month) required. Thus, a continuous reheating furnace of 100 t/h capacity has been selected. The fuel is an M gas of 2 500

Table 19. Operation parameters, TGT rates, and energy saving measures for slabmaking soaking pit.

		Rimmed, semi- killed	Killed	Cold ingot
Ingot charging temp. (°C)		1 235	940	room
Ingot extraction temp. (°C)		1 250	1 250	1 300
Combustion air preheated to (°C)		450	450	450
Furnace body insulation sealing		Yes	Yes	Yes
No or almost-none heating ratio (%)		20	—	—
Ditto rate (10³ kcal/t)		6	—	—
Intermittent combustion ratio (%)		57.4	—	—
Ditto rate (10³ kcal/t)		28	—	—
Direct rolling ratio (%)		22.6	—	—
Ditto rate (10³ kcal/t)		50	—	—
Best actual record (10³ kcal/t)*		29	115	410
Energy saving measures	Charge ingot higher	—	50 °C up — 16.4 %	350 °C — 23.2 %
	Raise air preheating temp. (450 °C → 600 °C)	— 7.9 %	— 7.9 %	— 7.9 %
	Preheat the M gas to 400 °C	— 7.4 %	— 7.4 %	— 7.4 %
TGT fuel rate (10³ kcal/t)*		25	82	270

* Ton-heated ingots

kcal/Nm³, the combustion air is to be preheated to 400 °C, and all the blooms are to be hot charged at 500 °C.

The STD rate was determined by taking the usual energy saving measures into account over the average actual achievements, from which the TGT rate was derived by assuming practicing of future measures. Those are shown in Table 21. Here, the STD PR,

Fig. 12. Energy flow through slabmaking reheating furnace in TGT operation.

34 kWh/t, is the actual results averaged, while the TGT 29 kWh/t, some 16 % less, is when the combustion blower revolution control and power saving at the mill table drive motors are practiced. The utilities like steam and hot scarfer fuel have been set as shown in Table 20. The energy flow at the bloom heating furnace for TGT operation is shown in Fig. 13.

5. The Rolling Sector

The major energies being consumed in the Rolling Sector are the fuels for reheating furnaces, heat treatment furnaces, and annealing furnaces, and the electric power for rolling mills. The FR for the continuous reheating furnace was computed out by taking the heat balance on actual achievements considering the radiation loss from furnace body, loss due to cooling water, and the quantity of scale. To accomplish better heat economy, the reheating furnace may be either the extended hearth type or the recurrent waste heat recovery type. Of the two the latter was adopted because it is better adaptable to

Table 20. Energy rates for slab and billet plants.

		Slabs		Billets			
		STD	TGT	STD		TGT	
				Bars	Pipes	Bars	Pipes
Fuel rates	Rimmed (10^3 kcal/t-heated ingot)	40 (84)	25	114(119)	—	44	—
	Killed (10^3 kcal/t-heated ingot)	115(224)	82	189(218)	224	100	155
	Cold ingot (10^3 kcal/t-heated ingot)	399(418)	270	441(523)	453	285	340
	Total (10^3 kcal/t-heated ingot)	55	37	157	240	76	168
Power rate (kWh/t-slab)		34	26	62		52	
Other rates	Hot scarfer fuel (10^3 kcal/t-slab)	4	4	1		1	
	Steam (kg/t-slab)	7	7	12		12	
	Oxygen (Nm^3 /t-slab)	5	5	4		4	
	Compressed air (Nm^3 /t-slab)	13	13	25		25	
	Water (m^3 /t-slab)	12	12	9		9	

Note: Parenthesized figures are averages of N=8 for slabs and N=4 for billets.

Table 21. Energy saving measures and TGT rates for bloom-making reheating furnace.

	Energy saving measures	Reduction (%)	Fuel rate (10^3 kcal/t-heated ingot)	Notes
Present			300	All the ingots to be HC'ed at 500 °C
	Charging temp. raised by 200 °C	20		Improved burner, more stringent use of O_2 , and others Raise the air preheating temp. from 400 to 600 °C
	Improved combustion and strengthened insulation	3.4		
	Light load operation	8.0		
	Better use of recuperator	9.0		
	Improved heat pattern on DDC	10.0		
STD	Sum total of above measures	41.7	175	To a gas temp. of 350 °C
	Improved furnace profile	1.7		
	Preheating of M gas	5.9		
TGT	Sum total of above measures	7.5	162	

Table 22. Heat balance at the hot rolling reheating furnace.

		Cold slab		Hot charging	
		STD im- proved heat recovery	TGT low temp. extrac- tion	STD	TGT low temp. extrac- tion
Waste heat recovery (%)		65	65	65	65
Exhaust gas temp. at recu- perator inlet (°C)		671	652	616	607
Combustion air preheated to (°C)		610	592	557	548
Fuel gas preheated to (°C)		257	251	235	231
Exhaust gas temp. at recu- perator outlet (°C)		237	231	218	215
Slab charging temp. (°C)		30	30	450	550
Slab extraction temp. (°C)		1 200	1 170	1 200	1 170
Heat balance table (10 ³ kcal/t)					
Input	Fuel combustion heat	261	253	195	169
	Recovered heat	65	61	44	38
	Charged slab sensible heat	3	3	57	73
	Total	321	317	296	280
Output	Extracted slab sensible heat	196	190	196	191
	Exhaust gas sensible heat	100	94	68	58
	Radiation from furnace body	10	9	9	9
	Cooling water loss	23	24	23	22
	Total	321	317	296	280

Fig. 13. Energy flow through bloomer reheating furnace in TGT operation.

the hot charge rolling (HCR), whereas the furnace efficiency and the heat recovery rate are the same for both at *ca.* 70 % and *ca.* 62 %, respectively, when examined on the basis of charging cold, extracting at 1 250 °C, a stack of 150 m high, and a draft of 50 mmAq. The STDs were determined on the basis of actual achievements, while the TGTs are for low temperature extraction practice that necessitates an increase in the PR with other utilities held unchanged.

1. The STD and the TGT Rates for the Rolling Sector
(1) The Hot Strip Mill Plant

The reheating furnace for the hot rolling line is of the walking beam type continuous furnace with a length of 45 m, width 10.5 m, capacity 300 t/h, and handling slabs of an average thickness 230 mm and average weight 17.2 t. The STD is set, as seen in Table 2, for a charging temperature of 450 °C, an HCR ratio of 19 %, an HDR rate of 20 kt/month, or 6 %, and a waste heat recovery of 65 %, whereas the TGT is for a higher charging temperature of 550 °C, a higher HCR ratio of 40 %, though no HDR, where 89×10³ kcal/t is assumed for HDR as the holding FR*, and 10×10³ kcal/t for HCR as the warming FR⁺⁴. Those rates and the heat balance are given in Tables 22 and 23 for cold charging and hot charging. It will be noted that the PR for TGT is up 2 kWh/t because the extraction temperature is lowered from 1 200 °C by 30 °C.

(2) The Plate Mill Plant

The continuous reheating furnace is of the walking beam type, 35 m long, 8 m wide, handling slabs of a mean thickness 230 mm and a mean weight 9 t at a rate of 150 t/h. The STD operation is a charging at 450 °C, an HCR ratio of 30 %, extraction at 1 200 °C, waste heat recovery of 65 % (preheating the combustion air to 600 °C and the fuel gas to 230 °C), while that for TGT is for charging at 550 °C, HCR ratio

40 %, extraction lowered by 30 °C (necessarily raising the PR by 2 kWh/t), and the same recovery rate, where the FRs are those that were computed out on the heat balance. Those are shown in Table 23.

As for the batch furnace, on the other hand, both the STD and the TGT rates are those that are estimated from representative values by taking such measures as lowering of the air-to-fuel ratio, intensification of waste heat recovery from 30 to 50 %, reduction of the furnace body radiation loss by 60 % with improved insulation. Those are presented in Tables 23 and 24.

The heat treating furnace is a 90 m long non-oxidizing type that handles plates of 18 mm mean thickness. Figure 14 shows the relationship between heat treating time and plate thickness as a side information. The rates are the same for STD and for TGT on the basis of popular energy saving measures of low air-to-fuel ratio, improved furnace body insulation, improved heat recovery (*e.g.*, the preheating temperature of combustion air is raised up by 150 to 400 °C for quenching and normalization, and up 100 to 280 °C

* In the modern hot rolling plants, three different methods of HCC (Hot Strip Mill Cold Charging), HCR (Hot Charge Rolling) and HDR (Hot Direct Rolling), each comprising a convenient batch, are practiced. For HCC and HCR, the reheating furnace is kept at a standard operation temperature of, say, 1 300 °C. During practicing HDR, when the reheating furnace line is entirely skipped, however, the furnace is held at a lower temperature of, say, 900 °C, which is determined in consideration of fuel economy, the speed of warming up to receive the next HCC and HCR batches, thermal fatigue of refractories, *etc.*. The fuel rate to keep the furnace in readiness at the low temperature is here termed the “holding FR”, while that for warming the furnace again to the operation temperature is here called the “warming FR”.

Table 23. STD and TGT rates for rolling sector.

		STD slabs handled (kt/month)	TGT rates (10 ³ kcal/t or kWh/t)	STD slabs handled (kt/month)	TGT rates (10 ³ kcal/t or kWh/t)
Hot strips	Fuel (Sum)	316	248	316	216
	Cold slab charging	(75 %) 236	261	(60 %) 190	253
	HCR	(19 %) 60	195	(40 %) 126	169
	HDR	(6 %) 20	89*	0	0
	Holding and warming	316	10	316	10
	Power	313	80	313	82
Plates	Fuel (Sum)	120	273	120	253
	Continuous cold charging	(70 %) 77	280	(60 %) 72	272
	Continuous HCR	(30 %) 36	219	(40 %) 48	196
	Batch furnace	7	299	7	299
	Holding and warming	120	10	120	10
	Power	115	90	115	92
Bars	Fuel (Sum)	38	219	38	183
	Cold slab charging	(50 %) 19	227	(30 %) 11	221
	HCR	(50 %) 19	191	(70 %) 27	153
	Holding and warming	38	10	38	10
	Power	36	80	36	82

* Holding only

Table 24. Heat balance at the batch furnace.

		Present*	STD (= TGT)**
Air-to-fuel ratio		1.2	1.1
Waste heat recovery (%)		30	50
Effect of improved insulation (%)		0	60
Furnace body radiation loss (10 ³ kcal/t)		1 010	404
Heat contained in furnace body (10 ³ kcal/t)		3 212	1 285
Heat balance table (10 ³ kcal/t)			
Input	Fuel combustion heat	433	299
	Recovered heat	62	67
	Charged slab sensible heat	3	3
	Total	498	369
Output	Extracted slab sensible heat	195	195
	Exhaust gas sensible heat	209	136
	Radiation from furnace body	22	9
	Heat contained in furnace body	72	29
	Total	498	366

* Average of several representative furnaces.

** Energy saving measures of lowered air-to-fuel ratio, intensified waste heat recovery, and improved furnace insulation have been presumed.

for tempering), and improved seal for preventing the escape of N₂. Those are summarized in Table 25. The PR is set at 155 kWh/t for quench-and-tempering, and 27.5 kWh/t for normalization.

(3) The Bar Mill Plant

The reheating furnace is of the walking hearth type, 35 m long, 10 m wide, and a capacity of 120 t/h. The billets are 140 mm square and 1.3 t. The STD operation is hot charging at 300 °C, HCR ratio 50 %,

Fig. 14. Relation between plate thickness and heat treatment time.

extraction at 1 170 °C, and heat recovery 65 %, whereas the TGT is hot charging high at 500 °C, greater HCR ratio of 70 %, and extracting low at 1 140 °C.

The FR was computed out from the heat balance, and, as may be seen in Table 23, it is even lower than the cases of hot rolling and plate rolling because of the low extraction temperature and thanks to the walking hearth which suffers no cooling water loss. The notion for holding and warming heats and the increased PR on lowered extraction temperature is the same as for the previous two cases.

(4) The Seamless Pipe Mill Plant

The rates, both STD and TGT, are the representative actual results for medium diameter pipes. The continuous reheating furnace for seamless pipe billets is of an FR of 275×10³ kcal/t, the rolling PR is 120 kWh/t, the FR for heat treatment is 350×10³

Table 25. Heat balance at the plate heat treating furnace.

		Quenching or normalization		Tempering	
		Present	STD (=TGT)	Present	STD (=TGT)
Air-to-fuel ratio		1.25	1.15	1.25	1.15
Combustion air heated to (°C)		250	400	180	280
Radiation from furnace body (10 ³ kcal/h)		1 275	953	654	491
Nitrogen rate (Nm ³ /t)		110	60	110	60
Heat balance table (10 ³ kcal/t)					
Input	Fuel combustion heat	400	312	216	176
	Preheated air sensible heat	30	37	11	14
	Charged slab sensible heat	3	3	3	3
	Total	433	352	230	193
Output	Extracted slab sensible heat	145	145	92	92
	Exhaust gas sensible heat	212	153	78	59
	Nitrogen sensible heat	32	17	23	12
	Radiation from furnace body	44	34	34	27
	Total	433	352	230	193

kcal/t, and the PR is 27.5 kWh/t.

(5) The Cold Rolling Plant

The practical results achieved by the individual lines of the member firms have been adopted both for the STD and for the TGT. Those are shown in Table 26.

(6) Summary

The Table 27 gives an overall summation of STD and TGT rates by individual production lines through those five plants. It will be seen that the per product tonnage overall energy rate is 775.9×10^3 kcal/t for STD, which can be improved further by 23.1×10^3 kcal/t to 752.8×10^3 kcal/t, which is the TGT.

In this table, some numerical discrepancies may be noted against Tables 22 to 26. Those are due to the adoption of different denominators for the same numerator; for example, for the pickling line, the denominator is the tonnage of coils with scale still adhered onto in Table 26 (a PR of 6.5 kWh/t), whereas in Table 27 it is that of descaled coils (6.7 kWh/t). Those two are equated by the pickling yield of 97 % in such a way as $6.5/0.97=6.7$.

2. Operational Variations for Rolling Sector

Effects of practicing (a) lowering of extraction temperature, (b) raising of the hot charging temperature, and (c) increasing of the HCR ratio on the total energy are examined for the hot rolling, the plate rolling, and the bar rolling plants. The results are summarized in Fig. 15, where it will be noticed that the effect of those three measures taken integrally is great-

Table 26. STD (=TGT) rates for cold rolling plants.

	Pickling	Cold rolling	C.A.L.	E.C.L.	Batch annealing	C.G.L.	Temper rolling	E.T.L.
Fuel (10 ³ kcal/t)	—	—	169	—	175	230	—	—
Power (kWh/t)	6.5	63	45	10	20	69	10	140
Steam (kg/t)	30	—	90	30	—	70	—	120

Fig. 15. Effects of operation variations of rolling sector.

Table 27. The STD and the TGT rates for the rolling sector.

	Production (kt/month)	Fuel (10 ³ kcal/t)	Power (kWh/t)	Steam (kg/t)	Water (m ³ /t)	Air (m ³ /t)
Hot rolling	313	250 (218)*	80.8 (82.9)*	7.1	25.2	15.1
Pickling	192	—	6.7	31	3	—
Cold rolling	166	—	63.8	—	25	20
Cleaning	75	—	10	30	—	—
Annealing, batch	75	175	20	—	—	—
Annealing, continuous	42	169	45	90	—	—
Tempering	117	—	10	—	—	—
E.T.L.	16	—	140	120	—	—
C.G.L.	49	230	67	70	—	—
Plate	115	285 (264)*	93.9 (96.1)*	10.4	20.9	20.9
Plate, Q-and-T'ed	4.8	509	155	—	—	—
Plate, normalized	7.2	333	21.5	—	—	—
Bars	36	231 (193)*	84.4 (86.7)*	21.1	31.7	21.1
Pipes	36	305.5	133.3	—	33.3	22.2
Pipes, heat treated	28	350	27.5	—	—	—
STD	Sum	358.7	139.1	43.7	35.3	24.4
	CV (10 ³ kcal/t-product)	358.7	340.8	35.0	35.3	6.1
	Gross energy rate=775.9×10 ³ kcal/t-product					
TGT	Sum	330.6	141.0	43.7	35.3	24.4
	CV (10 ³ kcal/t-product)	330.6	345.8	35.0	35.3	6.1
	Gross energy rate=752.8×10 ³ kcal/t-product					

* Parenthesized figures are TGT values.

Table 28. Yields and energy rates through steelmaking and rolling processes.

		Continuous casting		Ingotmaking		
		Cold charging	HCR	Cold charging	HDR	HCR
Charging temp. (°C)		Room temp.	550	Room temp.	—	850
Yield (%)	Continuous casting	98.00	98.00	—	—	—
	Ingotmaking	—	—	92.00	91.00	92.00
	Hot rolling	97.15	97.25	97.15	97.75	97.25
	Overall	95.21	95.31	89.38	88.98	89.47
Energy rate (10 ³ kcal/t)	Continuous casting	37.0	37.0	—	—	—
	Ingotmaking	—	—	159.6	182.7	159.6
	Hot rolling	502.8	416.4	502.8	331.9	386.1
	Total	539.8	453.4	662.4	514.6	545.7

er than the simple summation of the three. In the calculation, the rates for steam, water and compressed air were always the STD values.

3. Operation Variations Bridging Steelmaking and Rolling Sectors

The operation bridging the Steelmaking and the Rolling Sectors is diversifying because of increasing CCR and enlargement of HCR and HDR portions. For this, five variations were considered in order to compare the resultant rates and gross yield under the following presumptions.

(1) The steel is rimmed, whose ingot yield is as given by the report of the Ingotmaking Research Group, the Joint Research Society.⁶⁾

(2) The decrease of ingot yield when HDR'ed, increase of hot rolling yield, and increase of hot rolling yield when HCR'ed are all as given by the report of the Hot Strip Research Group, the Joint Research Society.⁷⁾

(3) The ingotmaking FR is 32×10³ kcal/t for ordinary rimmed steels and 50×10³ kcal/t for the HDR stocks.

(4) The CC grooming is excluded from the discussion.

(5) The reheating furnace FR when hot charging at 850 °C for HCR is 140×10³ kcal/t.

The result is as shown in Table 28. It will be seen that the difference in the yield between the best, the

case of CC stock HCR'ed, and the worst, that of cold ingot, is 5.93 %, where the energy rate difference is as much as 209×10^3 kcal/t. Between the two practices in the CC to hot rolling, the 550 °C hot charging marks 86.4×10^3 kcal/t less than the cold charging. These observations show how great the effects of CC, HCR, and HDR are for yield and energy saving.

IV. Energy Balance of the Model Steel Works

The total energy balance through the entire Model Steel Works is calculated on the basis of the operating conditions of Chapter II and the energy saving measures and the variations discussed in Chapter III for both the STD and the TGT as shown in Table 29. The presumptions involved are:

(1) The CVs of various fuels and utilities are as given by Table 30.

(2) Distribution of fuel gases, though should be done by considering furnace efficiencies, gas balance, layout of the consuming apparatuses, etc. as a grand system, are unequivocally set as follows: M gases, each of an appropriate CV, for the coke oven and the hot stove; an M gas of 2 500 kcal/Nm³ for the soaking pit, reheating furnace and lime calcinator kiln; and COG for furnaces other than those and including the heat treating furnaces (Table 31).

(3) As the demand on the power and utility is so much dependent on the local circumstances that surround the steel works, no detailed restrictions were imposed on the equipment, but only the following specifications are set for calculations:

(i) Power Generation

The power boilers are all to burn the byproduct gas that is left after distributed to other equipment,

Table 29. Summary of major STD and TGT rates.

	STD	TGT
Coke oven	Coking FR= 576×10^3 kcal/t-coal	Provision of CDQ for power and/or steam generation
Sintering	Breeze rate=45 kg/t Power rate=44 kWh/t (including power for desulfurization plant)	Practice of combustion air preheating, preheated sintering, and steam generation by utilizing the cooler exhaust gas
BF	FR=450 kg/t (CR=415, OR=35) Hot stove FR= 490×10^3 kcal/t with combustion air preheated by waste gas TRT Dehumitizer	FR=446 kg/t (CR=411, OR=35) Hot stove FR= 476×10^3 kcal/t with combustion air preheated by waste gas TRT Dehumitizer Top pressure equalizing/relieving recovery Top gas dry dust collector Recovery of slag sensible heat
BOF & CC	LDG recovery rate=100 Nm ³ /t (HMR=92 %) CCR=70 %	LDG recovery rate=104 Nm ³ /t OG heat recovery by steam generation
Ingotmaking	Slab, rimmed 40×10^3 kcal/t-ingot Slab, killed 115 " Billet, rimmed 114 " Billet, killed 215 " (for bars and pipes)	Slab, rimmed 25×10^3 kcal/t-ingot Slab, killed 82 " Billet, rimmed 44 " Billet, killed 141 " (for bars and pipes)
Hot strip	FR= 248×10^3 kcal/t-slab PR=80 kWh/t-slab HDR=6 % ; HCR=19 % Fuel gas preheated	FR= 216×10^3 kcal/t-slab PR=82 kWh/t-slab HCR=40 % Fuel preheating temp. up by 100 to 550 °C Extraction temp. down by 30 to 1 170 °C
Plate	FR= 273×10^3 kcal/t-slab PR=90 kWh/t-slab HCR=30 % Fuel gas preheated	FR= 253×10^3 kcal/t-slab PR=92 kWh/t-slab HCR=40 % Fuel preheating temp. up by 100 to 550 °C Extraction temp. down by 30 to 1 170 °C
Bar	FR= 219×10^3 kcal/t-billet PR=80 kWh/t-billet HCR=50 % Fuel gas preheated	FR= 183×10^3 kcal/t-billet PR=82 kWh/t-billet HCR=70 % Fuel preheating temp. up by 200 to 500 °C Extraction temp. down by 30 to 1 140 °C

Table 30. Energy/calory conversion table.

	Calorific value rate
Coking coal	7 700 kcal/kg
Coal for BF injection	7 250 kcal/kg
Coke	7 200 kcal/kg
Tar	8 650 kcal/kg
Oil for BF injection	9 200 kcal/l
Crude light oil	9 720 kcal/kg
COG (STD base)	4 579 kcal/Nm ³
BFG (STD base)	696 kcal/Nm ³
LDG (STD base)	2 000 kcal/Nm ³
Oxygen (STD base)*	1 715 kcal/Nm ³
Steam**	800 kcal/Nm ³
Power (STD base)	2 450 kcal/kWh

* =0.7 kWh/Nm³×2 450 kcal/kWh
** 10 ata, 200 °C, with a boiler efficiency $\eta_B=85\%$

Table 31. Distribution of byproduct gases.

Apparatus	Gases used	CV (kcal/Nm ³)
Coke oven	BFG+COG	1 000
BF hot stove	BFG+COG	1 110
Soaking furnace Continuous heating furnace Batch heating furnace Lime calcination kiln	BFG+COG	2 500
Heat treatment furnaces* Sinter igniter furnace BOF and CC Chemical processes, BF runners, etc.	COG	4 579**
Power boilers	The rest of BFG and COG and the whole of LDG	

* For plates and cold rolled products, ** STD base

Table 32. Waste heat recovery apparatuses for TGT.

	Apparatus specifications	Steam generation and conditions
CDQ coke sensible heat recovery	Coke production : 254 kt/month Coke temps. ; charged at : 1 050 °C discharged at : 200 °C	Steam generation : 154 t/h Steam conditions : 100 ata, 540 °C Power generation : 38.8 MW (transformer end) Net power generation rate : 103 kWh/t-coke or 77 kWh/t-coal
Sinter cooler heat recovery	Exhaust gas : 9 100 Nm ³ /min or 500 Nm ³ /t-sinter (each stack) Heat recovery applied to the No. 1 stack only ; gas temp. : 260 °C, and of the 9 100 Nm ³ a) 1 000 Nm ³ /min for combustion air preheating, b) 4 300 Nm ³ /min for preheated sintering, and c) 3 800 Nm ³ /min for steam generation	Steam generation : 16.9 t/h or 18 kg/t-sinter Gas temps. : 260 to 100 °C Steam conditions : 10 ata, 200 °C
BF slag heat recovery	Slag production : 164.1 kt/month or 310 kg/t-pig Heat : 422×10 ³ kcal/t-slag	Steam generation : 75 t/h Steam conditions : 40 ata, 430 °C
BOF OG sensible heat recovery		Steam generation : 44 t/h or 60 kg/t-steel
Soaking pit waste gas heat recovery	Exhaust gas : 96 Nm ³ /t-ingot	Steam generation : 3 t/h or 12 kg/t-ingot Steam conditions : 10 ata, 200 °C

whereby the deficiency is to be purchased while the excess to be sold off. There is no citation of burners, boilers, capacities, number of equipment, *etc.*, except the generation efficiency, which is 35.1 % for STD and 36.6 % for TGT, both the transformer outlet end rate.

(ii) The BF Blower

The BF blowers are of the electric motor drive type, and the dehumitizer is the induction cooling type absorbing refrigerator.

(iii) The Oxygen Plant

The oxygen plant is to produce oxygen and nitrogen only, that is, no argon-making is planned. The PR is 0.7 kWh/Nm³-O₂ at STD, 0.65 at TGT.

(iv) The Process Steam

The process steam is to be made by an exclusive purpose boiler of efficiency 85 % when STD, but in TGT, all of the steam is to be generated by recovered heat. The steam condition is 10 ata and 200 °C.

(v) The Process Compressed Air

The air supply is source distributed, dual line system. The total requirement and the PR are 150 Nm³/t-crude steel at 0.1 kWh/Nm³ for STD and 140 at 0.09 for TGT.

(vi) Utilities for Other Sectors Including Administration and Control

The PR for water is 7 kWh/t-crude steel, and other auxiliary requirements are for fuels 20×10³ kcal/t-crude steel, for power 5 000 kW (3 650×10³ kWh/month), and for steam 10 t/h (7 300 t/month).

The heat recovery at TGT is to be done by the centralized power generation on an extraction mixed pressure condensing turbine system, which is also to supply the process steam through controlled steam extraction from the turbine as shown in Fig. 16.. The waste heat to be recovered in the TGT operation is from the 5 sources listed in Table 32.

1. Energy Balance in STD and TGT Operations

The results of calculations are summarized in Table 33 and Fig. 17. It will be seen that in the STD, the dependence of this Model Works on coal is 92 %, and the whole of the fuels for heating and coking and 79 % of the power is met with by the byproduct gases and the recovered power. In the TGT, on the other hand, not only all the necessary fuels, power and steam is supplied on the byproduct gases, but some 36 million kWh of electricity can be sold off to outside.

The per tonnage crude steel energy rate is $5\,175 \times 10^3$ kcal/t in the STD and $4\,696 \times 10^3$ kcal/t for TGT, a further decrease of remarkable 9.3 %.

2. Effects of Operation Variations on STD

As the energy of any integrated steel works is utilized as in an integral system, variations of any one of the processes can affect the total energy balance. Of various variations discussed in Chapter III, the BF oil rate (OR), the volatile matter percentage of the coking coal (VM), and the continuous casting ratio (CCR) are considered as particularly efficacious.

(1) Variation in OR

The BF operation conditions of Table 11 were applied to three cases of (a) OR=35 kg/t, (b) OR=

17 kg/t, and (c) all coke. The results are shown in Table 34 and Fig. 18. The decrease of OR, hence the increase of CR (coke rate), makes the purchased power to become less, though the energy rate to become greater.

(2) Variation in VM

As examined in Chapter III, the Cokemaking Sector, any change in VM affects, through its effects on coke yield, COG generation rate, hence through changes in coking coal requirement and quantity of COG, on the requirement of power generation auxiliary fuel and others. The results of calculation conducted for three cases of VMs 25, 27, and 29 % (i.e., $VM=27 \pm 2$ %) are shown in Tables 35 and 36, and in Fig. 19.

To summarize, the effects of changes in VM by ± 2 % on the energy balance are as follows;

Coal rate	640±16 kg/t-pig
Auxiliary energies	225±39×10 ³ kcal/t-crude steel
Salable energies*	277±23×10 ³ kcal/t-crude steel
Energy rate	5 175±38×10 ³ kcal/t-crude steel
* tar and others	

(3) CCR

The increase in CCR has a great effect on energy saving by eliminating the ingotmaking process and improving the yield. The evaluation of this energy saving, however, cannot be done in a straightforward manner because the conventional expression of energy rate per ton of crude steel cannot well cover the cases when materials balance is changed due to changes in the ratio of crude steel to products and in the ratio of return scrap to purchased scrap. Therefore, the appreciation was done here on the basis of per tonnage product energy rate with both the purchased scrap and the products fixed.

Thus, calculations were made on the basis of the

Fig. 16. Waste heat recovery flow.

Table 33. Energy balance and energy rates for STD and TGT.

		STD			TGT		
		Monthly transaction	Calorific value (10 ⁹ kcal)	%	Monthly transaction	Calorific value (10 ⁹ kcal)	%
Purchased	Coking coal (t/month)	338 500	2 606.5	89.7	334 500	2 575.7	93.4
	Injection oil (l/month)	19 700	181.2	6.2	19 700	181.2	6.6
	Power (10 ³ kWh/month)	48 332	118.4	4.1	—	—	—
	Sum		2 906.1			2 756.9	
Sold off	Coke breeze (t/month)	2 500	18.0		5 800	41.2	
	Tar (t/month)	12 200	105.4		12 000	104.2	
	Crude light oil (t/month)	2 500	24.5		2 500	24.1	
	Power (10 ³ kWh/month)	—	—		36 000	84.6	
	Sum		147.9	5.1*		254.1	9.2*
Net input (10 ⁹ kcal/month)			2 758.2			2 502.8	
Energy rate (10 ³ kcal/t-crude steel)			5 175			4 696	
Energy rate (10 ³ kcal/t-product)			5 606			5 087	

* Percentage as of the purchased

Fig. 17. Energy balance flow and fuel-power consumption balance in STD operation (left) and in TGT operation (right).

Table 34. Changes in energy structure according to change of BF oil rate.

Oil rate (kg/t)		35	17	0
Purchased	Coking coal (kt/month)	338.5	360.5	384.6
	Injection oil (kl/month)	19.7	9.6	0
	Power (10 ⁶ kWh/month)	48.3	37.2	33.3
	Sum in 10 ⁹ kcal/month	2 906.1	2 955.2	3 033.0
Sold off	Coke breeze (kt/month)	2.5	4.6	7.0
	Tar (kt/month)	12.2	13.0	13.8
	Crude light oil (kt/month)	2.5	2.7	2.9
	Power (10 ⁶ kWh/month)	0	0	0
	Sum in 10 ⁹ kcal/month	147.9	171.3	198.0
Net input (10 ⁹ kcal/month)		2 758.2	2 783.9	2 835.0
Energy rate (10 ³ kcal/t-crude steel)		5 175	5 223	5 319

examination presented in *Chapter III*, the Steelmaking Sector, for a monthly output of slabs and billets set at 436 and 78 kt, respectively, and the CCR varied from 70 to 80 % as shown in Fig. 20. Here, the decrement in the in-house return scrap due to improved yield is assumed to be compensated for by appropriately changing the converter charge mix (*e.g.*, increasing the HMR (hot metal rate)) to give rise to the predetermined quantities of products and

Fig. 18. Changes in energy balance according to change of BF oil rate.

purchased scrap. It will be seen in Table 37 and Fig. 20 that the results are that a 10 % raise in the CCR means an increase in the crude steel energy rate by 19 × 10³ kcal/t, but a decrease in the products energy rate by 42 × 10³ kcal/t.

Table 35. Changes in coke oven operation parameters according to change of VM.

VM (%)	25	27 (STD)	29	Notes
Lump coke needed (kt/month)	220.0	220.0	220.0	TR and CR constant
Coking coke needed (kt/month)	330.3	338.5	347.0	
Gross yield (%)	76.7	75.0	73.3	$= -0.85 \text{ VM} + 99.1$
Lump coke yield (%)	66.6	65.0	63.4	$= -0.80 \text{ VM} + 86.5$
CUR (%)	97.5	100.0	102.5	
Tar recovery rate (kg/t)	30.4	36.0	41.6	$= 2.8 \text{ VM} - 39.6$
COG recovery rate (Nm ³ /t)	314.5	327.0	339.6	$= 6.0 \text{ VM} + 150$
Coking fuel (10 ³ kcal/t)	561.6	576.0	590.4	$= 0.245 \text{ CUR} + 33.1$

Table 36. Changes in energy structure according to change of VM.

VM (%)		25	27(STD)	29
Pur-chased	Coking coal (kt/month)	330.3	338.5	347.0
	Injection oil (kl/month)	19.7	19.7	19.7
	Power (10 ⁶ kcal/month)	56.8	48.3	39.8
	Sum in 10 ⁹ kcal/month	2 863.7	2 906.1	2 950.6
Sold off	Coke breeze (kt/month)	2.0	2.5	3.0
	Tar (kt/month)	10.1	12.2	14.5
	Crude light oil (kt/month)	2.5	2.5	2.6
	Sum in 10 ⁹ kcal/month	126.1	147.9	172.3
Net input (10 ⁹ kcal/month)		2 737.6	2 758.2	2 778.3
Energy rate (10 ³ kcal/t-crude steel)		5 136	5 175	5 213

Table 37. Effects of changes in CCR on energy rate and heat balance.

CCR (%)		70 % (STD)	80 %	Difference
Energy rate (10 ³ kcal/t-crude steel)		5 175	5 194	+19
Energy rate (10 ³ kcal/t-product)		5 606	5 564	-42
Crude steel throughput (kt/month)		533	527	- 6
Product throughput (kt/month)		492	492	0
Pur-chased	Coking coal (kt/month)	338.5	336.9	
	Injection oil (kl/month)	19.7	19.65	
	Power (10 ⁶ kWh/month)	48.3	45.5	
	Sum in 10 ⁹ kcal/month	2 906.1	2 886.4	-19.7
Sold off	Coke breeze (kt/month)	2.5	2.8	
	Tar (kt/month)	12.2	12.1	
	Crude light oil (kt/month)	2.5	2.5	
	Sum in 10 ⁹ kcal/month	147.8	149.1	+ 1.3
Total in 10 ⁹ kcal/month		2 758.3	2 737.3	-21.0

Fig. 19. Changes in energy balance according to change of VM.

3. Examination of Self-sufficiency Energy Balance on TGT Operation

As discussed in Section IV. 1, in the event of TGT operation, not only all the fuels and power except the oil for BF injection can be supplied on the byproduct energies, but a considerable amount of energy will be had as excess. Further, if the all coke operation is practiced, the excess will become even greater as

shown in Tables 38 and 39. This excess energy can be sold off in a form of gas, electricity or steam intending for neighboring firms or for general consumers, but here two cases of self-sufficient utilization are examined in terms of injection of pulverized coal or COG into the BF. The results are shown in Table 39 and in Fig. 21. It will be seen that in all those cases a large portion of the excess energy can be absorbed while reducing the energy rate considerably.

V. Dynamic Management of Energy Demand/Supply

For any integrated steel works, the byproduct gases are hard to utilize because their generation and consumption are irregular and because they are difficult to store by nature. In the past, the steel works used to counteract those difficulties simply by resorting to oil and by purchasing power, and it was indeed due to the function of adjusting the demand and supply of those energies that not only the stable supply of energy was ensured whenever and wherever it was needed, but the values of byproduct gases were raised.

As discussed in Chapter IV, however, when the energy saving is progressed so extensively as to the TGT, divorcing of oil will have been realized and a considerable amount of salable excess energy will be had

Fig. 20. Material flow for CCRs of 70 % (left) and 80 % (right).

Table 38. Changes in operation parameters according to change of BF fuel.

		TGT OR=35 kg/t	All coke	COG injection	Pulverized coal injection
Blast furnace	FR (kt/t-pig)	446	468.2	454	454
	CR (kt/t-pig)	411	468.2	429.1	399.1
	Injection fuel rate (kg/t-pig)	35	0	24.9*	54.6
	Blast volume rate (Nm ³ /t-pig)	1 050	1 121	1 036	1 035
	BFG generated (Nm ³ /t-pig)	1 518	1 591	1 545	1 503
	BFG calorific value (kcal/Nm ³)	685	661	693	677
	CO efficiency, η_{CO} (%)	52.1	51.6	52.0	52.8
	Blast temp. (°C)	1 315	1 120	1 315	1 315
	Blast humidity (g/Nm ³)	6	6	6	6
	Tuyere front temp. (°C)	2 463	2 462	2 458	2 463
	Slag rate (kg/t-pig)	310	313	310	310
Hot stove	Gas calorific value (kcal/Nm ³)	1 116	811	1 129	1 129
	FR (10 ³ kcal/t-pig)	471	421	464	464
TRT power generation (kWh/t-pig)		42.7	44.8	43.5	42.3
Coke oven	Lump coke required (kt/month)	217.4	247.7	227.0	211.3
	Coking coal required (kt/month)	334.5	381.0	349.2	325.1
	Coke oven CUR (%)	98.8	112.0	103.2	96.0

* 50.7 Nm³/t-pig

in hand. When the all coke operation is fully implemented, moreover, this trend will become much more apparent. This means that the *in toto* management and effective utilization of energy when produced in

excess must be intensified through the whole of a steel works. As to how to achieve this end, greatly varying arguments and opinions were expressed in the Committee meetings, but all appeared to converge on

Table 39. Changes in energy structure according to change of BF operation mode.

		All coke		COG Injection		Pulverized coal injection	
		Trans- actions	Heat Equivalent (10 ⁹ kcal/m)	Trans- actions	Heat Equivalent (10 ⁹ kcal/m)	Trans- actions	Heat Equivalent (10 ⁹ kcal/m)
Purchased	Coking coal (kt/month)	381.0	2 933.7	349.2	2 688.8	325.1	2 503.3
	Injection fuel (kt/month)	—	—	—	—	28.9	209.4
	Power (10 ⁶ kWh/month)	—	—	4.9	11.5	—	—
	Sum in 10 ⁹ kcal/month		2 933.7		2 700.3		2 712.7
Sold off	Coke breeze (kt/month)	10.4	74.9	7.2	51.8	4.8	34.6
	Tar (kt/month)	13.7	118.6	12.6	108.7	11.7	101.2
	Crude light oil (kt/month)	2.8	27.5	2.6	25.1	2.4	23.4
	Power (10 ⁶ kWh/month)	65.9	154.8	—	—	30.2	71.0
	Sum in (10 ⁹ kcal/month)		375.8		185.6		230.2
Net input (10 ⁹ kcal/month)			2 557.9		2 514.7		2 482.5
TGT energy rate (10 ⁸ kcal/t-crude steel)			4 799		4 718		4 658
TGT energy rate (10 ⁸ kcal/t-product)			5 199		5 111		5 046

Fig. 21. Changes in energy balance according to change of BF operation practice on TGT base.

how to minimize the energy cost.

For this, three prerequisites of “decreasing energy consumption”, “selecting cheaper energies”, and “supplying energies stably” appear to be natural. However, the problems here are:

- 1) how to supply which byproduct gas to which apparatus with what CV?;
- 2) how best should the demand and supply be adjusted?;
- 3) in what form the power equipment, namely, the energy converters, should best be?;
- 4) how to recover and convert the waste energy and where to apply it?; and
- 5) how to deal with the excess energy?

Here, several concrete examples are introduced and discussed.

1. Utilization of Byproduct Gases

No unified conclusions have been reached as to how best the byproduct gases should be utilized. Instead, there appears to be two schools of thought for this proposition. Namely:

- (1) One school has it that high CV fuels should be

preferentially supplied to equipment that need high temperatures. That is, the high CV COG is to be burnt at the reheating furnaces, while the low CV BFG is sent to the boilers. The merit of this method is that a high thermal efficiency and a high dispensability are obtained without investing much on the facility, and that much may be saved in the per CV energy transportation cost. The shortcomings are, on the other hand, that this method lacks the flexibility to take a fuel that happens to be available, and that it is not well adaptable to changing energy situation.

(2) The other is to try to utilize any low CV fuels at any and all thermal apparatuses by developing the necessary technologies. The use of M gases for coke ovens, hot stoves, and reheating furnaces is a realization of this notion.

Generally, the first is the easier for immediate adoption, for it is easy to see that this one gives better thermal efficiency. However, it is to be kept in mind that the above statement is valid only when the equipment remains identically the same. That same thermal efficiency can be realized for the same apparatus by changing the equipment appropriately is harder

Fig. 22.
Rise of combustion temperature by preheating (a) the combustion air and (b) the fuel.

to conceive, but it is true enough. This is shown in Fig. 22 by means of relationships between the CVs of COG, BFG, and M gas and the theoretical combustion gas temperatures for an excess air rate m of 1.05. The effects of preheating the combustion air are presented in Fig. 22(a). Even if the fuel gas is not preheated, considerable rise of combustion gas temperature may be obtained. Thus:

Fuel gas		BFG	COG	M gas*	LDG**
Combustion air	20	1 220	2 070	1 870	1 970
Preheating temperature (°C)	600	1 390	2 430	2 190	2 230

* 2 500 kcal/Nm³; ** 1 920 kcal/Nm³

It is to be noted above that even with an M gas a combustion temperature over 2 000 °C is readily attainable.

The effects of preheating both the combustion air and the fuel gas may be seen in Fig. 22(b), where the air temperature is 600 °C. Thus, when the air temperature is 600 °C and fuel temperature is 400 °C:

Fuel gas	BFG	COG	M gas*	LDG**
Theoretical combustion gas temperature (°C)	1 590	2 490	2 270	2 350

* 2 500 kcal/Nm³; ** 1 920 kcal/Nm³

It will be noticed here that larger effect is had by lower CV gases. For example, the rise in the theoretical combustion gas temperature with air preheated to 600 °C and fuel gas from 20 to 400 °C is 200 °C for BFG, 60 °C for COG, and 80 °C for M gas.

As may be judged from above, the making of an M gas out of low CV BFG by adding COG and the

preheating of combustion air and fuel gas is to make the low grade gas usable for high temperature apparatuses. This means that the value of low grade fuel has been elevated, and that, at a certain expense to be made on equipment to raise the thermal efficiency, better energy balance and better adaptability to changes in energy situation will be ensured. Furthermore, as a side effect, by adjusting the CV of M gas properly, generation of NO_x is minimized and life of refractories prolonged because the temperature is held to the lowest necessary level.

Naturally, the utilization of byproduct gases must be contemplated, besides from the heat technology view points like above, from various other angles such as layout of facilities of generation and consumption, restrictions on demand/supply management, possibilities of future value-adding (for example, sales, extraction of pure H₂ and CO, application of C₁ chemistry,* etc.), environmental protection, and safety.

Thus, the first of the five problems set forth earlier, that of “how the CV of a fuel should be?” is, as far as the thermal efficiency can be adjusted to the same level, neither very important nor very independent. It is no more than one of those many factors mentioned just above that are to be considered in building up a system of minimum energy cost. What will be needed henceforth are the proper appreciation of the cost of byproduct gases, development of method of efficiently burning low grade gases, and development of technology to add more value to those gases.

2. Adjustment of Demand/Supply Gap

An excess gas can be used either directly as fuel and as chemical raw material or indirectly as electricity or steam intended for neighboring communities (Table 40). As the generation of those byproduct

* Pronounced “C-one-chemistry”, this term designates a future prospect (gaining supporters in Japan) of making such mono-carbon (or, C-sub-one) compounds, as C, CO, CO₂ the raw materials for higher order C-one chemicals like CH₄ and CH₃OH, on which new organic chemistry industry may be founded.

Table 40. Various ways of excess energy utilization outside the steel works.

Energy form	Utilization	Notes	Remarks
Byproduct and waste gases	1. Supply to local community as fuel		
	a) To power company	i. Today, it is mostly through the Co-operative Power Stations. ii. Some to the thermal power station of the power company.	There are 8 Cooperative PSs affiliated with steel works throughout the country.
	b) To city gas company	i. Much depends on the local situation. ii. Excess COG applicable, but alleviation of steady supply obligation is necessary. iii. Not much sale to be hoped for; seasonal fluctuations must be considered.	Today, city gases are generally made from LNG.
	c) To fuel industrial complex	i. Formation of an industrial complex with other firms along the flow of energy.	Industrial complexes on raw materials-products relation do exist.
	2. Supply as chemical raw materials	i. New technologies (<i>ex.</i> , C ₁ chemistry) need be developed.	
Power generated in-house	1. Sale to power company	i. Mutual accommodation system with the tied-up power company must be developed.	
	2. To power industrial complex	i. Formation of an industrial complex with other firms on the power generated in the steel works.	
Steam or waste hot water	1. Supply to local community	i. Hot water supply for civil uses if conditions are met.	
	2. Conversion to energy	ii. At the energy complex as process steam or as electric power.	
Tar and coke breeze	1. Sale as raw materials to chemical companies	i. As being practiced today.	

Table 41. TGT hourly gas balance (excluding the energy for power generation).

Gases	Normal operation			One BF banked			Hot strip line shut down		
	BFG	COG	LDG	BFG	COG	LDG	BFG	COG	LDG
Generated (10 ³ Nm ³ /h)	1 133	152	77	567	152	77	1 133	152	77
Consumed (10 ³ Nm ³ /h)	581	123	0	304	89	0	558	104	0
Excess (10 ³ Nm ³ /h)	552	29	77	263	63	77	575	48	77
Excess energy*									
in 10 ⁶ kcal/h		660			622			768	
in MW		281			265			327	

* Variation is *ca.* 22 % of the "normal".

gases fluctuates according to the state of operation, and because sale to outside generally prerequisites stable supply, the utilization of those gases need be considered both from the uses and from the demand/supply adjustment.

1. Management of Excess Gas

The adjustment of gas demand/supply is being done by hours, by days and weeks, and by months or longer terms as follows:

- 1) by hours; switching-over of fuel gas to be done at gas holders and at boilers,
- 2) by days to weeks; switching-over of fuel gas at facilities other than boiler, and logical assignment of off-days to each plant, and
- 3) by months and longer terms; readjustment of operational conditions and review of production schedule.

Even then, however, there will always remain some fluctuation that cannot be absorbed by those means,

and how to execute the final management is the problem.

For example, the quantity of the excess gas can vary from the normal 660×10^6 kcal/h of the TGT operation to 622×10^6 of the banking of one BF or to 768×10^6 of the scheduled stopping of the hot strip mill line. As may be seen in Table 41, this is a fluctuation of as much as *ca.* 20 %. Therefore, whatever method of dispensing those excess gases may be taken, be it straight selling off, to use as the raw material for C₁ chemistry, or conversion to electricity, it must be the one that can absorb that much variance. One way of doing this is to assign this function to the power boiler as exemplified by the two illustrations in Fig. 23, but then some auxiliary fuel need be purchased in either case.

2. Management of Electric Power

It was shown in Chapter IV that, as far as the monthly average goes, some 261.5×10^6 kWh/month of elec-

tricity can be generated on the excess gas and recovered energies, and that after supplying the total power demand of 225.6×10^6 kWh, *ca.* 36×10^6 kWh/month (13.8 % of the indigenous generation) may be sold off to outside. However, the actual situation does not revolve on the monthly balance, and what is more critical is the hourly balance.

Consider now the power demand by monthly average, one hour average, and instantaneous peak. Then, the power demand on the TGT operation will be:

	Monthly average	One hour average	Instantaneous peak
Power demand in MW	309	364	516
Factor	1.00	1.18	1.67

Fig. 23. Effective utilization of excess gas by power boiler system.

This means that in order to ensure the supply of the average power demand of 309 MW, 516 MW, or a factor of 1.67-times, is actually needed at any given time. Nevertheless, the in-house power generation on byproduct gases and recovered energies is able to cover only 358 MW. Therefore, some auxiliary fuel must be fed to the power boiler to fill up this gap. For this, following 4 cases are possible as shown in Fig. 24.

Case 1: Generate the power in-house to a certain level, and purchase the remainder from outside. In this case, a considerable amount of gas becomes excess, which will have to be sold off or otherwise be dealt with.

Case 2: Generate the power in-house up to the limit of excess energy. This will necessitate to purchase power to bridge over the peak demand, and conversely, during the time of low load, reverse flow of power will occur.

Case 3: Generate the power up to the peak. Purchase of power is no longer necessary, but auxiliary fuel must continually be consumed and, on top of it, the power reverse flow will become greater.

Case 4: Generate the power to a certain level beyond the peak. In this case, a certain amount of power can be sold off constantly, but a large quantity of auxiliary fuel will be needed.

Thus, some auxiliary fuel will have to be brought in to manage the demand/supply gap effectively and economically for fluctuations of byproduct gas generation and occurrence of peaks in power demand. Of course, the power consumption is desirably uniform

Fig. 24. Four cases of power supply/demand for integrated steel works.

throughout the works, for which purpose adjustment of the rolling mill loads, assignment of off-days to rolling plants, storage of energy in the form of products (*e.g.*, manufacture of ferroalloys by electric furnace, manufacture of liquid oxygen at oxygen plant, *etc.*) can all be an effective measure.

3. Some Thoughts on Power Facilities and Energy Recovery

1. Improvement of Energy Conversion Efficiency of Power Facilities

The power facilities are those apparatuses that convert byproduct gases into electricity or steam, and electric power into compressed air, oxygen, pressurized water, and such. As the energy that is being expended by those facilities amounts to over 30 % of the total, the conversion efficiency can directly affect the total energy efficiency. Among those, the greatest is the in-house power generation facilities, which, due to the rapid rise of the energy cost, can now be process-designed for efficiency rather than for economy.

For example, conventionally, the thermal power stations of medium size, *e.g.*, 75 MW or less, are equipped with a turbine system of 4-stage extraction, regenerative cycle type with only the air preheated. This system develops a heat rate of 2 638 kcal/kWh and an overall efficiency of 32.6 %. If a 5-stage extraction, reheating and regenerative cycle type system with both the air and the fuel gas preheated is to be used, however, the heat rate will be as small as 2 299 kcal/kWh and the efficiency 37.4 %, a remarkable 13 % improvement in the conversion efficiency. This is illustrated in Table 42. In the case of the present Model Works operating on TGT, this difference can amount to as much as 27×10^6 kcal/kWh, an amount that surpasses the energy saving achievable with allout dry coke quenching (CDQ).

If a gas turbine combined cycle plant, such as shown in Fig. 25 is to be installed, furthermore, an overall power generation efficiency of 37.0 to 39.5 % can be attained.

2. Recovery of Waste Energy and Effective Utilization

Before attempting waste energy recovery, the input energy should be decreased first. Then, for any waste energy that still remains over, such recursive type heat recovery as preheating of the combustion air and the fuel gas should be considered. The waste energy yet remaining after those steps have been taken will have to be recovered as a source for other processes. Here, from the recovery efficiency and the return-on-investment viewpoints, the preference should be placed on the use first as the heat for preheating or drying, second as steam, and third as electric power.

In the case of the TGT operation of the present Model Works, adoption of various energy saving measures has been presumed to have preceded recovery. For example, the heats recovered from coke and slag

Table 42. Improvement of power generation efficiency by adopting gas preheating, reheating/regenerative cycle.

	100kg/cm ² G×500℃ Regenerative cycle (4 stage steam) (extraction)	100kg/cm ² G×500℃ Reheating/regenerative cycle (5 stage steam) (extraction)
System schematic diagram
Boiler subsystem diagram
Air preheater only	Efficiencies (%)	Efficiencies (%)
	Turbine	40.3
	Boiler	87.3
	In-plant	7.0
	Overall	32.6
	Energy conversion (kcal/kWh)	2638
Both air preheater and gas heater	Boiler subsystem diagram
	Efficiencies (%)	Efficiencies (%)
	Turbine	40.3
	Boiler	92.5
	In-plant	7.0
	Overall	37.4
	Energy conversion (kcal/kWh)	2478

Fig. 25. Gas turbine combined cycle plant.

are to be utilized either as steam or as electric power flexibly and in accordance with the existing energy situation.

To practice heat recovery most efficiently and to utilize the recovered heat most effectively, pre-examination of

- 1) which one of the sources is the best for steam, and which one for electricity,
- 2) which is the most appropriate recovery system and what the steam condition should best be, and
- 3) how to accomodate the changes in steam demand and the occurrence of waste heat that are expected in future

is necessary. For this, making up of a map that shows in a glance the *status quo* of waste heat generation and steam demand at various plants and shops and building up of a comprehensive energy system that includes the power stations are highly effective.

VI. Conclusion

Fundamental notions and limitations of energy saving technologies, changes in energy structure, and problems to accompany those changes have been discussed for a hypothetical 8 million t class integrated iron- and steel-making works as a model. The conclusion that has been reached by the Energy Saving Technologies Research Group, the Heat Economy Technology Committee, the Joint Research Society of the ISIJ is:

Furtherance of such basic studies as how to improve the efficiency of individual energy apparatuses and how to determine the calorific value of a fuel gas for a particular application is of course necessary, but what is more important for the future is how to construct a cost minimum energy supply system, a system which shall be adaptable to changes in the energy situation.

Nomenclature

- BF: blast furnace
 BFG: blast furnace gas
 BOF: basic oxygen furnace (or LD converter)
 CC: continuous casting
 CCC: continuous continuous casting
 CCR: continuous casting rate (%)
 CDQ: coke dry quenching
 CBR: coke breeze rate (kg/t-sinter)
 COG: coke oven gas
 CR: coke rate (kg/t-pig)

- CUR: capacity usage rate (%)
 CV: calorific value (kcal/kg or Nm³)
 FR: fuel rate (kg/t-pig, -crude steel, or -product)
 HCR: hot charge rolling
 HMR: hot metal ratio (%) (or hot metal rate)
 HDR: hot direct rolling
 IC: ingot cast
 LDG: LD converter gas
 OR: oil rate (kg/t-pig)
 OG: off gas, particularly from a BOF
 PR: power rate (kWh/t-steel)
 STD: standard
 TGT: target
 TR: tapping rate (t/m³ (inner volume)·day)
 TRT: top-pressure recovery turbine
 VM: volatile matter (of coal) (%)

Abbreviation

- IISI: International Iron and Steel Institute
 ISIJ: The Iron and Steel Institute of Japan
 JISF: The Japan Iron and Steel Federation
 MITI: Ministry of International Trade and Industry

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REFERENCES

- 1) Report submitted to the Joint Research Society of ISIJ by the Energy Saving Technologies Research Group, the Heat Economy Technology Committee, "Energy Saving at Integrated Steel Works—Estimation of Limits and Visions for Future Energy Structure", (November, 1980), (limited circulation report).
- 2) T. Yamamoto: *Tetsu-to-Hagané*, **68** (1982), 49.
- 3) A. Rist and N. Meysoon: *Rev. Mét.*, **62** (1965), 995.
- 4) I. Muchi: *Seitetsu Kagaku Enshu* (Applications of Iron-making Chemistry), Yokendo, Tokyo, (1974).
- 5) A. Shigemi: *Seitetsu Handbook* (Handbook for Ironmaking), Chijin Shokan, Tokyo, (1979).
- 6) Report submitted to the Joint Research Society of ISIJ by the Ingotmaking Research Group (49th Meeting), November, 1979), (limited circulation report).
- 7) Report submitted to the Joint Research Society of ISIJ by the Hot Strip Research Group (28th Meeting), (March, 1978), (limited circulation report).