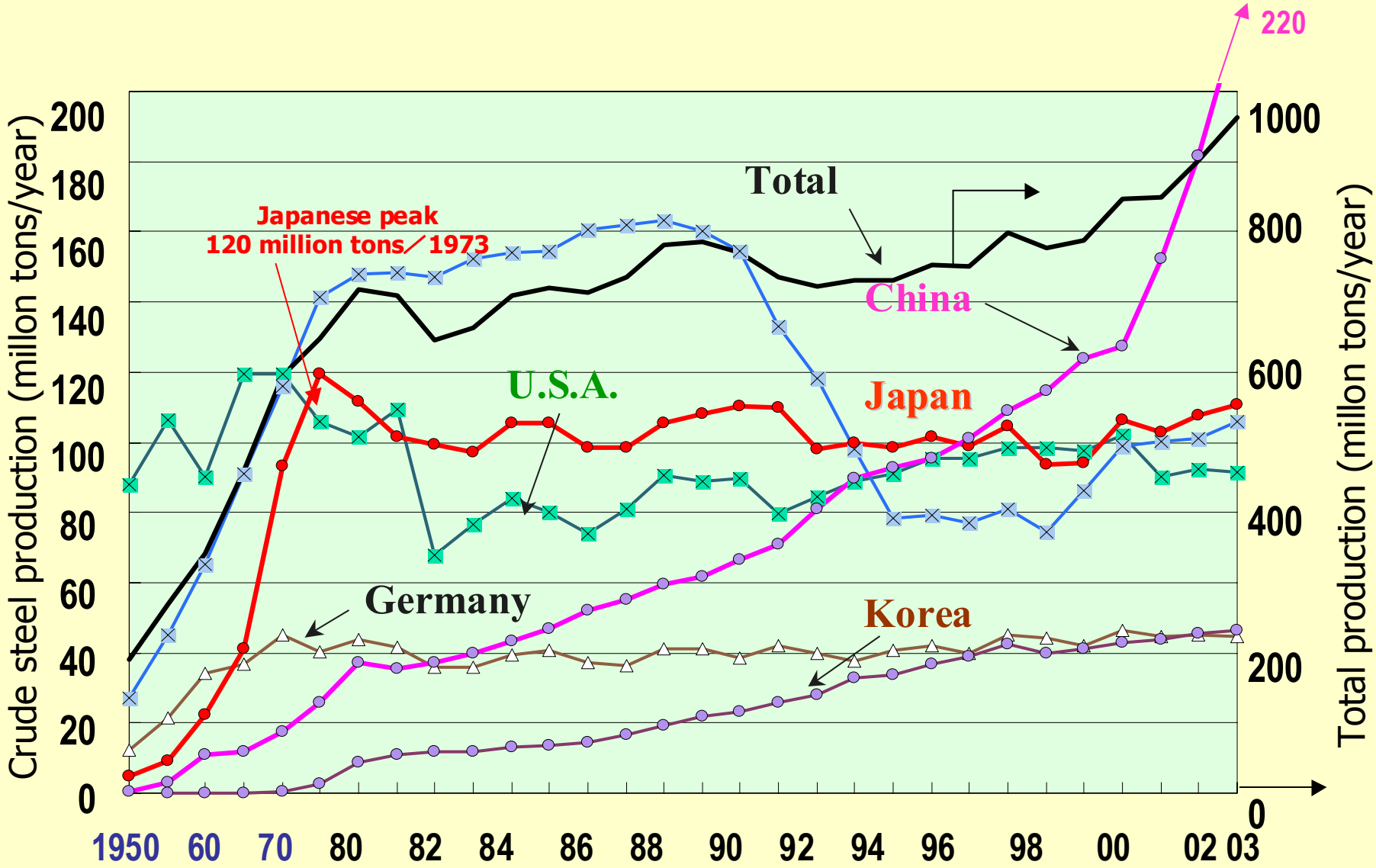
Development of Japan's Refining Technologies in the Past and Future

2004.6.2

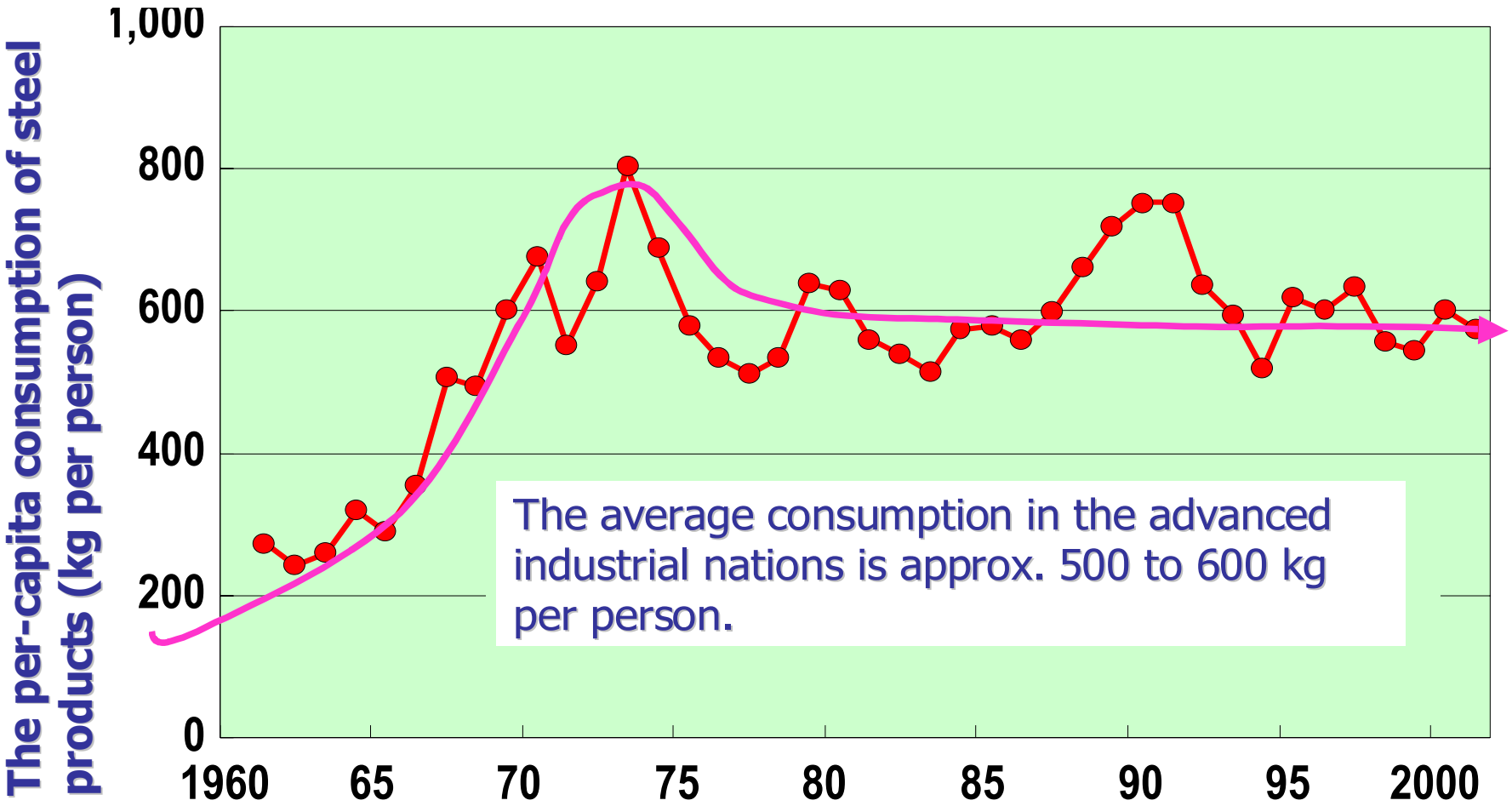
By **Kaoru Ichikawa**
Nippon Steel Corporation

1. Introduction
2. Behavior of Mn in the Steel-making process
3. History of Process Improvement and Influence on Manganese
   (1) Top-and-Bottom blowing converter
   (2) Hot metal pretreatment
   (3) LD-type hot metal pretreatment
   (4) MURC process
4. Steel product needs
   (1) Automobile sheet steel
   (2) Plate products
5. Future Development

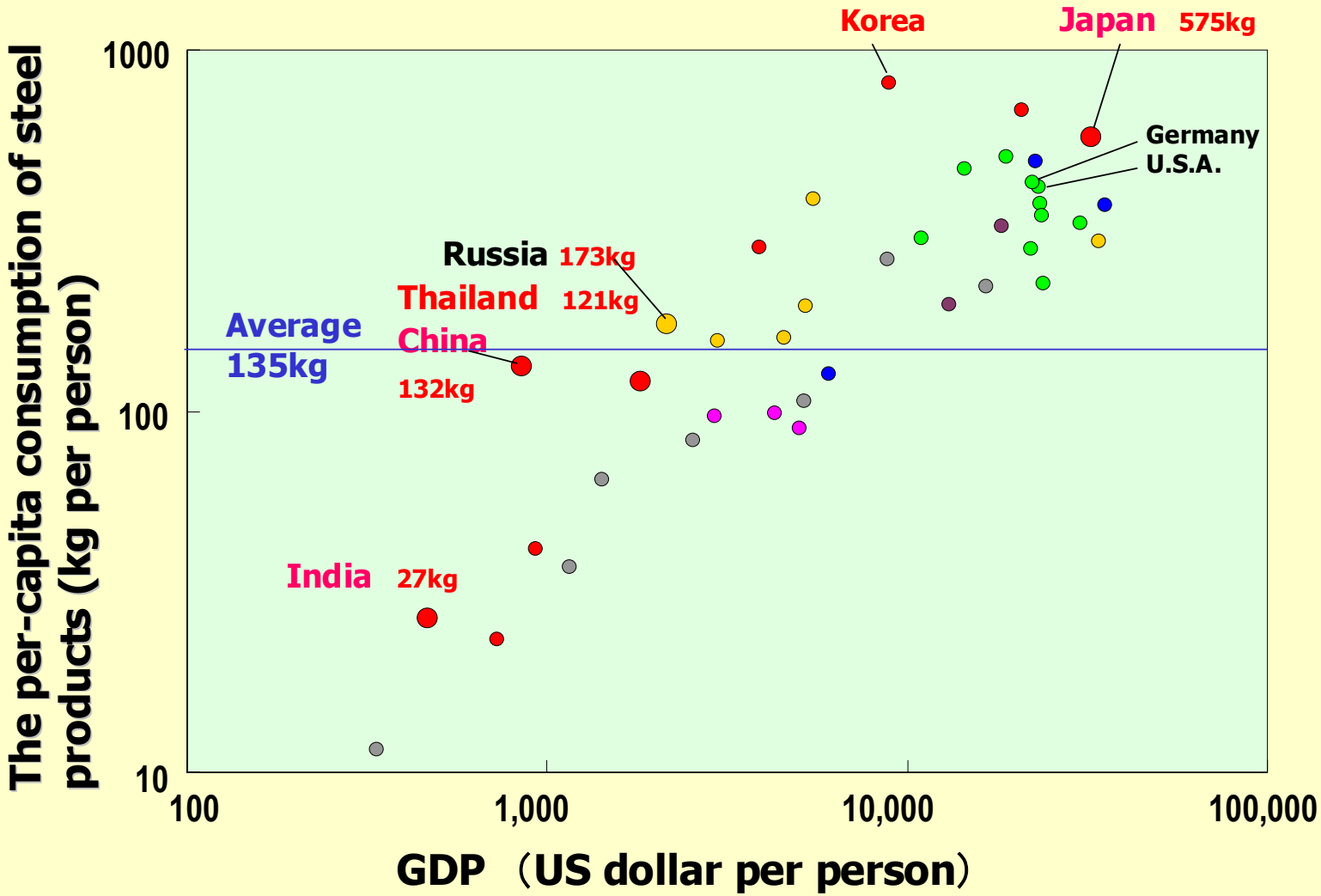
Crude steel production



Changes in the consumption of steel products in JAPAN

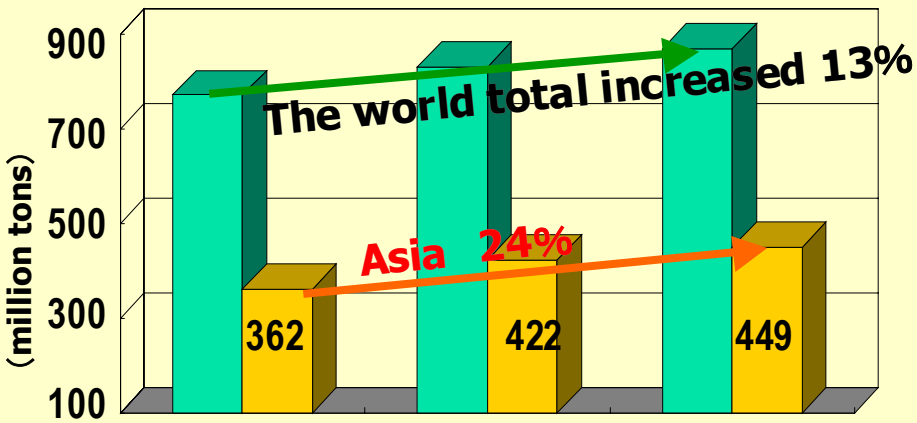


Consumption of steel product in the world (2001)



Trend in steel demand in the world

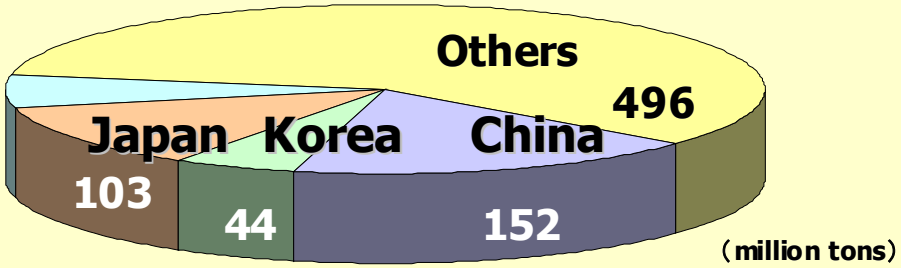
The steel demand

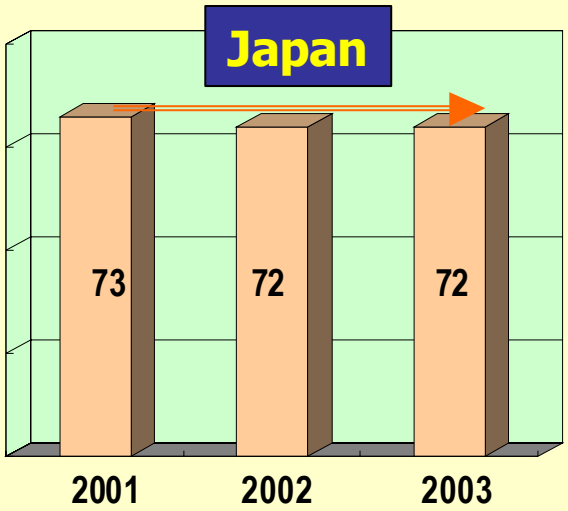


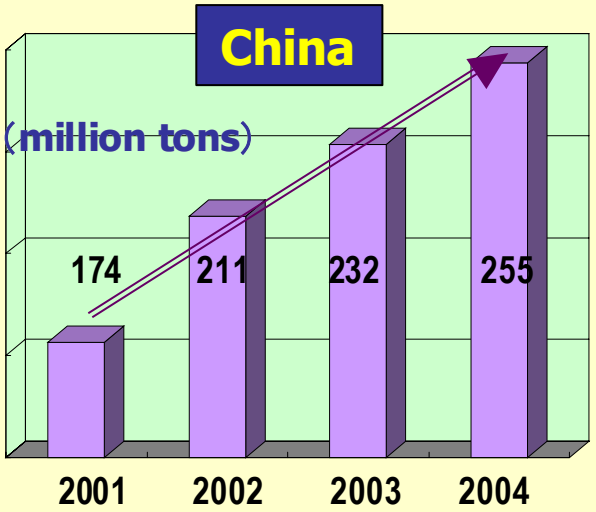
Crude steel（2001）

Total 846 million ton

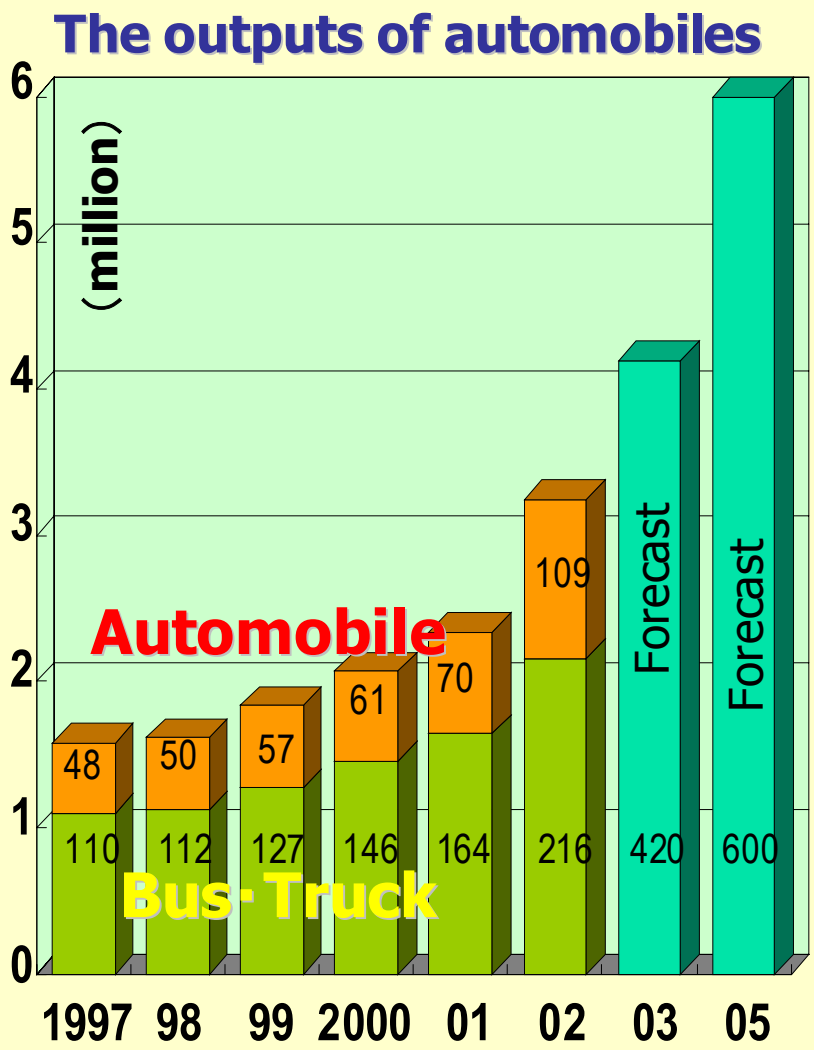
Asia 363 million ton（42%）

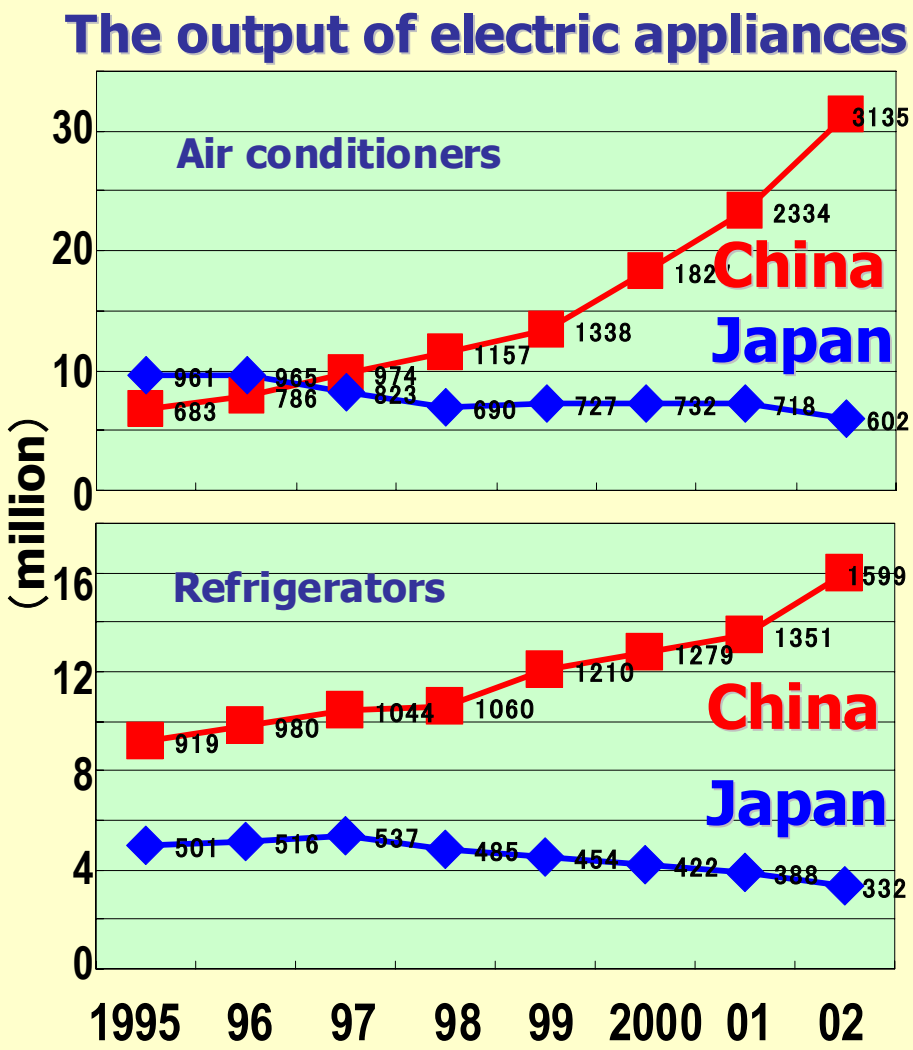




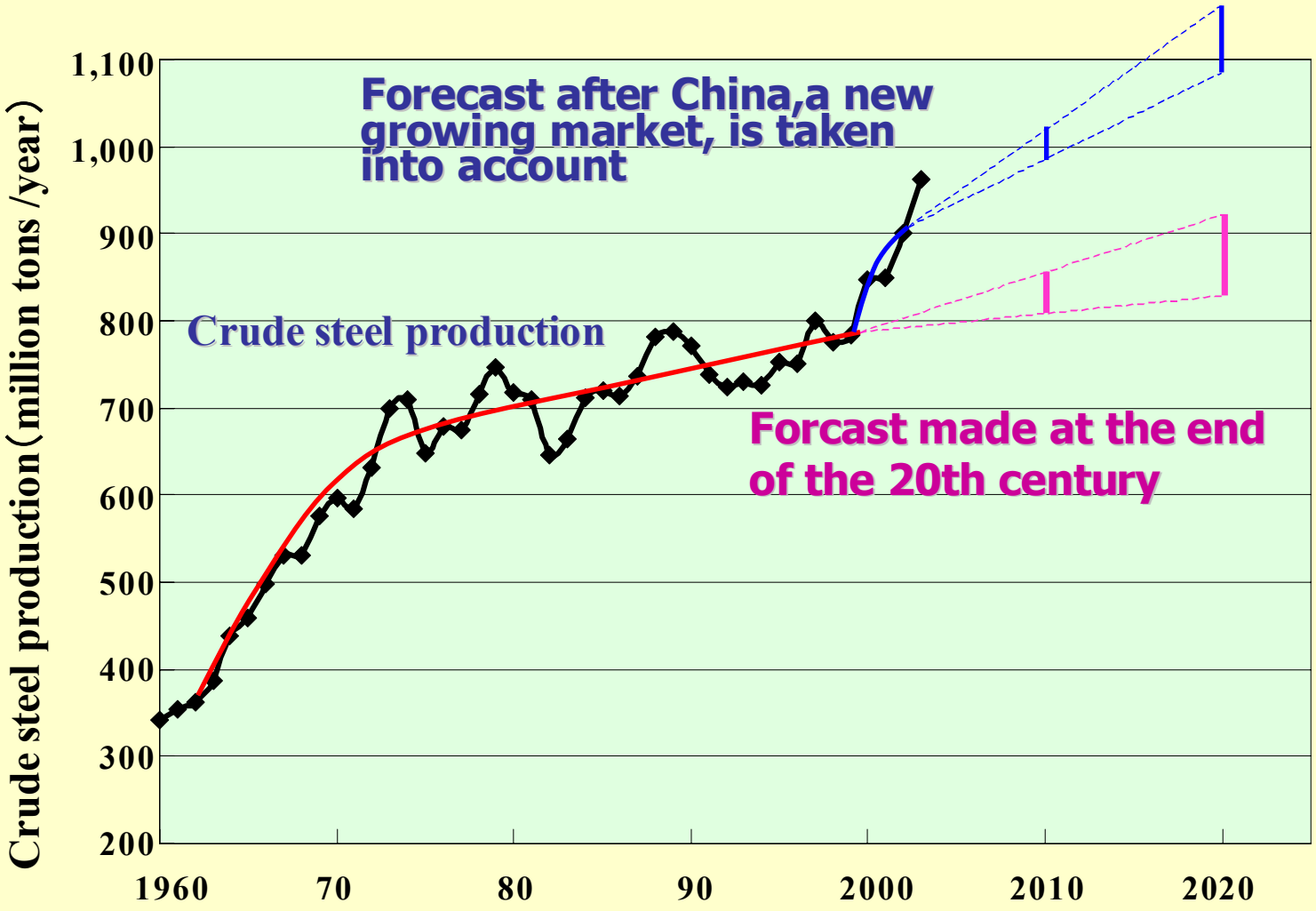


Economic development in China



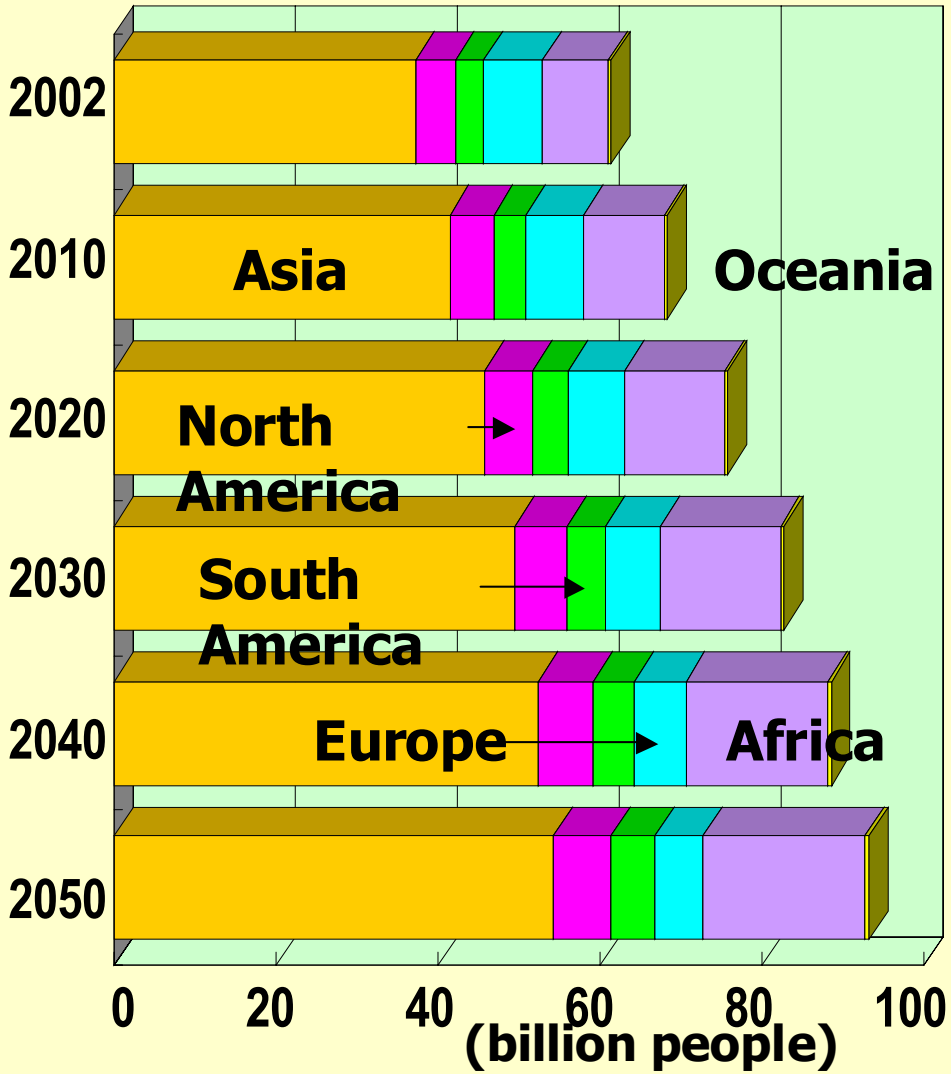


Crude steel production and the long-term trend in the world.

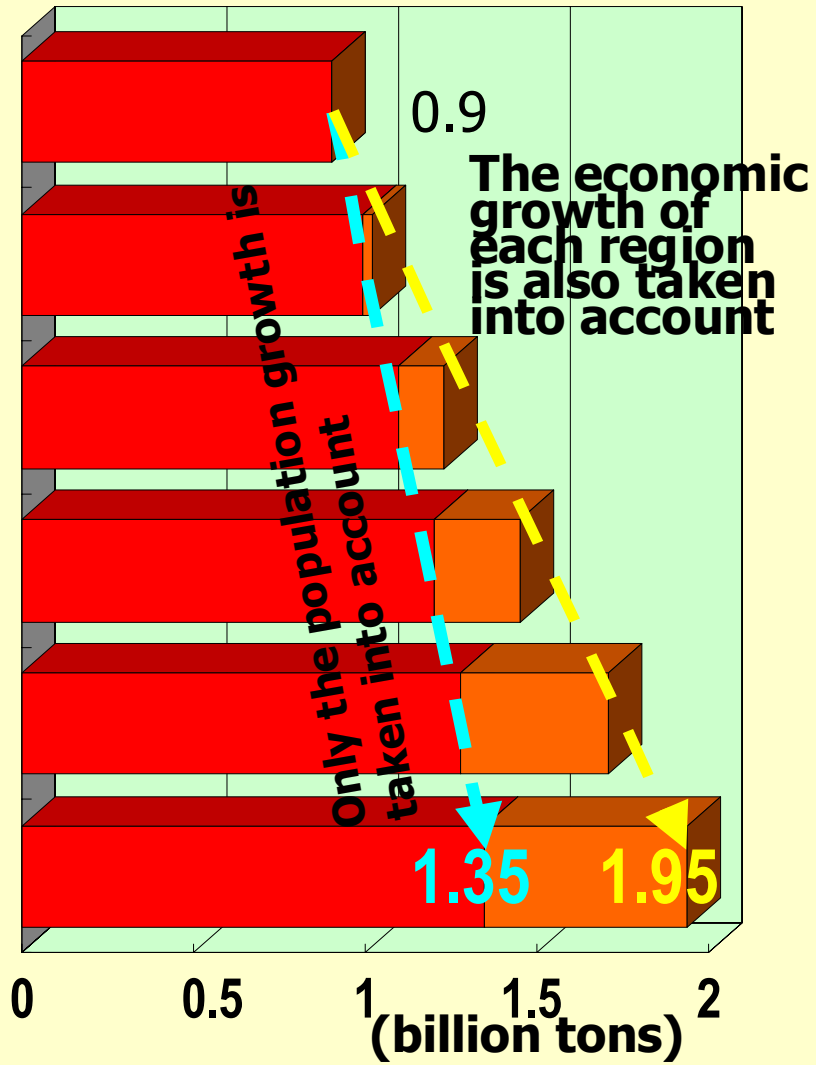


Forecast for increased steel demand

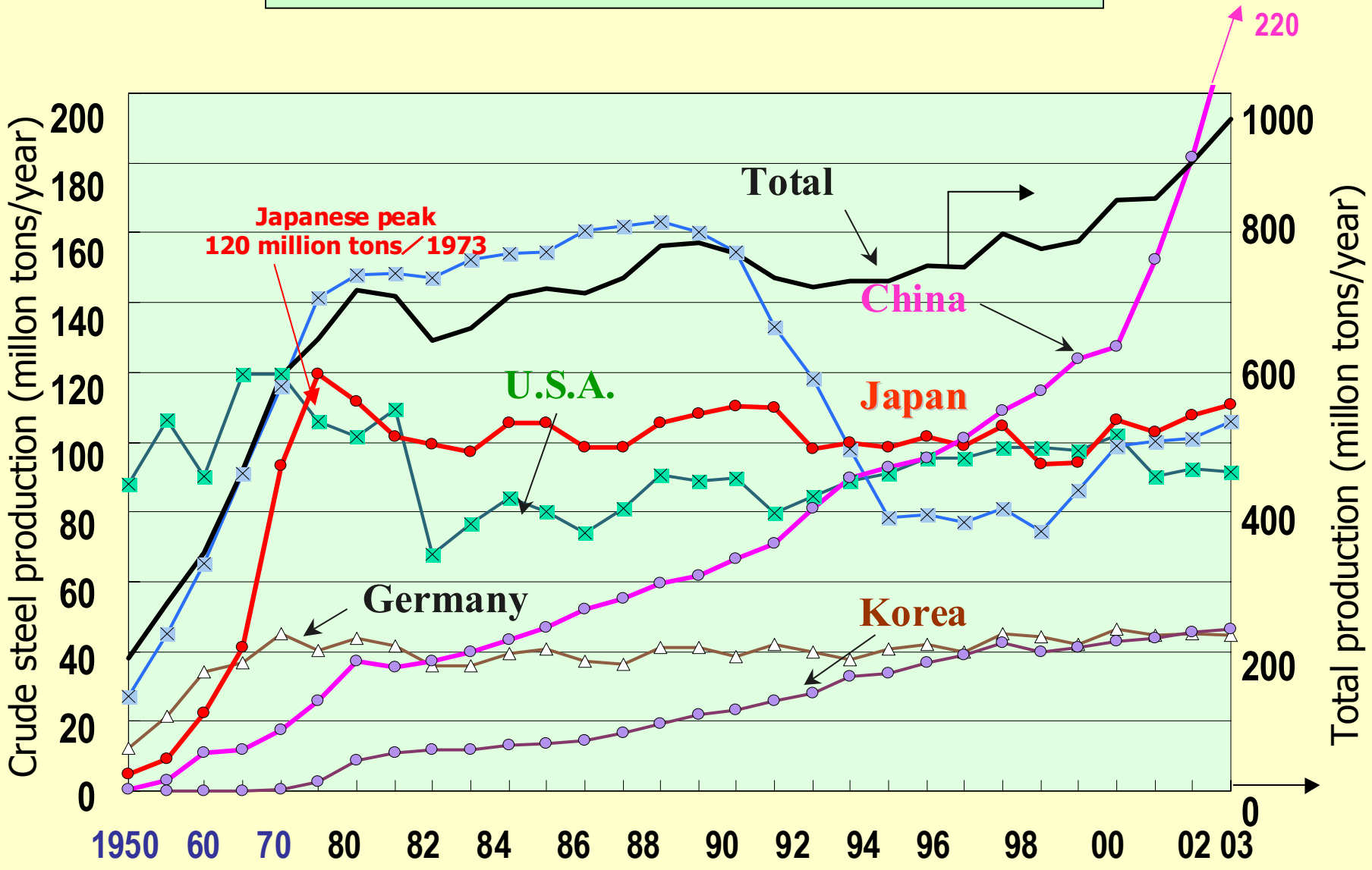
Forecast for the world population



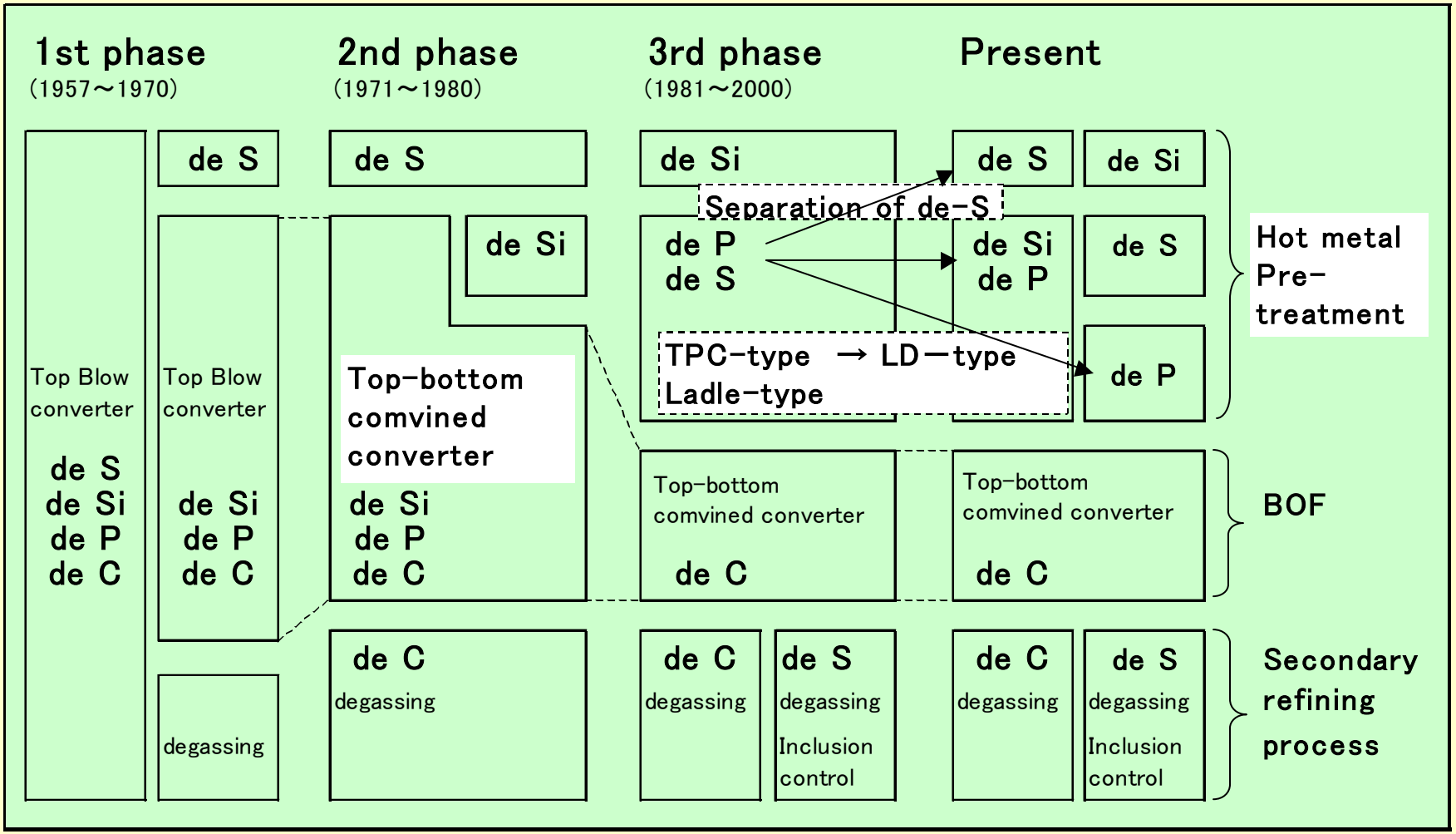
Forecasts for the crude steel production



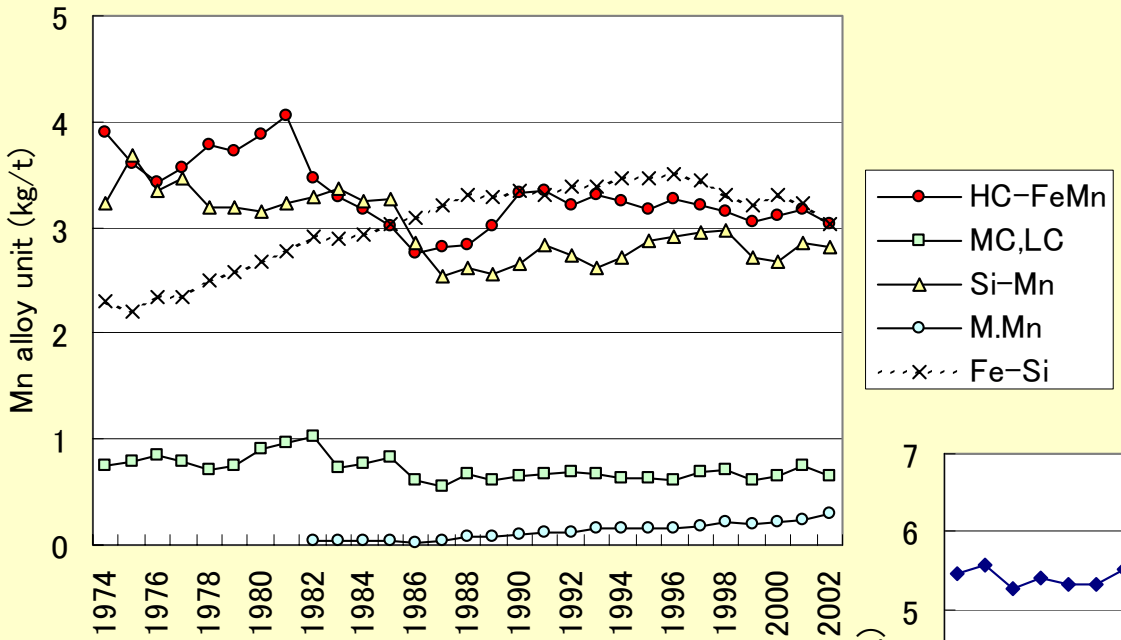
Crude steel production

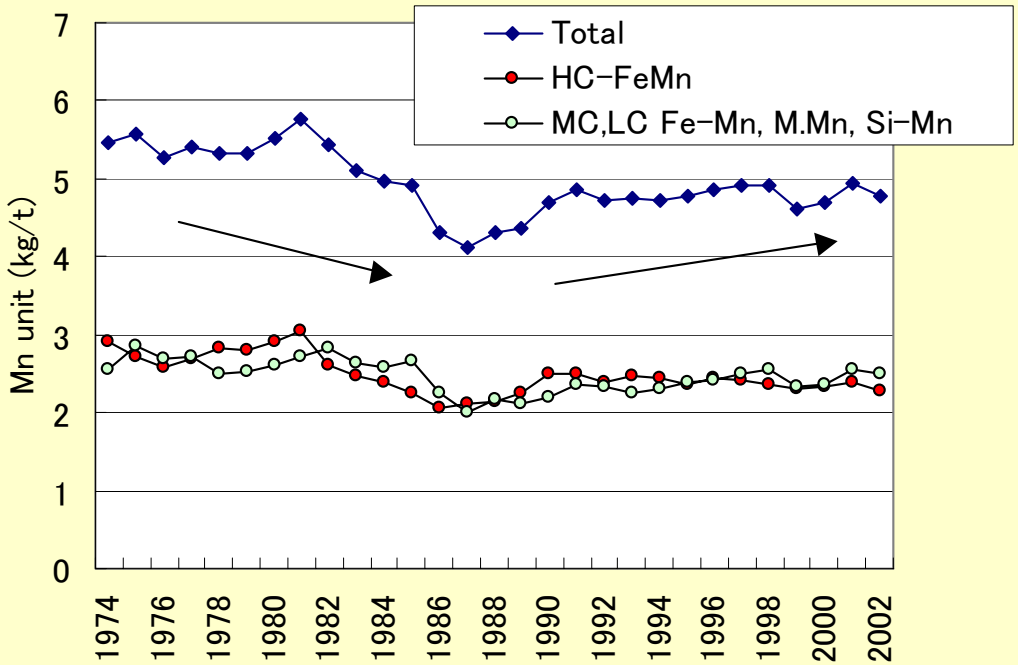


Progress in the division of refining function at Nippon steel.[1)]



Consumption of Fe-Mn alloy in Japan & Mn-equivalent consumption in Japanese steel [2].





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An example of the steel making method & acceleration conditions for respective reactions.

Process	Flux & oxygen	% content in Fe [C]	[Si]	[P]	[S]	[Mn]	Temp. (℃)
BF		4.5	0.4	0.1	0.02	0.3	1530
Hot Metal Pretreatment	(dS) CaO、Mg or Na_2CO_3 (dP) CaO、Fe-Ore、O_2	4	tr	0.02	0.005	0.2	1350
BOF	CaO、MgO Mn-Ore Fe-Ore、O_2	0.05	tr	0.02	0.005	0.15	1650
Secondary Refining	Alloy	0.001 ～0.3	tr ～0.5	0.005 ～0.03	0.001 ～0.03	0.15～1.5	-
Product							

Reaction	Condition		
	Basicity	PO_2	Temp.
Decarburization	-	High	-
Dephosphorization	High	High	Low
Desulfurization	High	Low	High
Reduction of MnO	High	Low	High

$$C + 1/2O_2 = CO$$

$$P + 5/4O_2 + 3/2CaO = 1/2Ca_3(PO_4)_2$$

$$S + CaO = CaS + 1/2O_2$$

$$Mn + 1/2O_2 = MnO$$

Example of calculation results of ferroalloys [3].

	[C]	[Si]	[Mn]
End point	0.05	0.00	0.15
Ladle aim	0.12	0.25	1.50
Upper limit	0.15	0.30	1.60
Lower limit	0.10	0.20	1.40

Alloy	HCFeMn	LCFeMn	Si-Mn	
Caic.	1272	0	5237	kg/heat
Set	1272	0	5237	
Yield	95	95	95	%

[C]	[Si]	[Mn]
0.05	0.00	0.15
0.09	0.25	1.50
0.12	0.30	1.60
0.07	0.20	1.40

HCFeMn	LCFeMn	Si-Mn	
0	2385	3615	kg/heat
0	2385	3615	
95	95	95	%

[C]	[Si]	[Mn]
0.05	0.00	0.15
0.08	0.25	1.50
0.11	0.30	1.60
0.06	0.20	1.40

HCFeMn	LCFeMn	Si-Mn	
0	2385	3615	kg/heat
0	2385	3615	
95	95	95	%

Chemical content (%)

	C	Si	Mn
HCFeMn	6.85	0.00	74.50
LCFeMn	0.86	0.00	81.00
Si-Mn	2.20	14.50	60.70

Manganese yield

$$Mn + 1/2O_2 = MnO$$

$$\log \frac{(\%MnO)}{[\%Mn]} = -1.79 + 1.07 \times \log(\%T.Fe) + 3.980 \times \frac{1}{T} - 0.048 \times \log(\%CaO/\%SiO2)$$

$$\text{Mn yield}\ (\%) = \frac{1}{1 + \frac{55}{71} \times \frac{1}{1000} \times \frac{(\%MnO)}{[\%Mn]} \times \text{Slag volume}} \times 100$$

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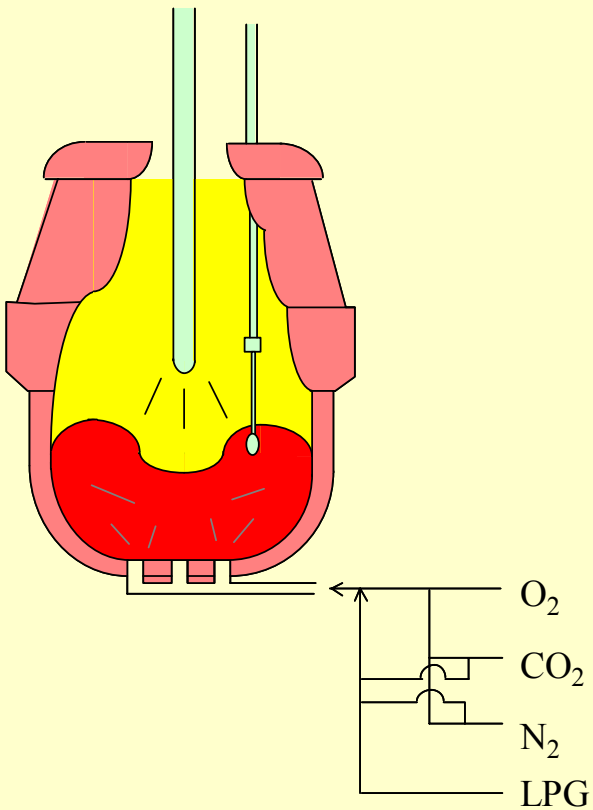
Outline of combined-blown processes [4)]

Process	Bottom tuyere construction	Bottom gas type	Bottom gas flow rate($Nm^3/t/min$)
LD-OB	Double-pipe tuyere	O_2,Ar,CO_2,N_2,LPG	0.10 to 0.60
LD-CB	Small-diameter pipe assembly plug	CO_2,N_2,(O_2)	0.01 to 0.10



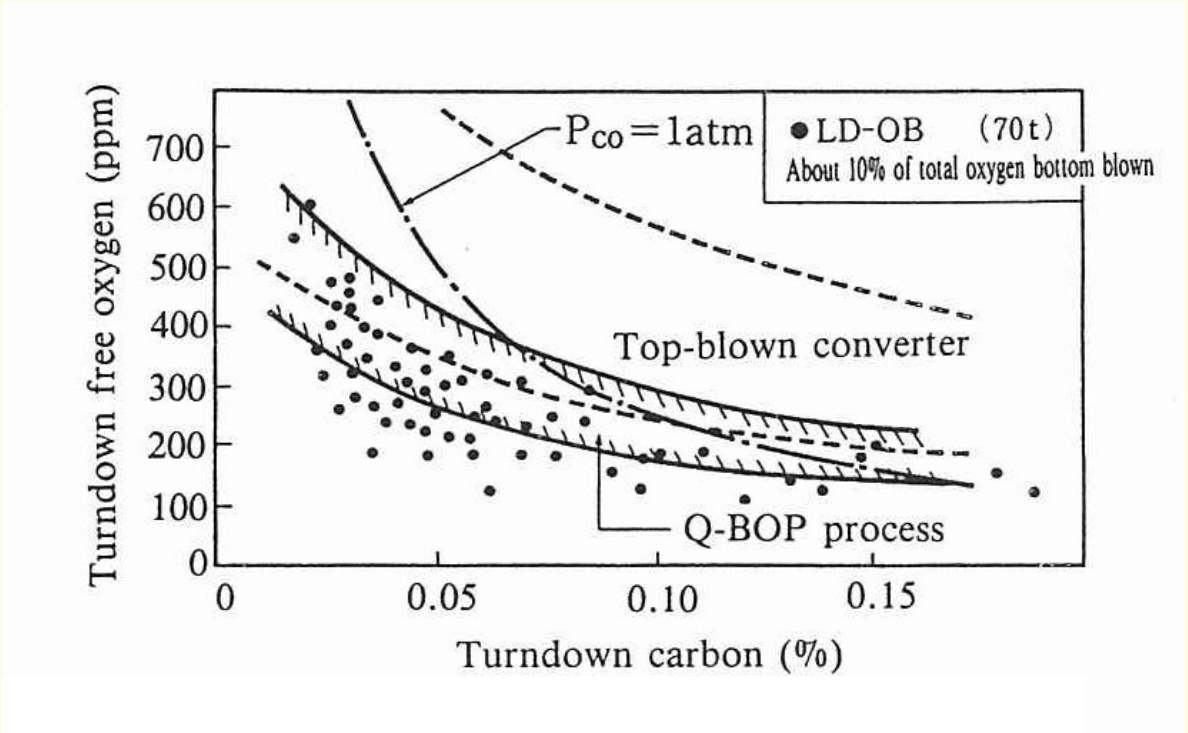
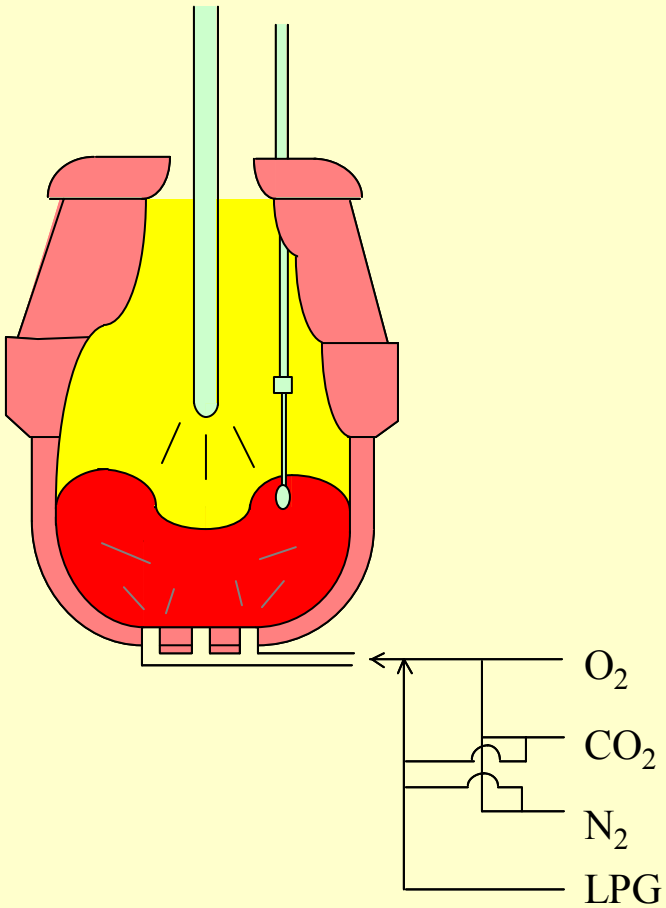
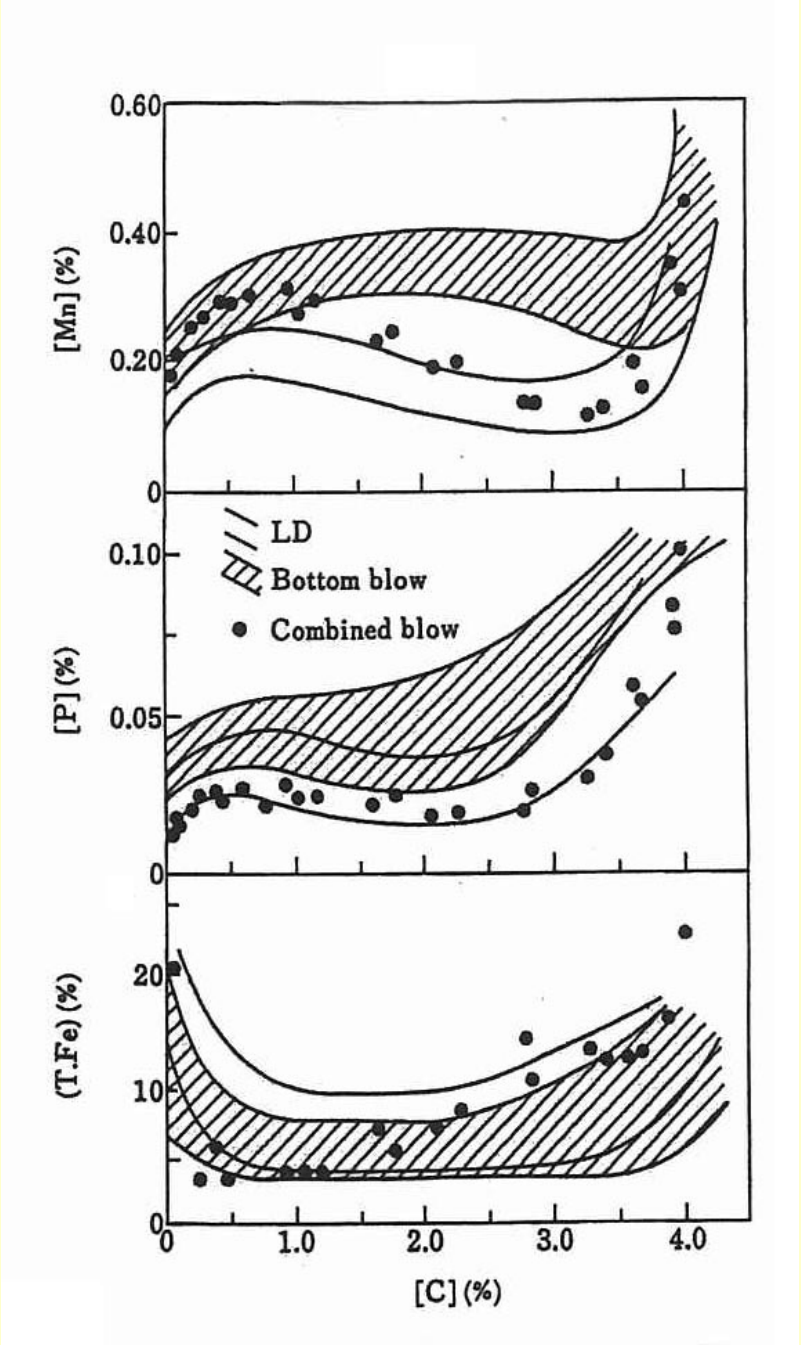


Fig. Relation between turndown free oxygen and turndown carbon in top-blown, bottom-blown, and combined-blown converter [4)].

Changes in reaction using the top-and-bottom blowing method [5].





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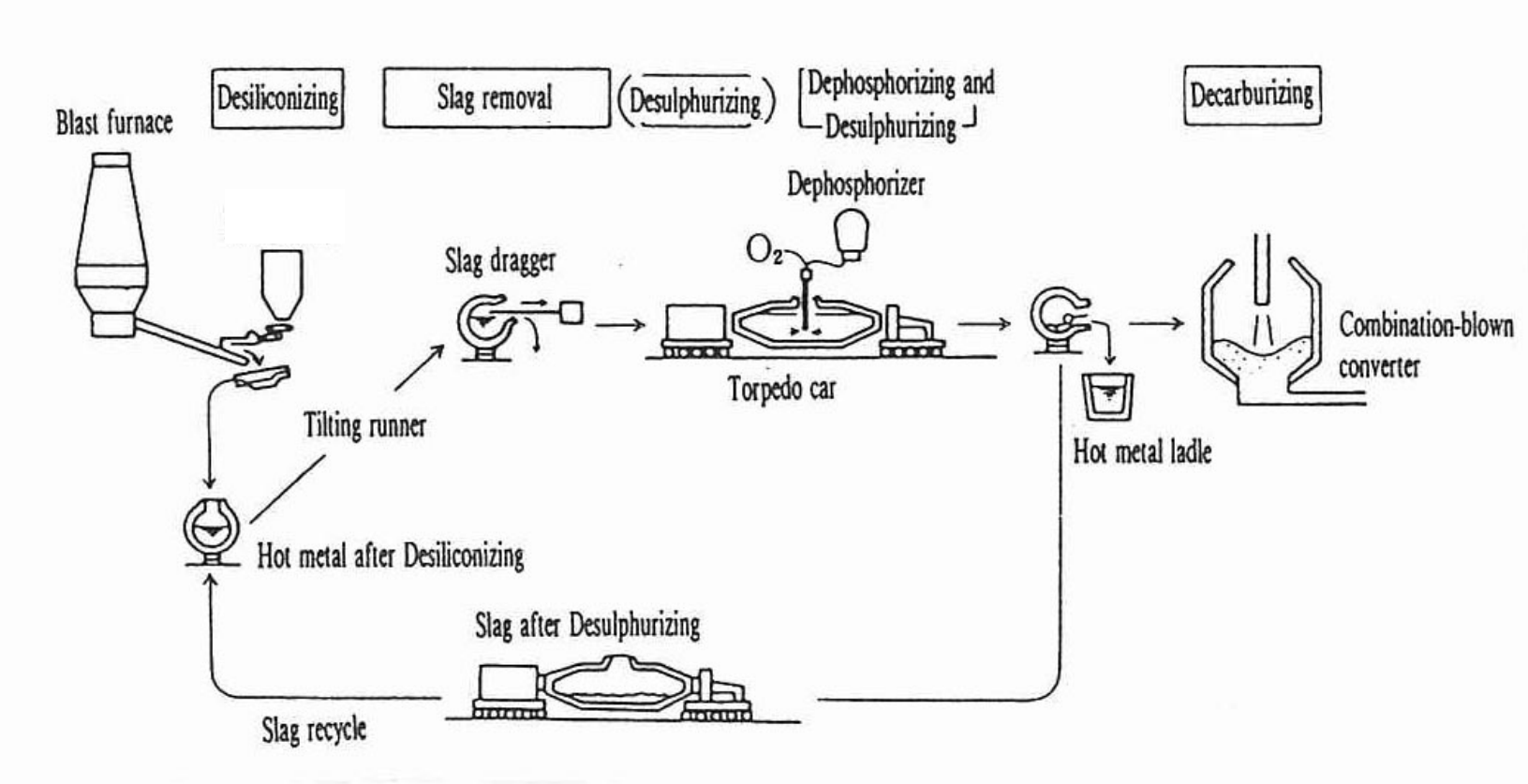
Recent advances of hot metal pretreatment in Japan [6].

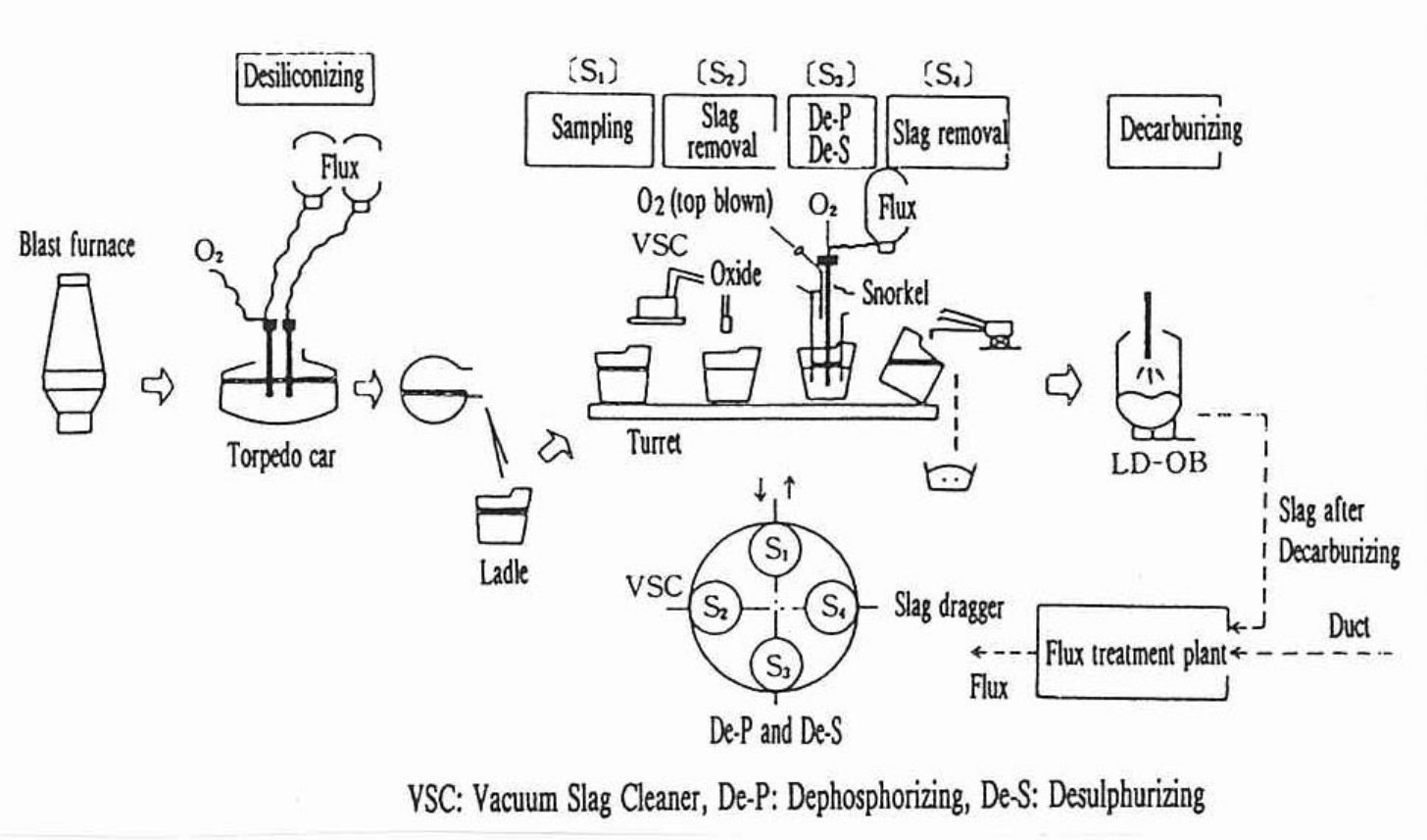
		82		84		86		88		90		92		94		96		98		00		02
Nipponn Steel	Kimitsu	★																		●		
	Yawata		★																			●
	Oita			★		▲															●	
	Nagoya			★					●													
	Muroran				★									●								
JFE	Chiba			★																		
	Mizushima				★																	
	Keihin					▲												●				
	Fukuyama				▲										●							
Sumitomo	Kashima	★					●															
	Wakayama				★				●								●					
Kobe	Kakogawa				★														★			
	Kobe		●																			

★ : TPC
▲ : Ladle
● : Converter

Example of torpedo car hot metal pretreatment process (Kimitsu, Nippon steel)[4].



Example of ladle hot metal pretreatment process (Oita, Nippon Steel) [4].

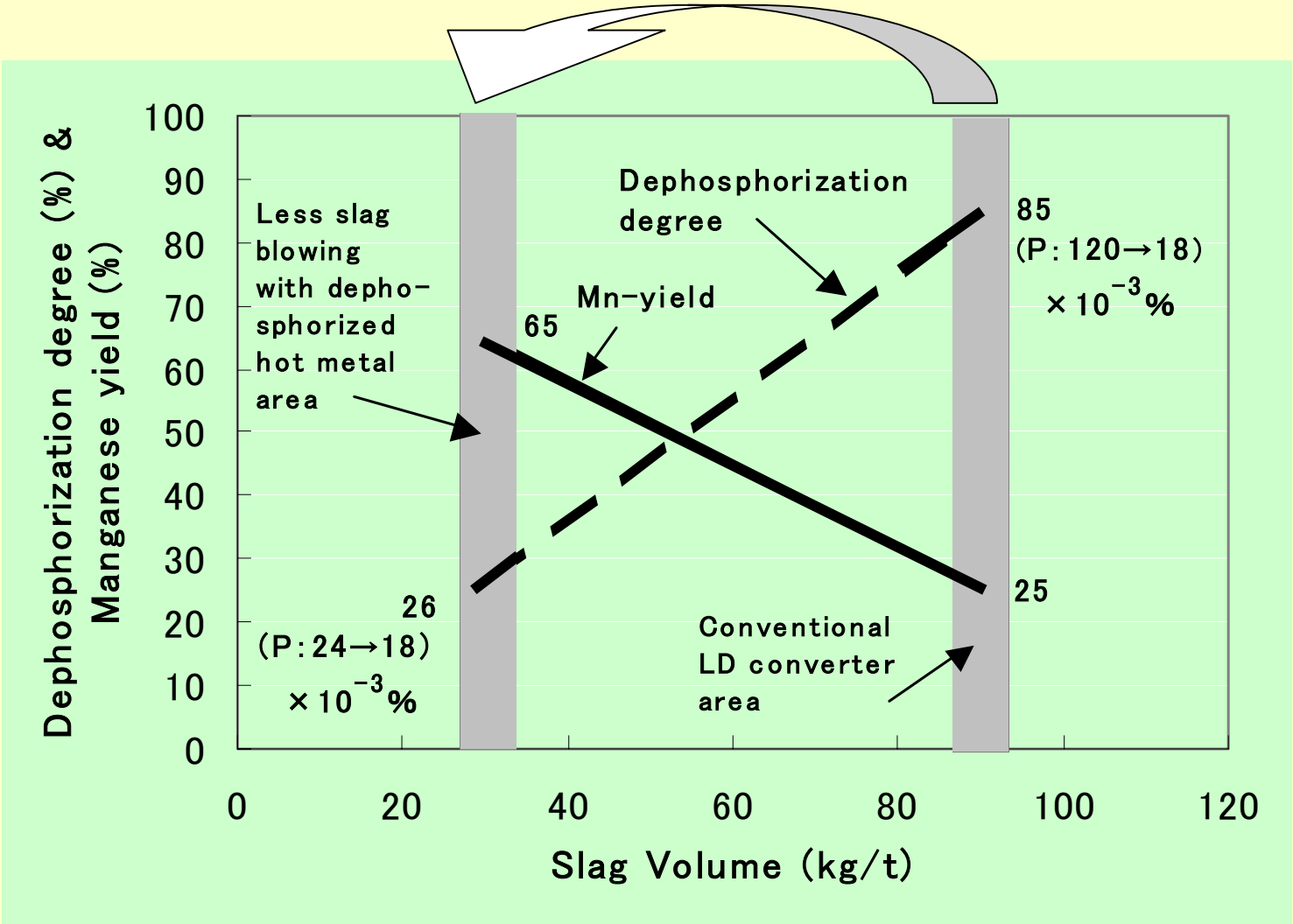


VSC: Vacuum Slag Cleaner, De-P: Dephosphorizing, De-S: Desulphurizing

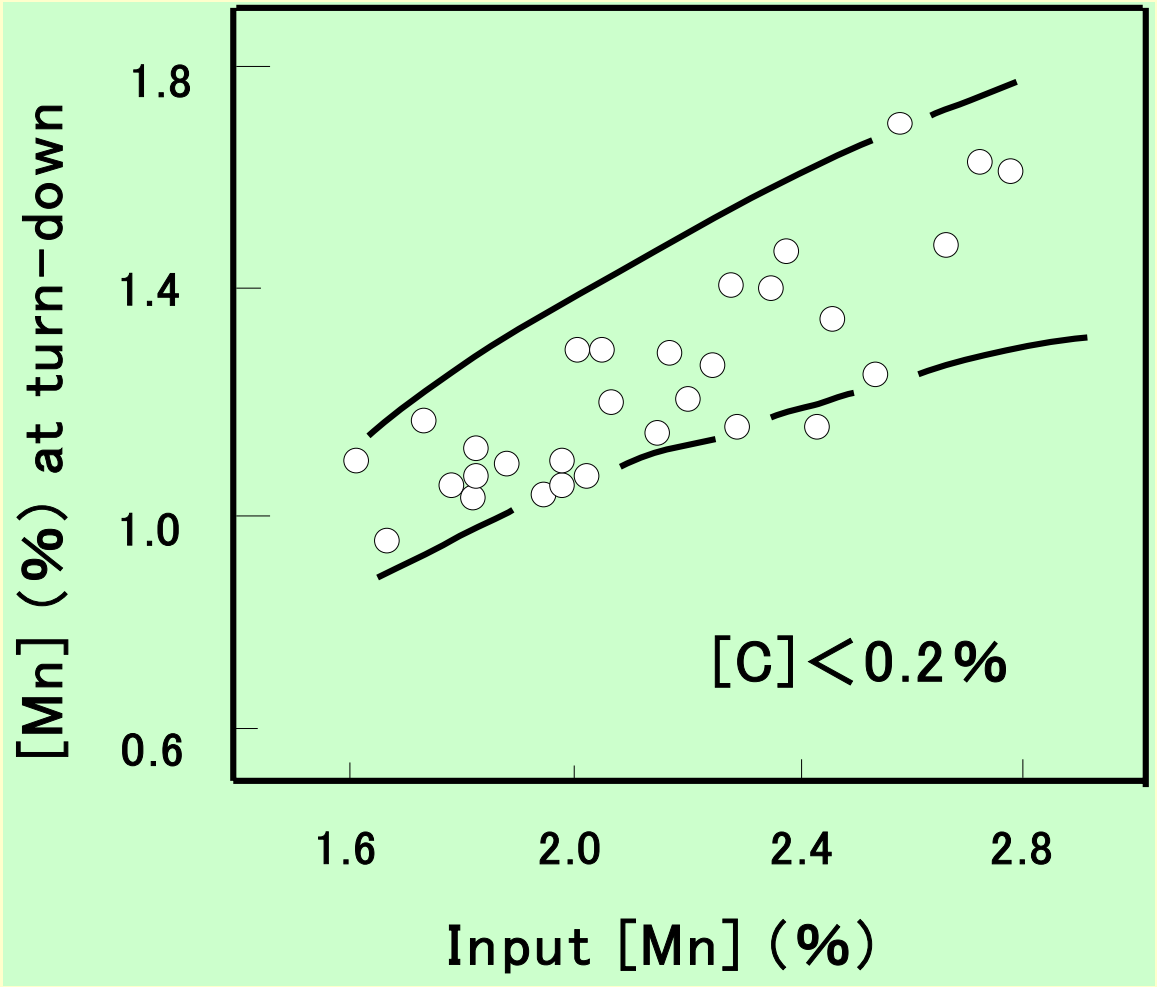
Changes in converter operating with introduction of hot metal pretreatment and LD-OB process (Kimitsu) [4].

	LD process (1981)	Hot metal pretreatment and LD-OB process (1989)
Monthly crude steel production capacity (t/furnace/month)	200,000	407,000
Hot metal pretreatment ratio (%)	0	69
Availability (%)	55.2	85.5
Tap-to-tap time (min)	34	28
Furnace life (heats)	1,795	5,340
Molten steel yield (%)	93.6	95.1
Total CaO consumption (kg/t)	**54.2**	**39.3**
Ferromanganese consumption (kg/t)	**6.4**	**4.2**

Effect of slag volume on dephosphorizing degree and manganese yield (Oita) [4].



Turn-down [Mn] by mass reduction of Manganese ore [7].



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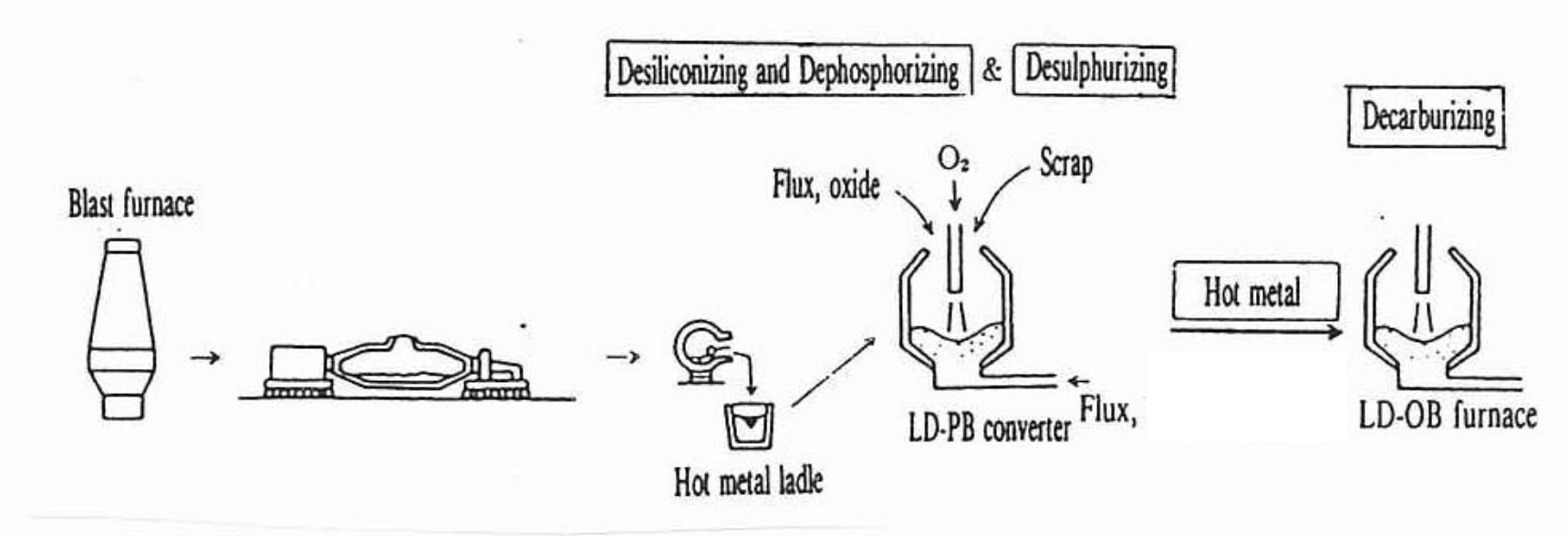
Example of converter hot metal pretreatment process (Nagoya ,Nippon Steel) [4].



Comparison of hot metal dephosphorization process and treatment conditions [8].

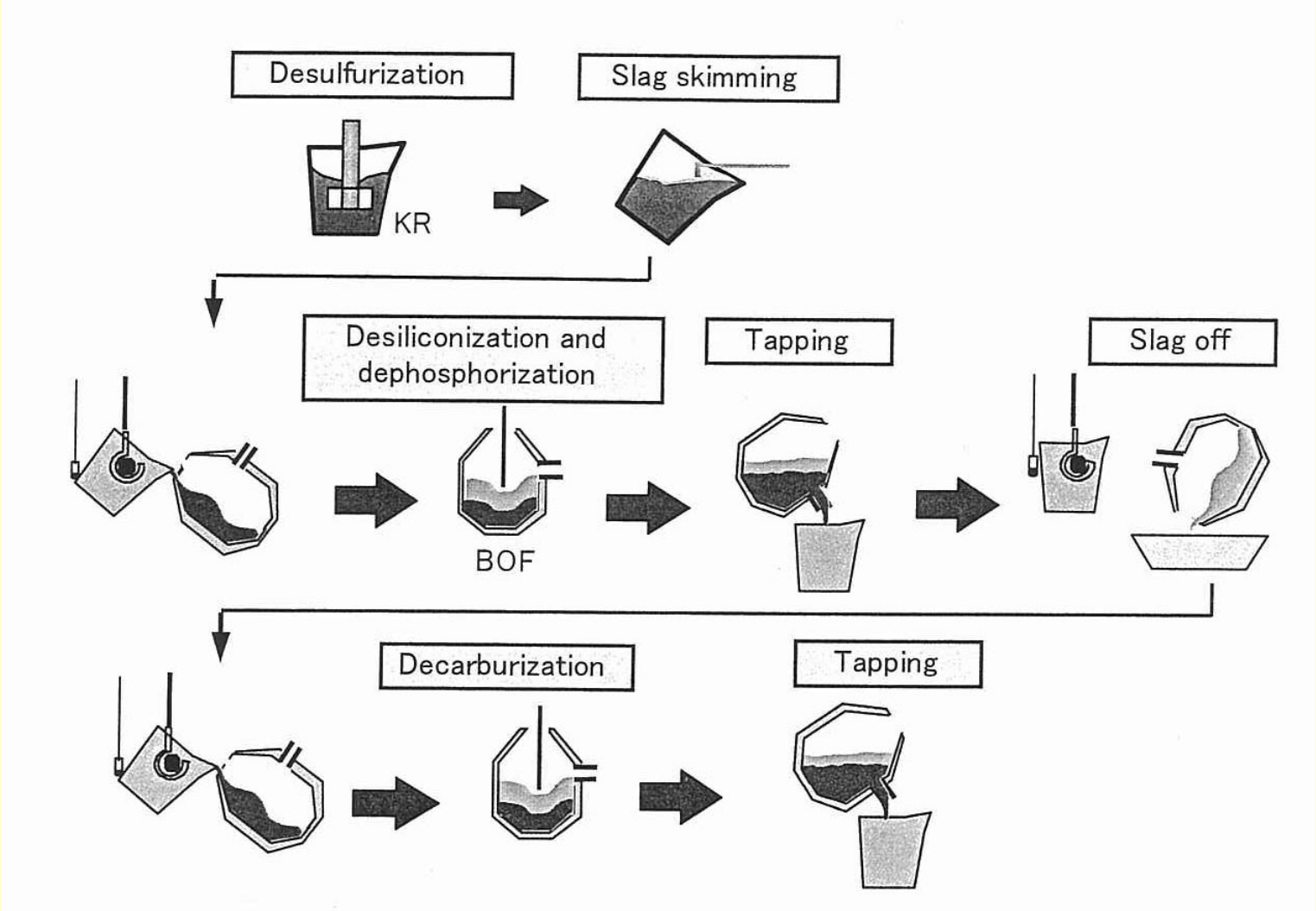
Process

	Free boad	Exhaust gas treatment	Stirring energy	Oxygen supplying rate	Oxygen gas ratio	Scrap melting	Initial investment cost
Injection Process	Small	Simple	Low	Low	Low	Impossible	Low
Top-and-bottom blowing converter	Large	OG System	High	High	High	Possible	High

Treatment condition

	Slag basicity	(T.Fe) content	De-Si before de-P	Addition of fluorspar	Slag foaming	Slag utilization
Injection Process	4-8	2-5	Imperative	Necessary	Small	Difficult
Top-and-bottom blowing converter	1-2	7-18	Not Imperative	Not Necessary	Large	Easy

KR desulphurization and LD-type dephosphorization (Kimitsu) [9].



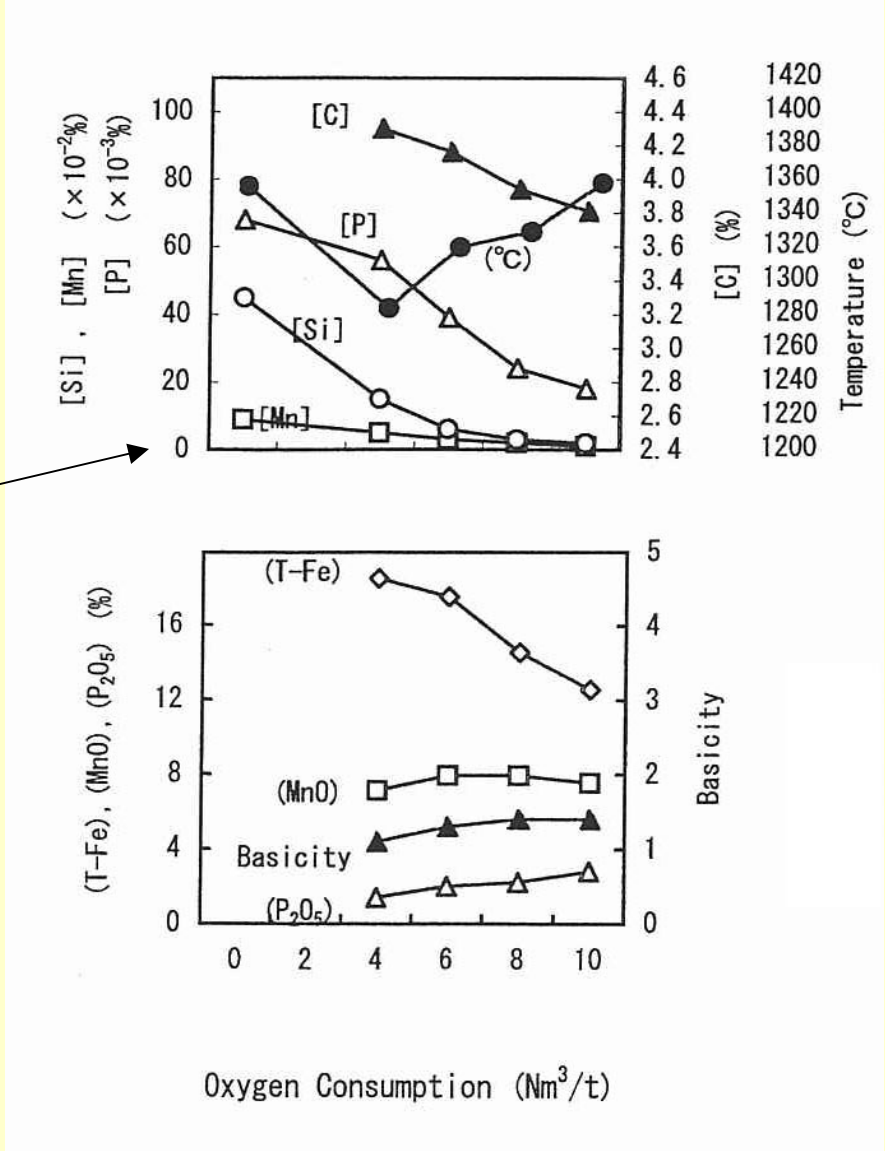
Manganese use in the LD-type process

For manganese use in the LD-type process,
manganese yield improvement
due to the decreased slag volume in the converter
can be obtained in the same way as using conventional technology.

However, a decrease in Mn during dephosphorization
cannot be avoided
due to increased %T.Fe and lowered basicity
during dephosphorization.

Evolution of chemical elements during desiliconization and dephosphorization at LD-type dephosphorization [10].

The [Mn] value goes down.



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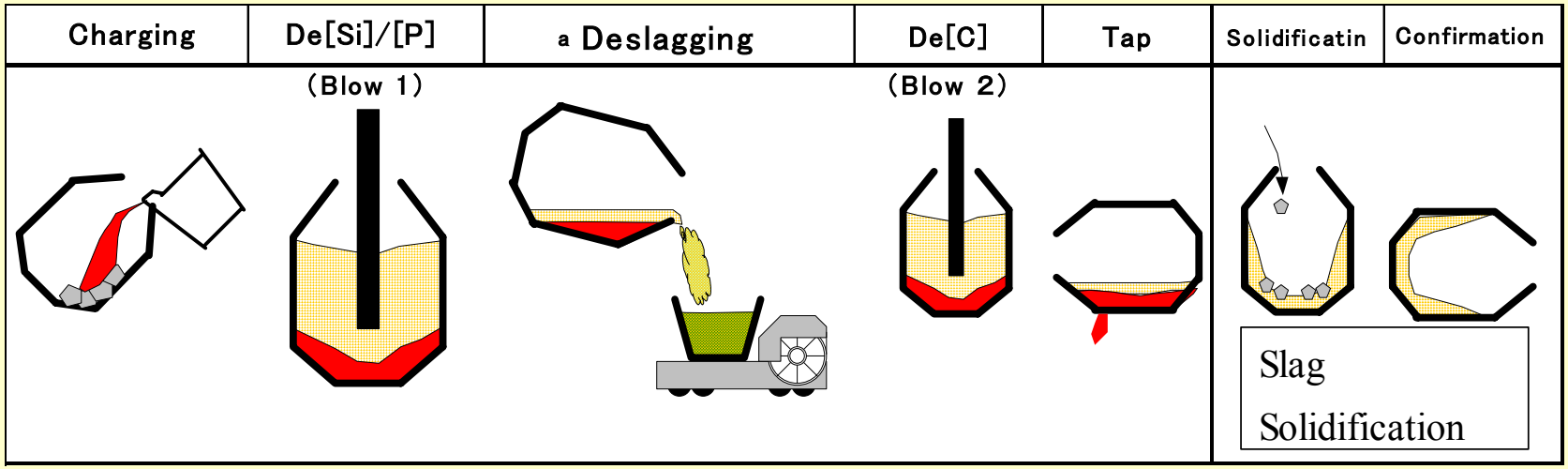
The Outline of MURC process （Oita） [11].



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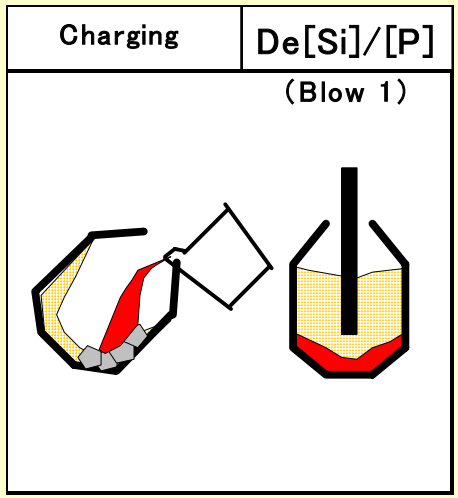


Speciality of MURC Process

・Low Basicity, High (T.Fe), Low Temperature →High Efficiency De[P]

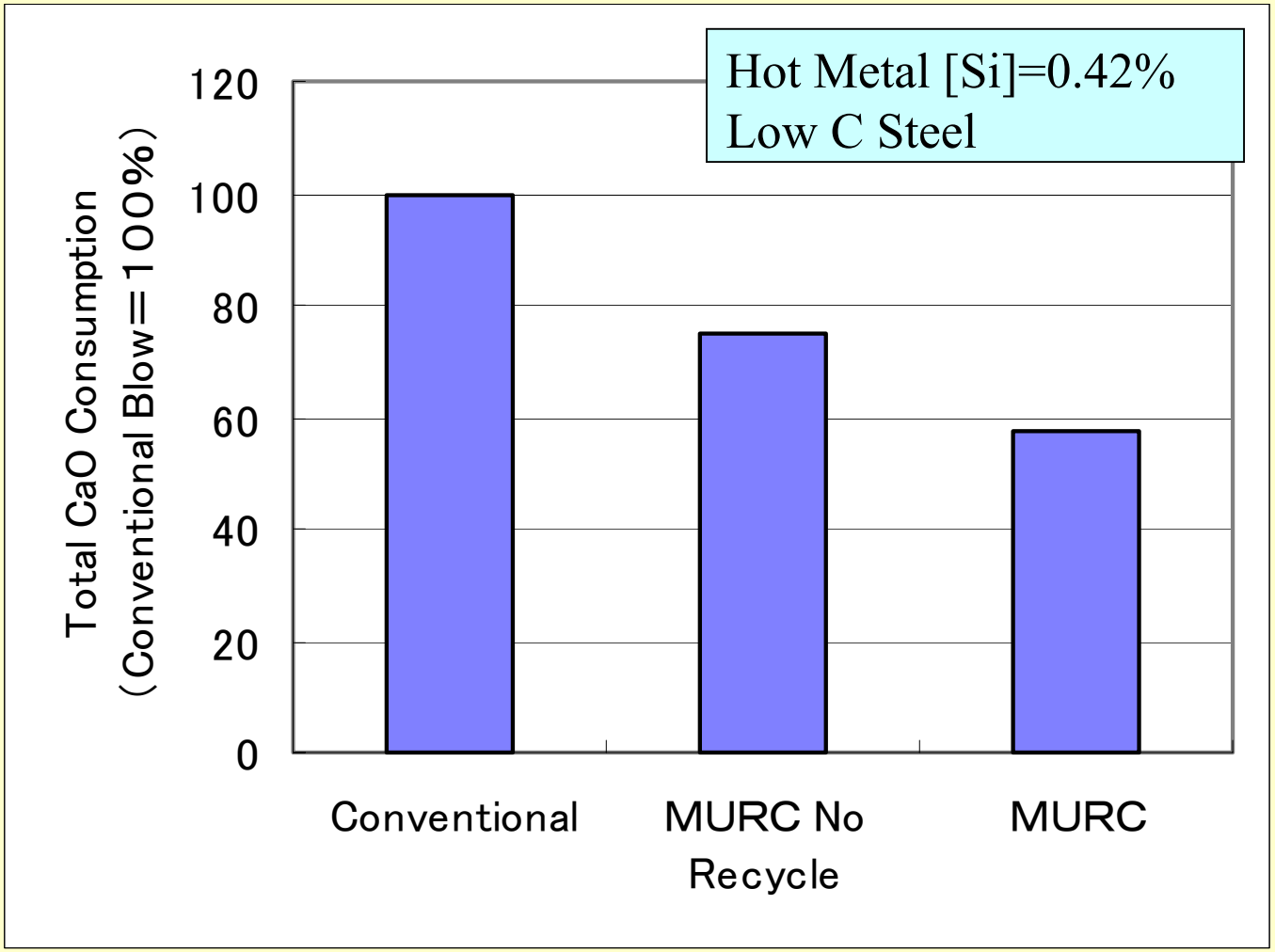
(CaO/SiO2≦2), (T.Fe)≧8%, (～1350℃)

・High Gaseous Oxygen Ratio,

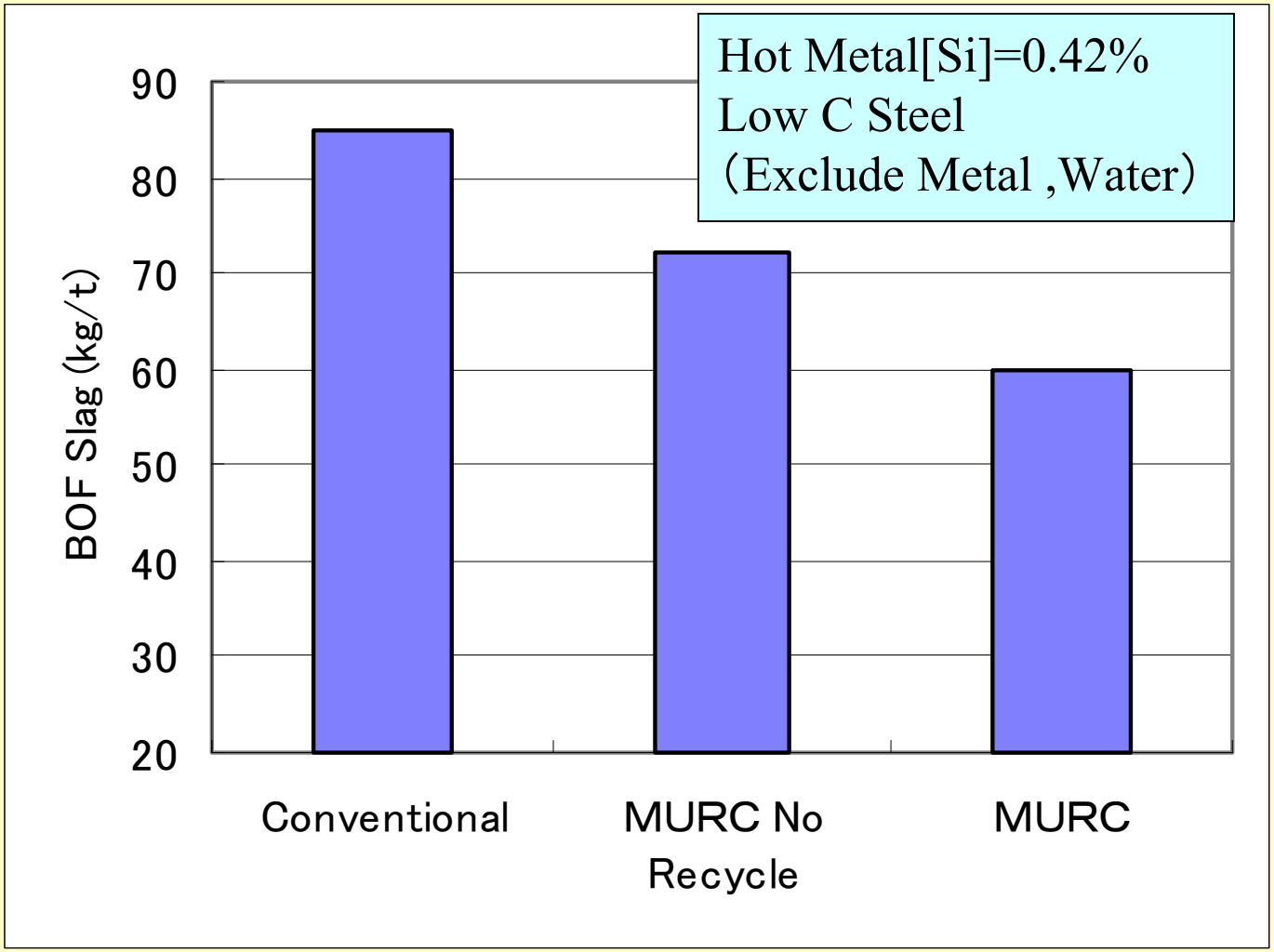
Low HMR Operation

・Slag Hot Recycle→Reduction of Slag

Reductionof lime consumption by MURC process [11].



Reduction of Slag Discharge by MURC process [11].



Manganese loss in the MURC process

Manganese loss in the MURC process increases as a result of low basicity and high %T.Fe during the dephosphorization process.

In addition, with dephosphorization and decarburization being operated continuously, the carry-over of phosphorus into the decarburization process increases, requiring light dephosphorization treatment in the decarburization process.

Since the smelting reduction of manganese ore becomes difficult with increased manganese loss, the turn-down [Mn] is consequently reduced compared to that in the conventional pretreatment process.

Manganese alloy in the LD-type pretreatment & MURC process

- **In the LD-type pretreatment method,**
  priority is given to using scrap and reusing or reducing slag,
  which is demanded by today's society.

- **On the other hand,**
  the MURC process focuses on improving heat loss
  and shortening the process time.

- **Neither technology emphasizes**
  reducing the volume of the Mn alloy used,
  So there is little or no reduction
  compared to the conventional pretreatment.

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Steel product needs

- Market demands related to steel products are becoming increasingly strict.
- There has been continuous cost reduction in the refining process and cost increase due to improved and upgraded quality of steel products.

→We shall examine the changes in improved and upgraded steel products using automobile sheet steel and heavy plate products as example.

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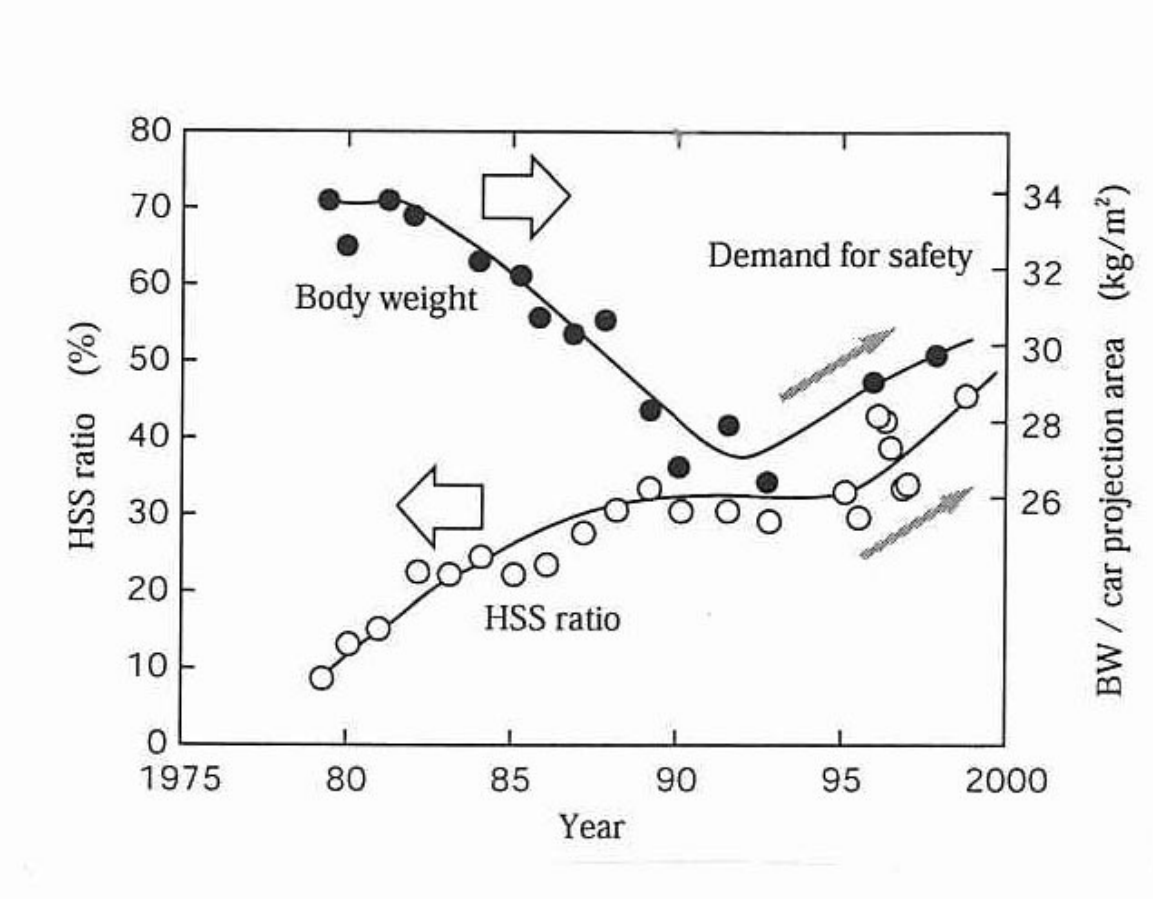
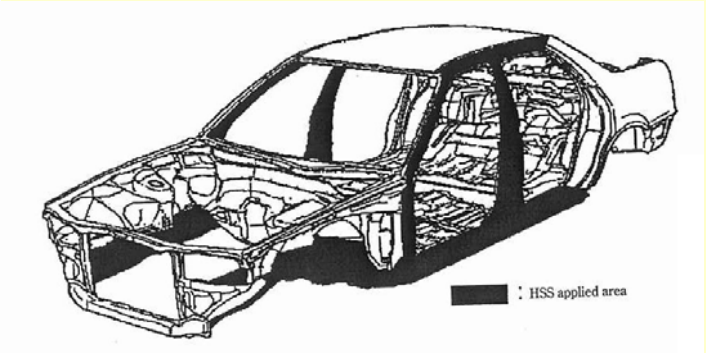
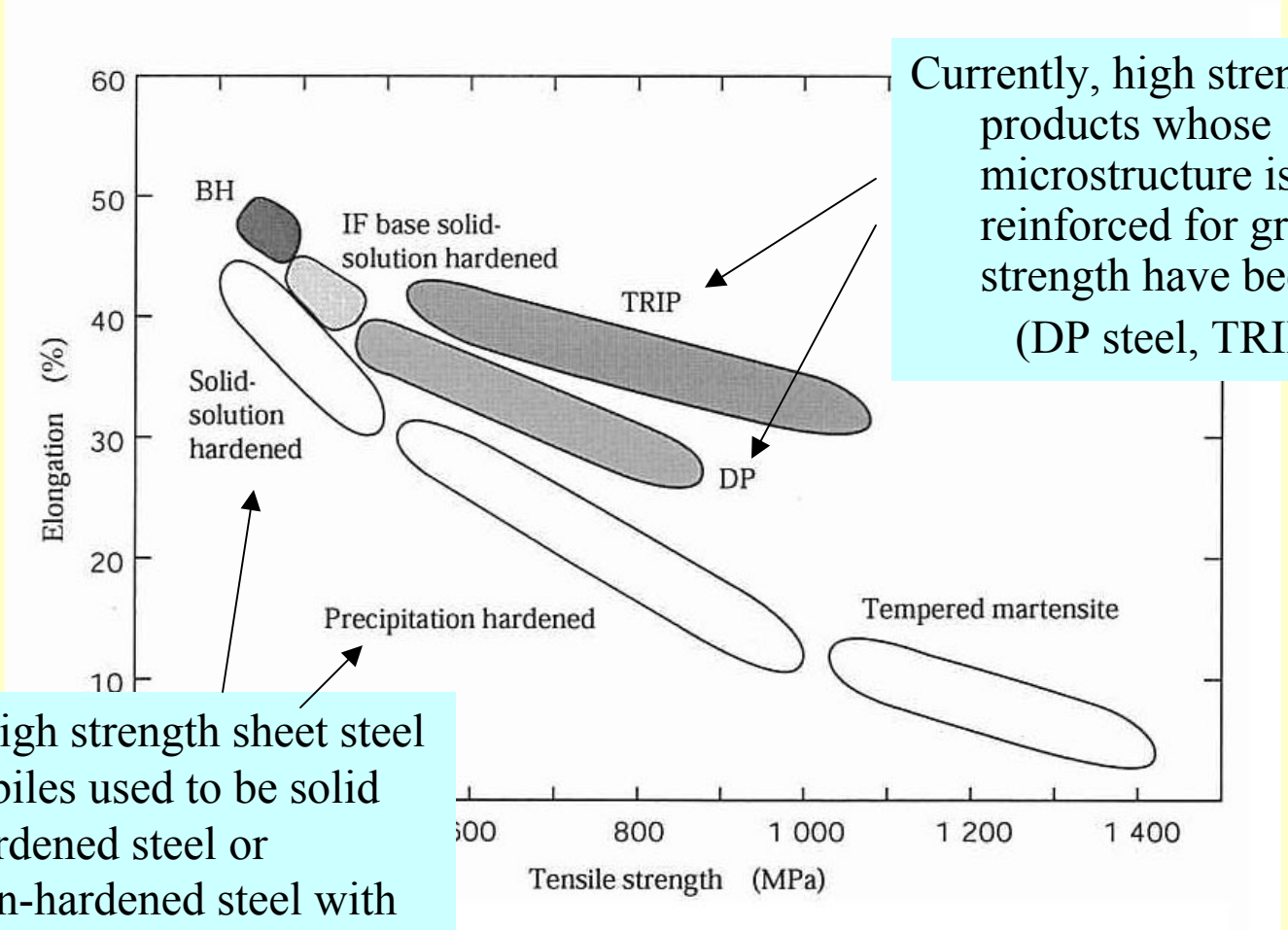
Trend of car weight and HSS ratio [12].





Application of TS 590 Mpa or higher steel to automobile [13].

Relation between tensile strength and elongation of HSS [14].



Currently, high strength steel products whose microstructure is reinforced for greater strength have been used.
(DP steel, TRIP steel)

Conventional high strength sheet steel for automobiles used to be solid solution-hardened steel or precipitation-hardened steel with alloy added.

Chemical compositions (mass%) and mechanical properties of the steels [15].

Type of steel	C	Si	Mn	Ti	Yield strength (Mpa)	Tensile strength (Mpa)	Elon-gation (%)
A Mild steel	0.05	0.01	0.24	–	241	384	43
B Solid solution hardened steel	0.08	0.02	1.46	–	370	487	30
C DP steel	0.05	0.89	1.25	–	432	618	27
D Precipitation hardened steel	0.09	0.01	0.80	0.07	539	636	22
E TRIP steel	0.15	1.48	0.99	–	510	644	37

1. Introduction
2. Behavior of Mn in the Steel-making process
3. History of Process Improvement and Influence on Manganese
    (1) Top-and-Bottom blowing converter
    (2) Hot metal pretreatment
    (3) LD-type hot metal pretreatment
    (4) MURC process
4. Steel product needs
    (1) Automobile sheet steel
    (2) Plate products
5. <u>Future Development</u>

Needs of the refining process and transition of the hot metal pretreatment process

Evolution of the hot metal pretreatment process	Needs of the refining process in each period
～1982 ・Small-quantity ・Low-P steel manufacturing process	Improvement in steel quality - Low-P steel manufacturing
1982～ ・Mass production process ・TPC type, Ladle type	Energy saving - Reduction in T.CaO (auxiliary material) - Improvement in iron yield - Reduction in Mn alloys
1999～ ・Mass production process ・LD type	Rationalization→Expansion of productivity Reduction in slag volume and reusing of slag
Process in future	Environmentally conscious product technology - Low environmental load - Minimized emission from the system: slag and dust - Reducing and recycling slag and dust - Reusing slag and dust - Reusing and recycling waste - Tires, automobiles and glass Process featuring high degree of freedom of material (High efficiency dephosphorization and desulphurization, and an economical source of heat) - Adjustability for high-phosphorus and high-sulfur hot metal (high-phosphorus ore and high-sulfur fuel) - Utilization of low-grade steel scrap and dust

Conclusion

As for manganese use in the process in view of the above prospects, we can assume that the smelting reduction of manganese ore in the converter will not be actively employed in the future since it decreases the scrap usage rate, increases slag generation and results in a low yield level of manganese; this is on the condition that the Fe-Mn price remains very economical.

As long as the main technological concern in the refining process focuses on improving the main reaction, namely dephosphorization, the supply of manganese that has different reactive characteristics will take the form that adds alloys.

The advantages of steel materials over other materials include volume, price, strength, toughness and versatility. For the above sheet steel and plate products, the need for higher grade, higher quality, and meeting strict requirements will grow in the steel market. The base for developing higher grade, higher quality steel products will be the addition of alloys to steel materials.

Fe-Mn alloys, especially low carbon alloys, will be in much greater demand from now.

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