

Japan's experience and prospect on resource management of metals: policies, strategies, and technologies

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Graduated Tohoku Univ. in 1980
Ph.D at Tohoku in 1985
Assist. Prof. at Tohoku 1985
Res. Assoc. at Carnegie Mellon Univ. USA in 1993
Prof. of Environmental Studies in 2001
Now Prof. Graduate School of Engineering



Major
Physical-chemistry on iron- and steelmaking
MFA and LCA



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Question

“Are metals, such as aluminum, copper, steel, etc., well recycled in our society?”

Answer

In the view point of quantity, YES.

But

In the view point of quality, NO



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What I want to tell you today is

1.

“Metals used in our society are mostly in the form of alloy rather than pure metals”

Exceptions

copper wire

aluminum foil

CP-Ti (commercially pure titanium)

other very minor products for special use



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What I want to tell you today is

2.

“Suppliers of primary metal resources (natural ore) are quite limited”

Mineral resource majors in the world

Vale (Brazil: iron ore)

Rio Tinto (UK, AUS: iron ore, coal, aluminum, copper)

BHP Billiton (AUS, UK: iron ore, coal, aluminum, copper)

Inco etc.



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Solution

“A country which does not have enough natural metal resources should recycle metal products with keeping their quality”

It is easy to say so but not easy to do so.



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Structure of environment related regulations in Japan

The Basic Environment Law

The Basic Law for Establishing the Recycling-based Society

Law Concerning Waste Disposal and Scavenging (Waste Disposal Law)

Law for Promotion of Effective Utilization of Resources

Construction Material Recycling Law

Law for Promotion of Sorted Collection and Recycling of **Containers and Packaging**

Law for Promotion of Recycling and Related Activities for Treatment of Cyclical **Food**

Resources

Law for the Recycling of Specified Kinds of **Home Appliances**

Law for the Recycling of **End-of-Life Vehicles**

Law on Promoting Green Purchasing)

Metal resources
related laws

<http://www.env.go.jp/en/laws/>



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Law for the Recycling of Specified Kinds of Home Appliances

Target products

Air conditioner



CRT (TV with Cathode-ray tube)



Refrigerator, Freezer



Washing machine



* Flat panel display



* Clothes dryer

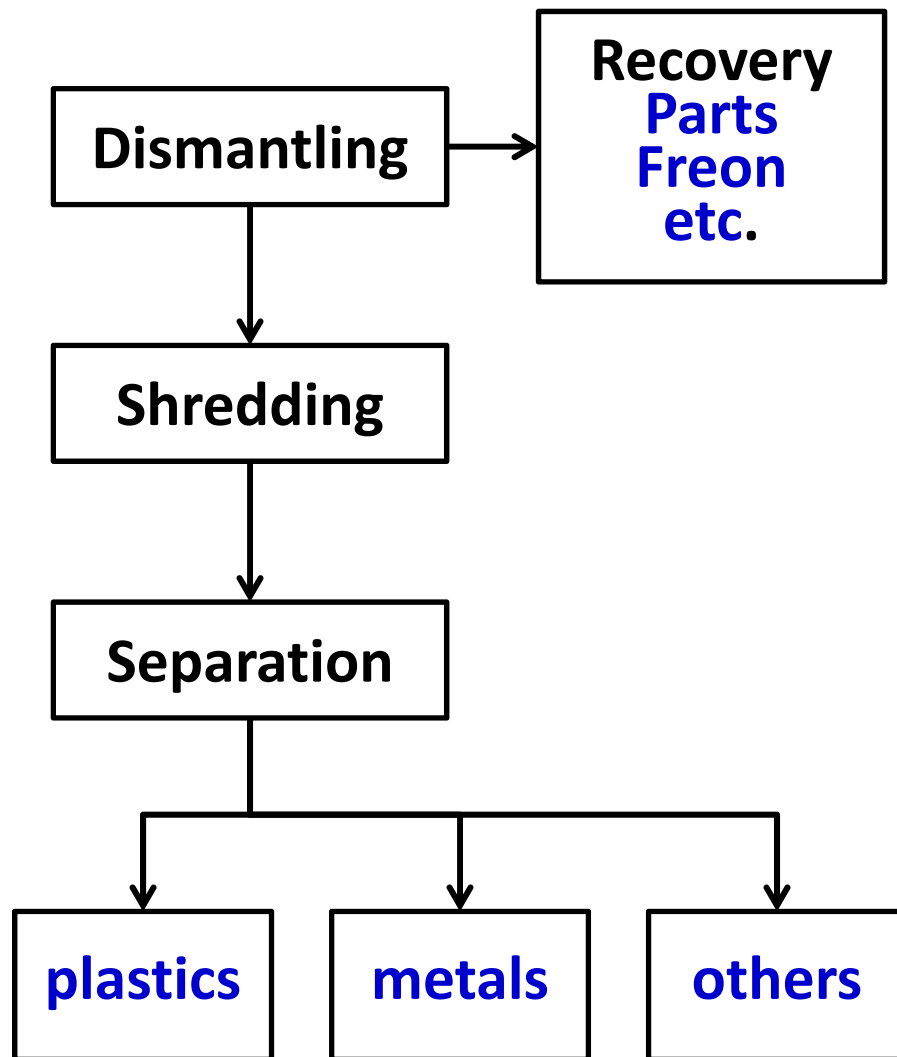


* from 2009



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Law for the Recycling of Specified Kinds of Home Appliances

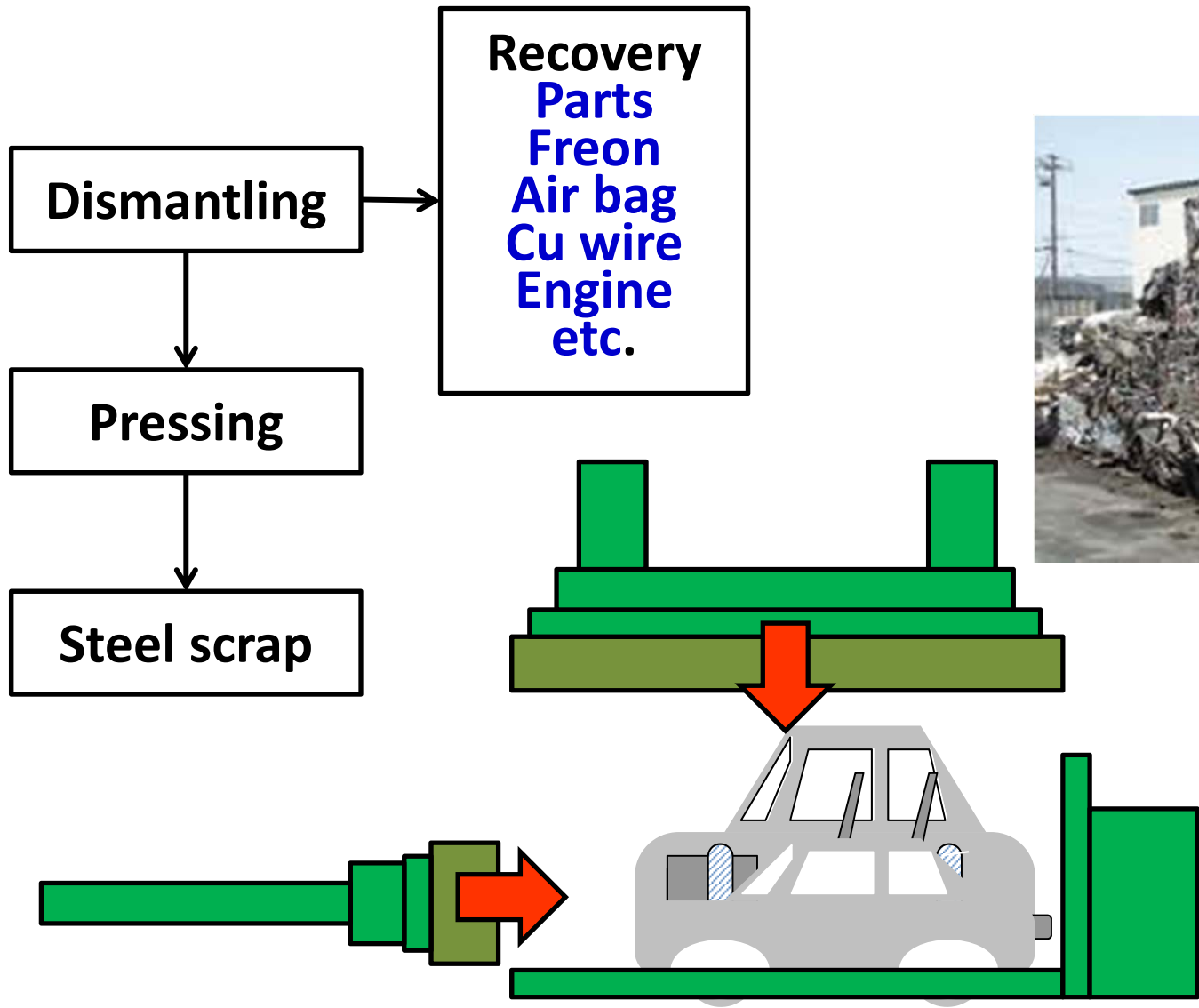


For example, East Japan Recycling Systems Corp.
<http://www.ejrs.co.jp/index.html>

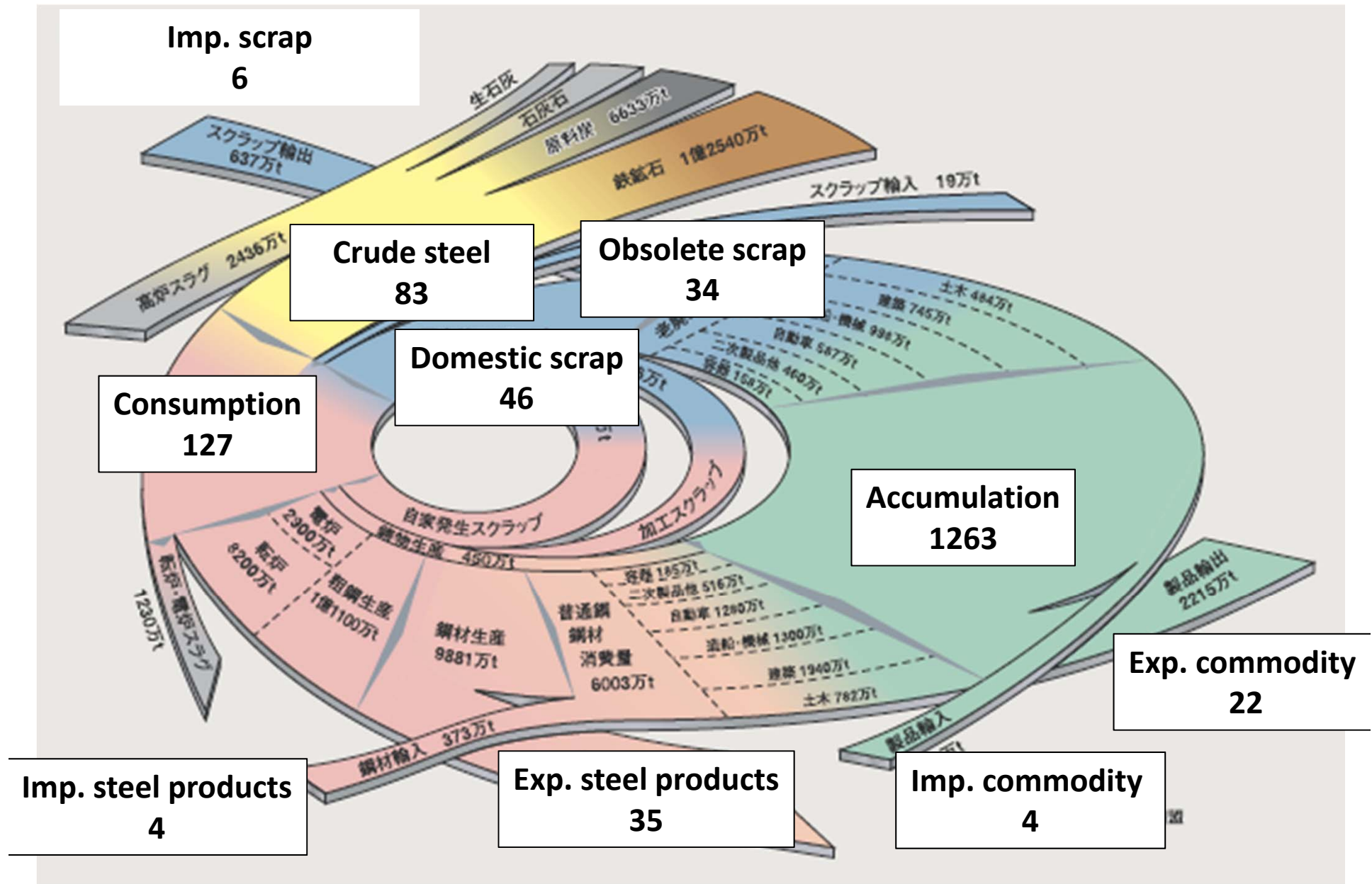


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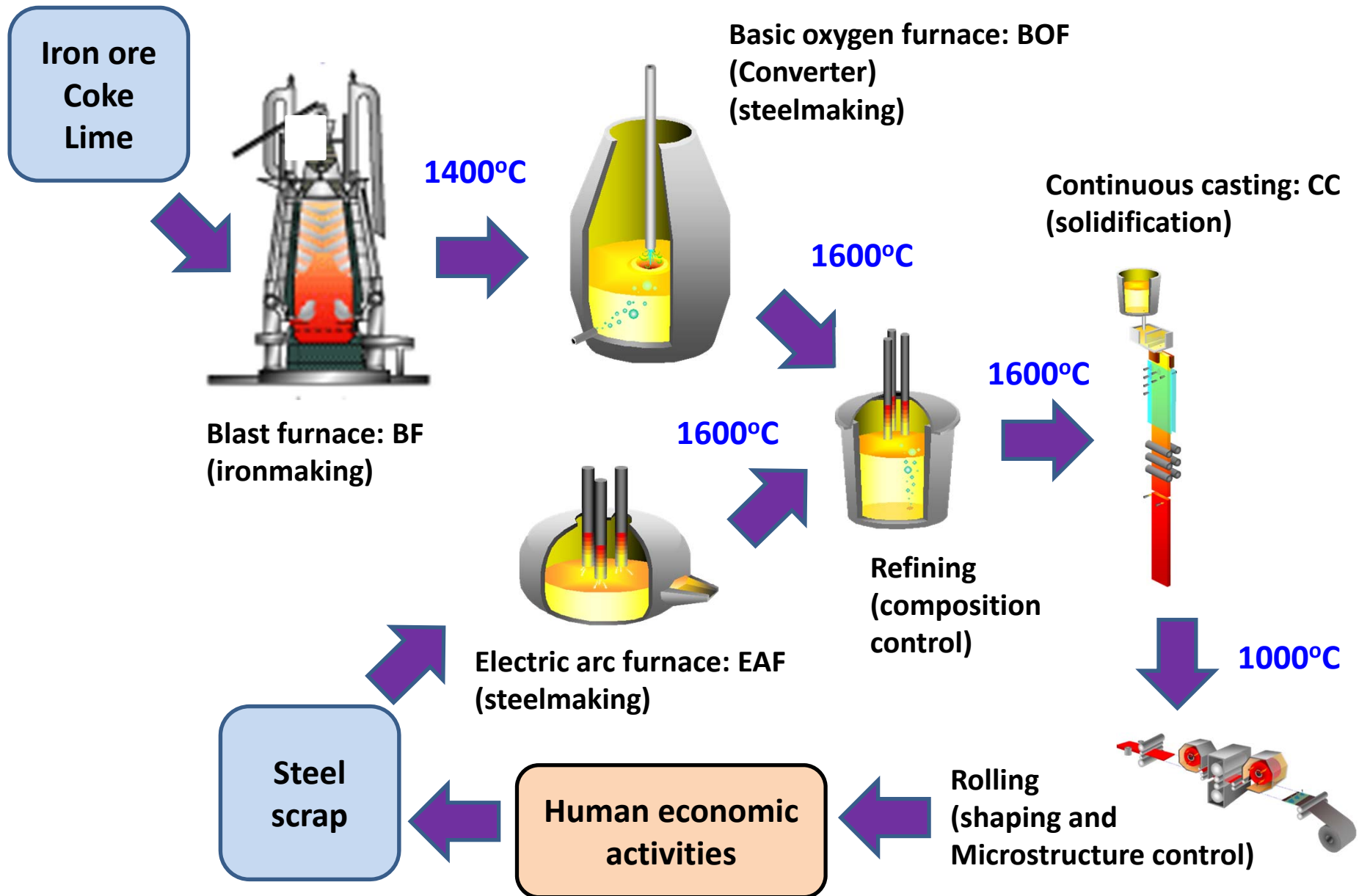
Law for the Recycling of **End-of-Life Vehicles (ELV)**



Iron and steel cycle in Japan (2003) source:JISF



Iron and steelmaking process



We should know

***“Steel is not pure iron.
Steel is alloy of iron (Fe) with other
various kinds of metals.
Big steel company produces more
than 1000 kinds of steel products
which have different shape and
composition ”***

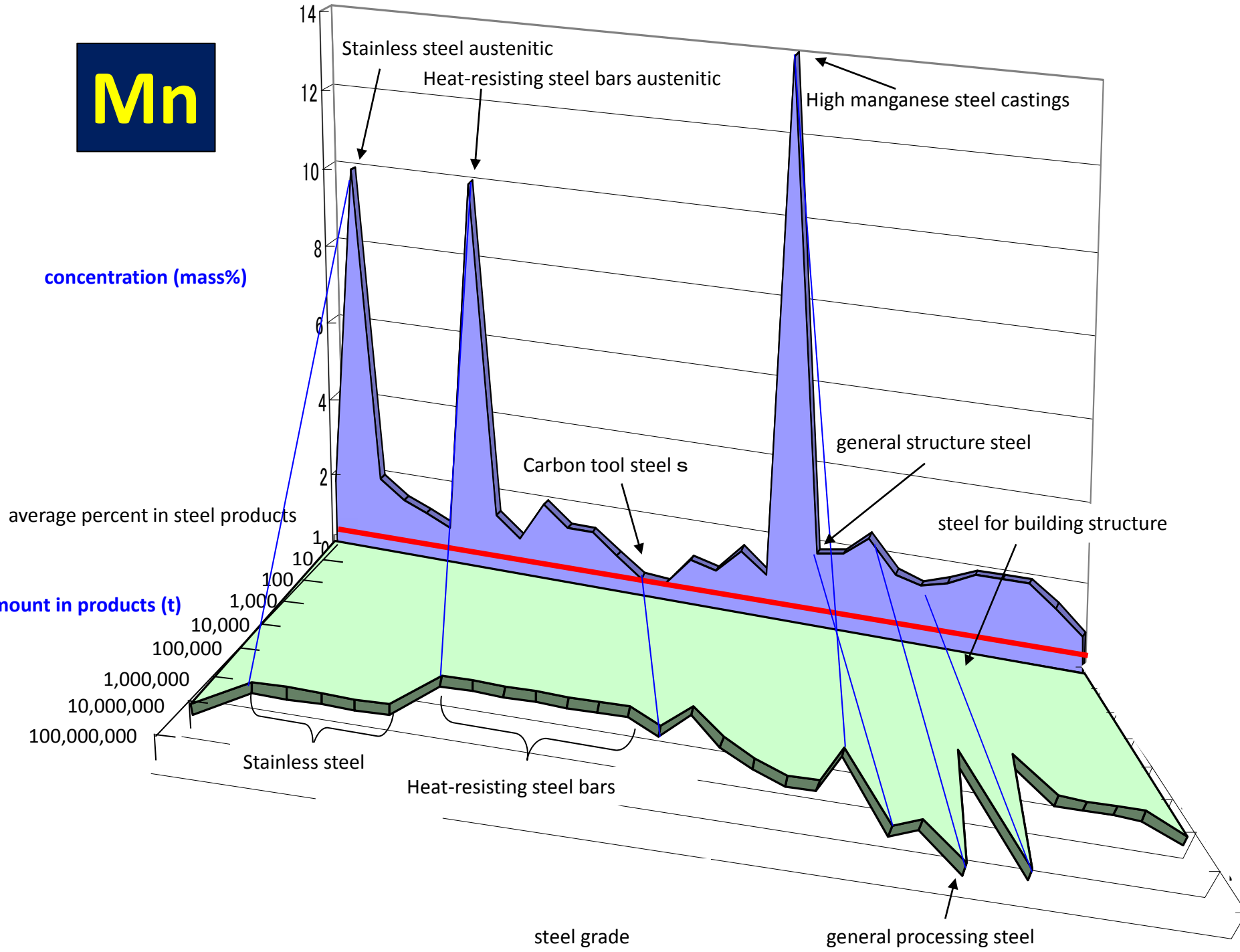


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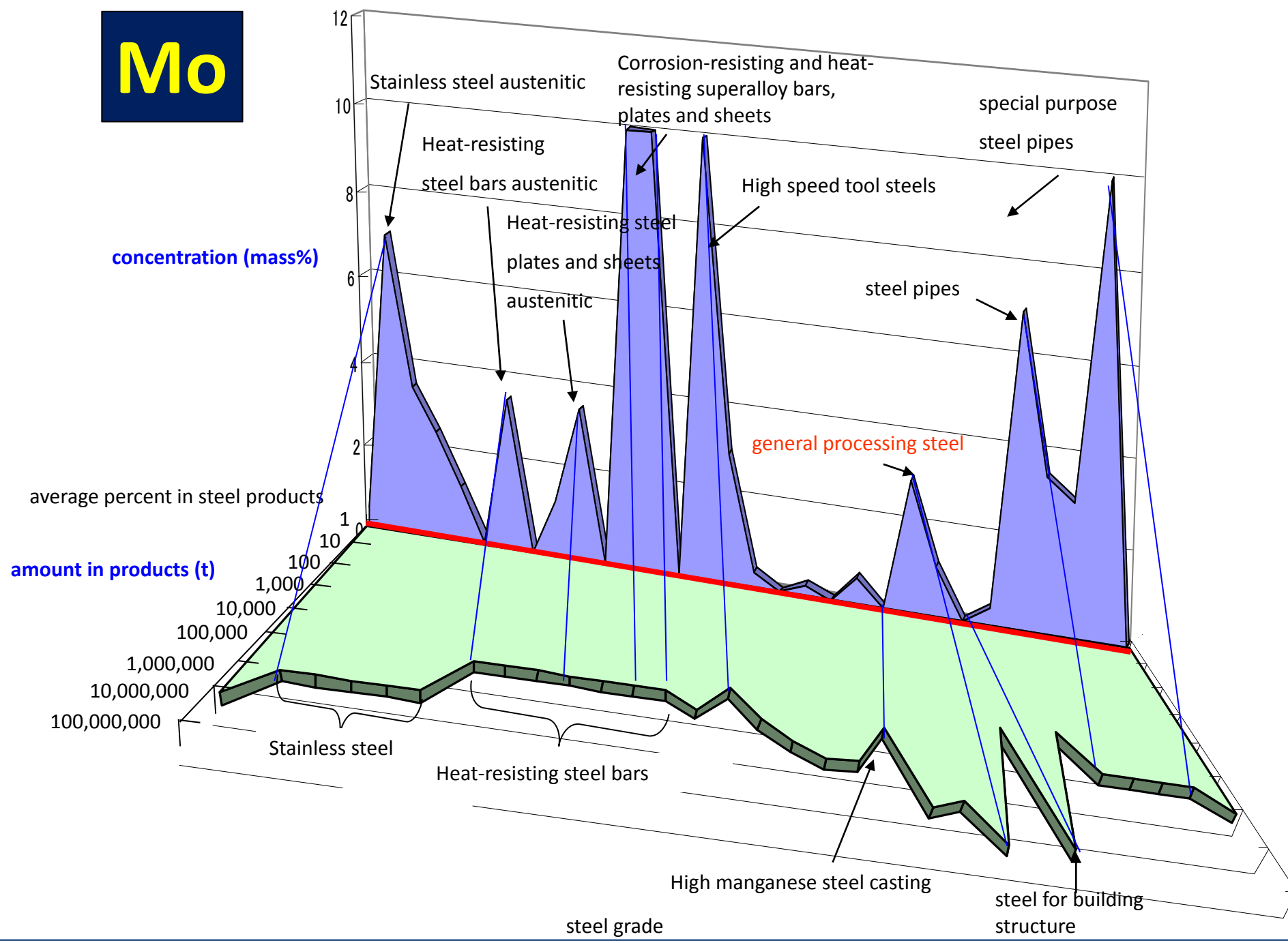
Mn

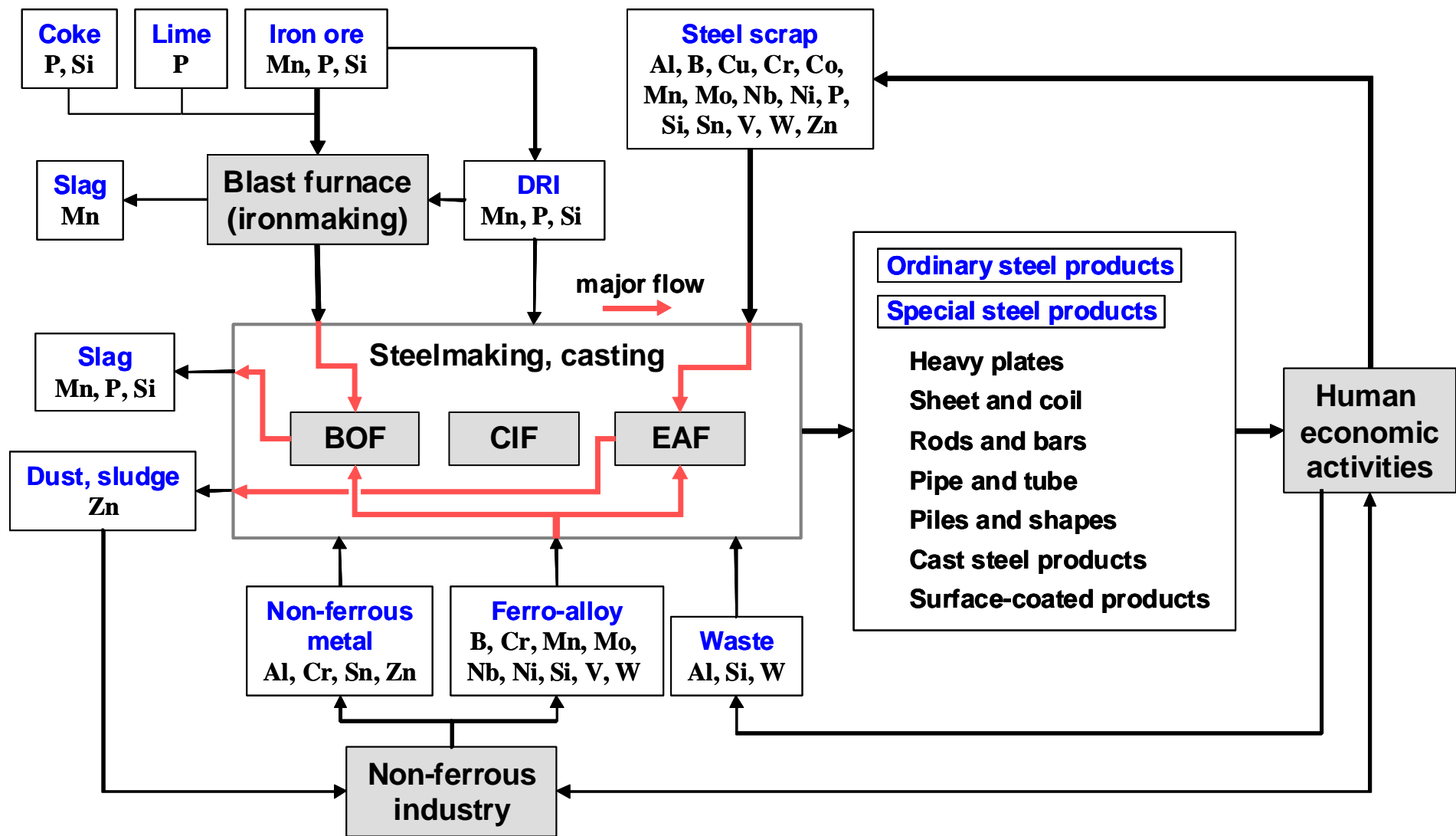
concentration (mass%)

amount in products (t)



Mo





Rare metals in the life-cycle of steel products

We have three major concerns for the sustainable steel recycling

1) Contamination by or loss of alloying elements, which are mostly important resources, in the usage of steel scrap as iron resource

Development of “scrap soating system based on composition”

2) Significant loss of valuable elements into slag during steel refining processes

Development of “slag-making technology” to recover P, Mn and Cr

3) unefficient intermediate process for dust treatment

Development of “dust-making technology” to recover Zn

Classification of rare metals used in steel

T. Nagasaka: Study on global flow of Metals- An example of material recycling -, Report of ISIJ (2008)

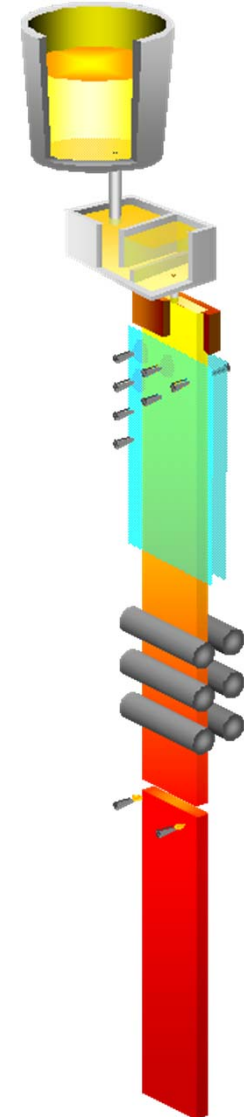
type	Element			
Well-used	Fe	C		
Passed through	Si	P	S	
One way diffusion	Mn	Mo	Nb	V
Partial circulation	Cr	Ni		
Waste accepted	W	Al*	Zn	



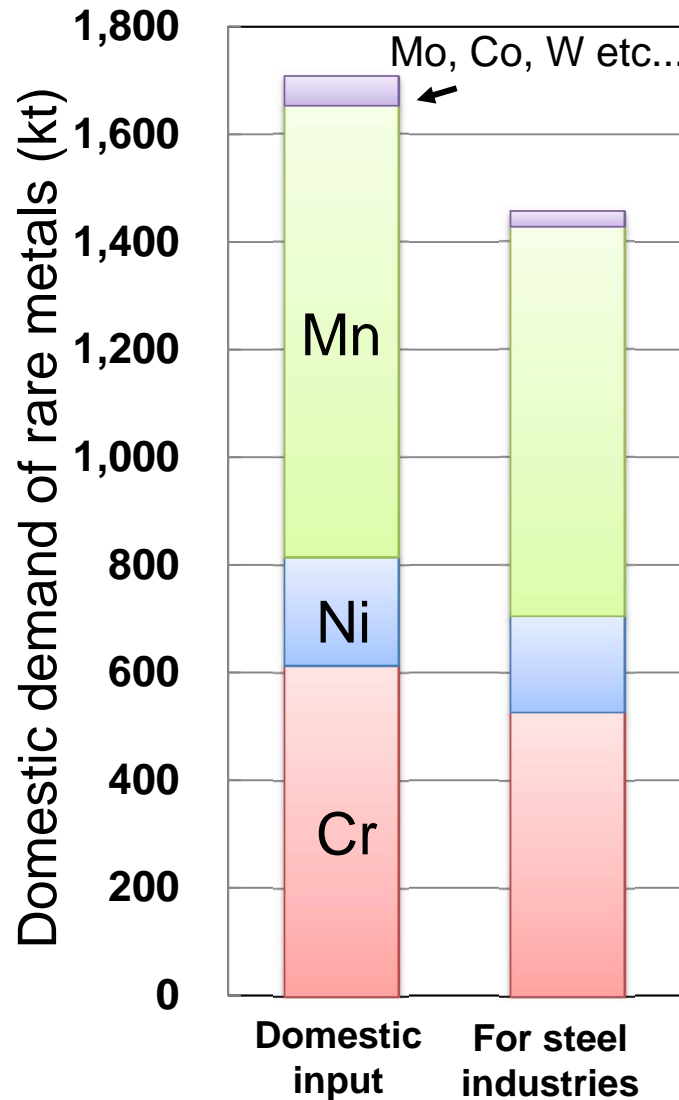
MFA is done in Tohoku

* including dross

Red: concentrated one in steel industry



Non-ferrous metal consumption (Al, Cu are not included)

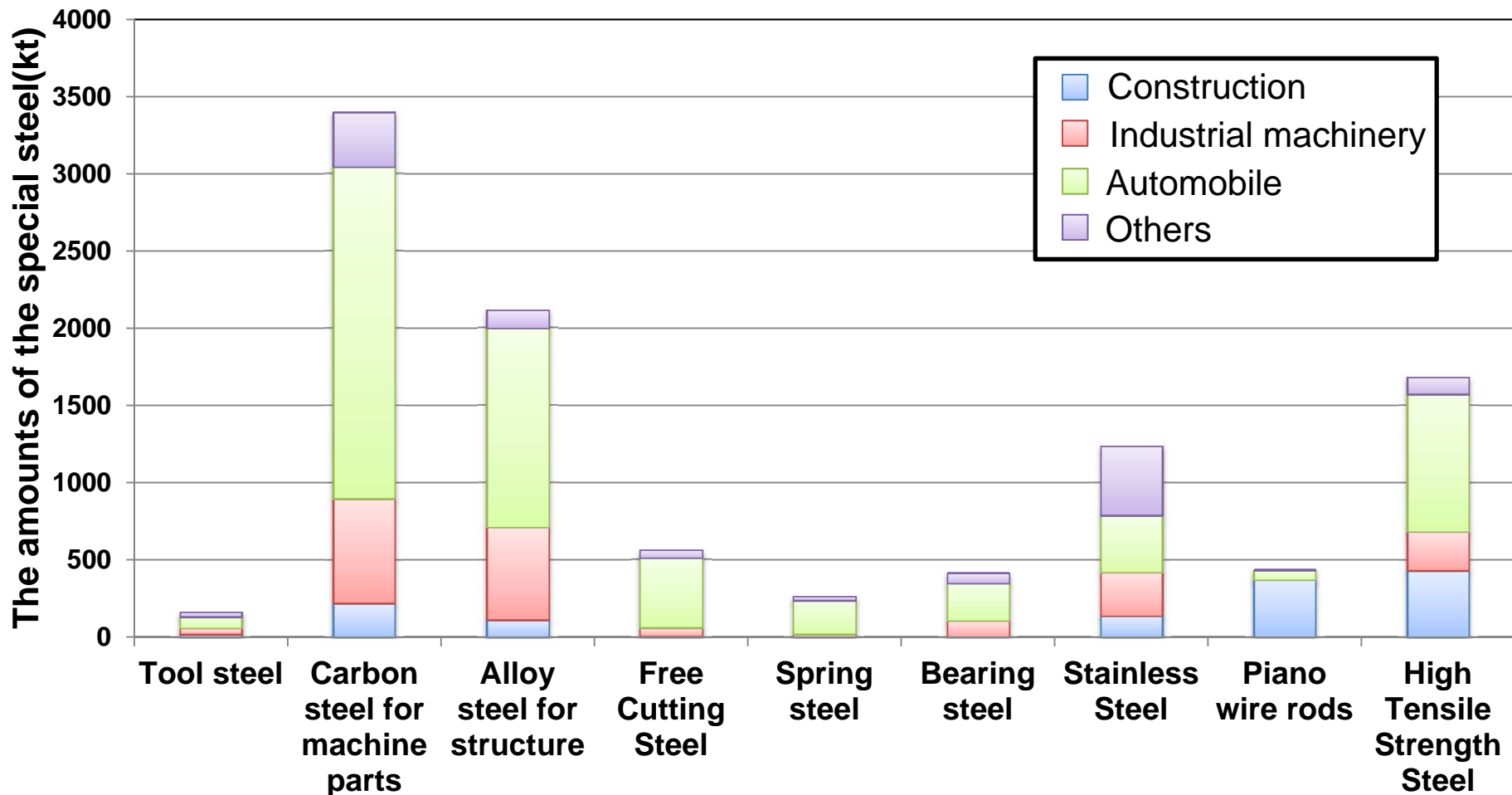


Steel industry use huge amount of other metals

- These metals are used to produce special steel material as alloying elements

Fig. The demand of rare metals for steel industries(2008)

Special steel consumption



Classification of the special steel

Fig. The amounts of the special steel consumption by industries(2008)

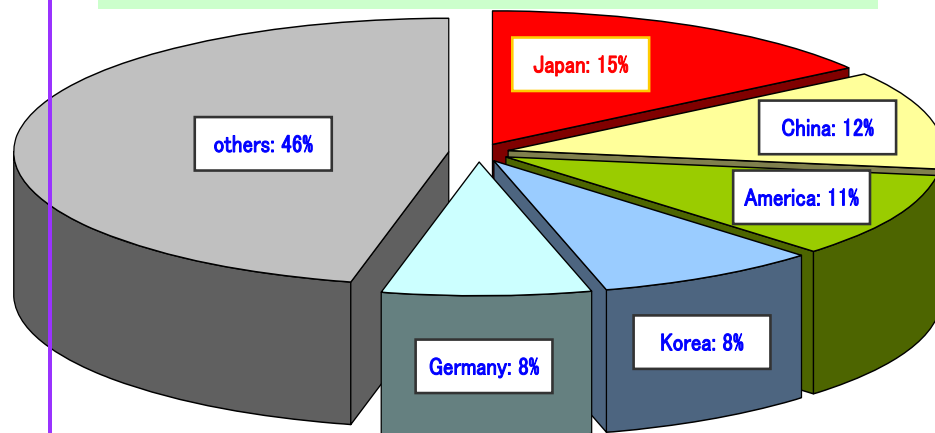
- Automobile industry is the largest user of special steel products, indicating that ELVs contain a significant amount of non-ferrous metals



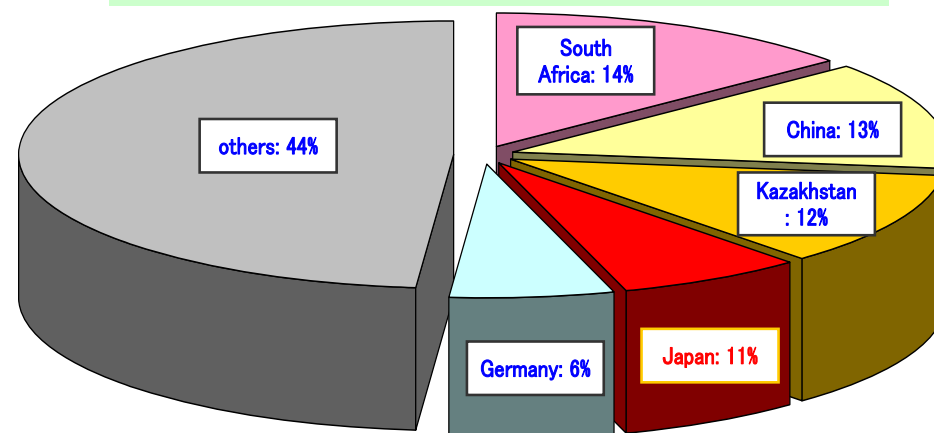
Demand of rare metals in the world

Large amount of rare metals are consumed in Japan. On the other hand, it is expected to **increase consumption** of rare metals **in other Asian countries** (China, Korea...) with industrial development.

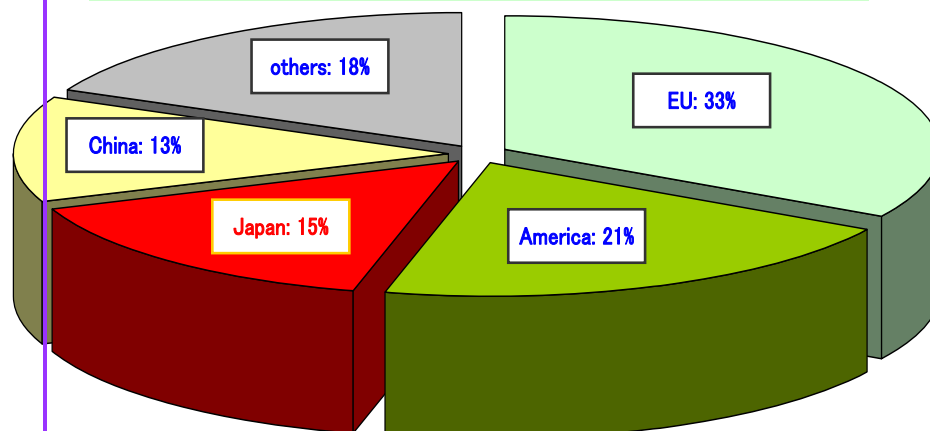
(a) Ni, Consumption(World) :
 $1,253 \times 10^3$ Ni-t (2004)



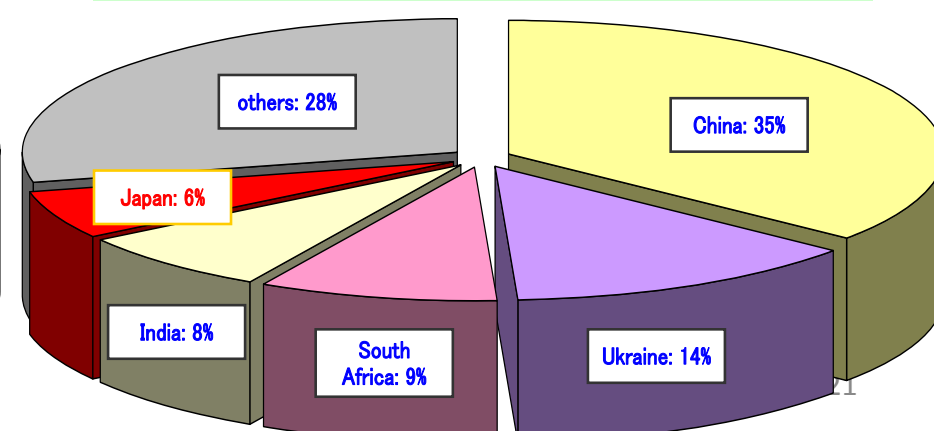
(b) Cr, Consumption(World) :
 $4,695 \times 10^3$ Cr-t (2003)



(c) Mo, Consumption(World) :
 175×10^3 Mo-t (2004)



(d) Mn, Consumption(World) :
 $19,630 \times 10^3$ t (2001)



Iron and steel cycling

Steel is first produced from iron ore

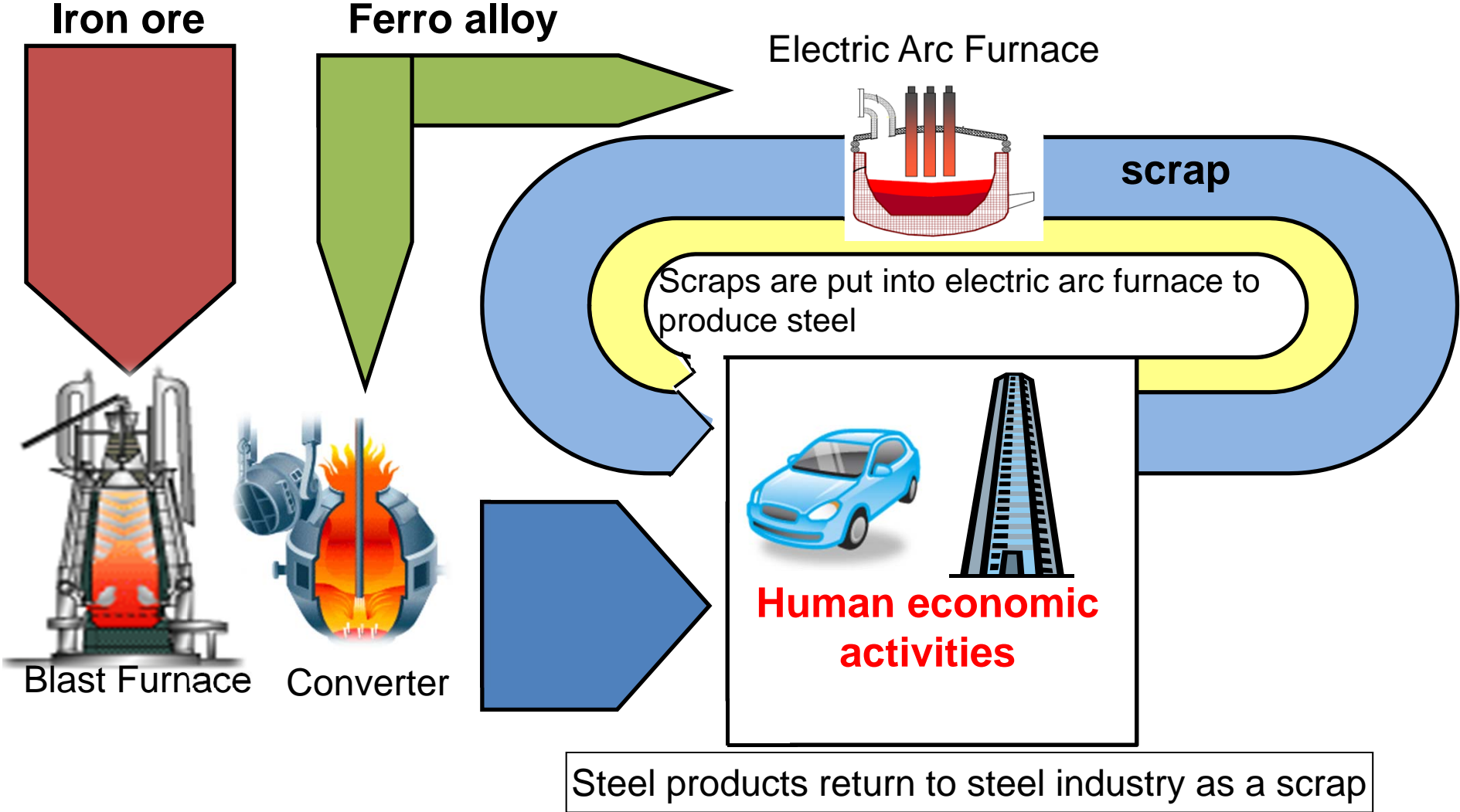
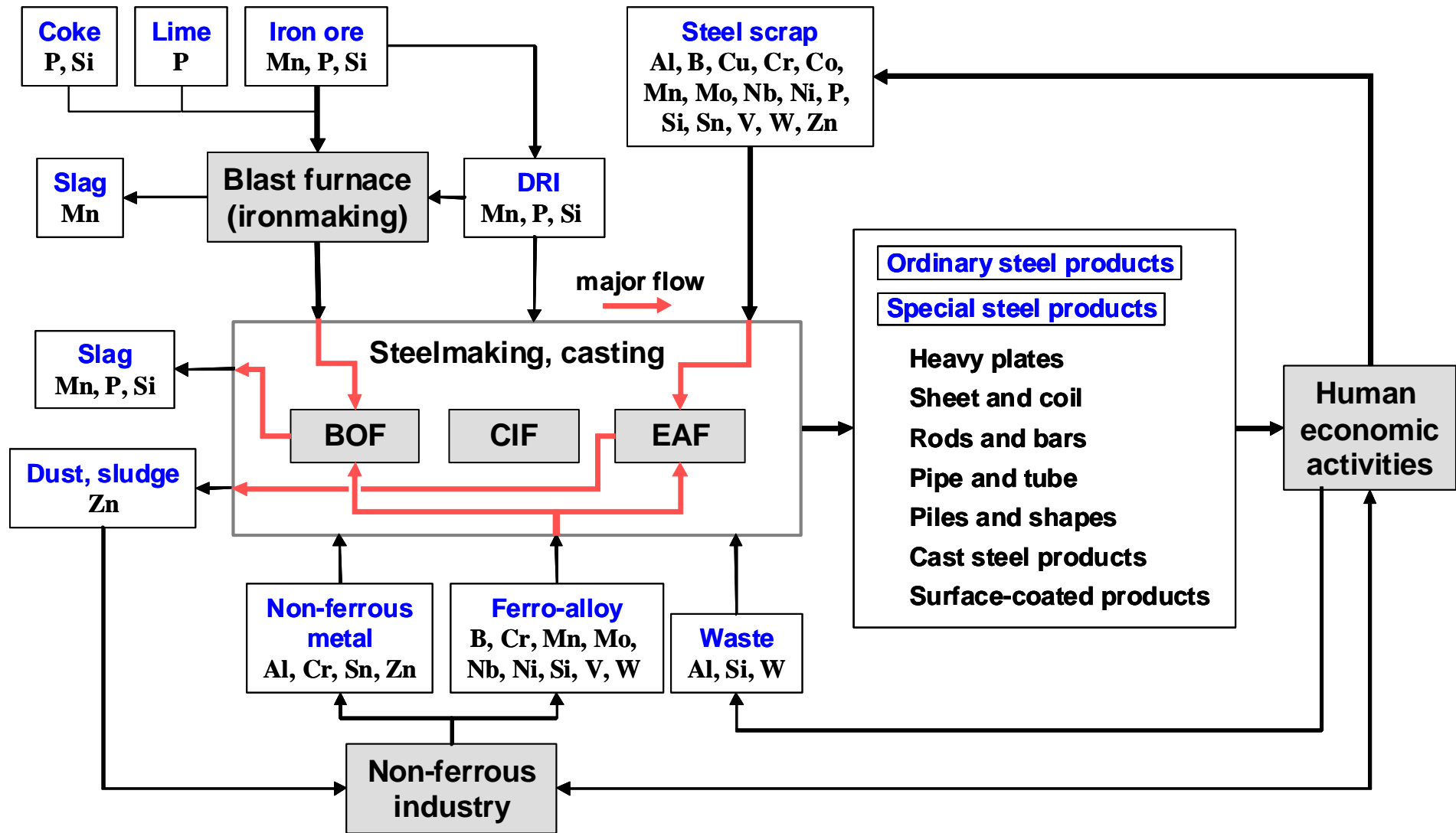


Fig. Schematic diagram of Iron and steel cycling in Japan

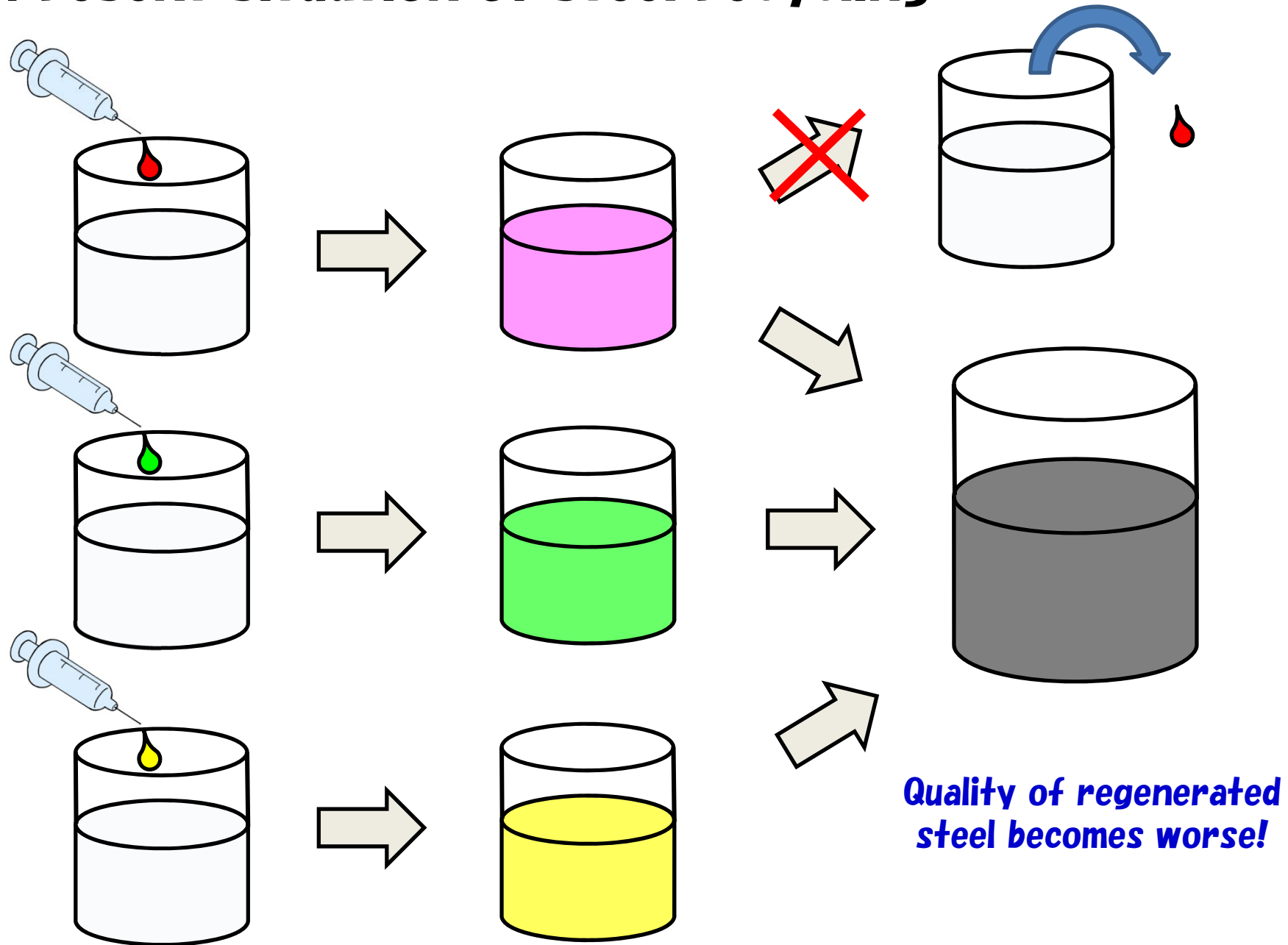
• Steel products produced from scrap account for about 30%

What about "scrap-sorting" ?



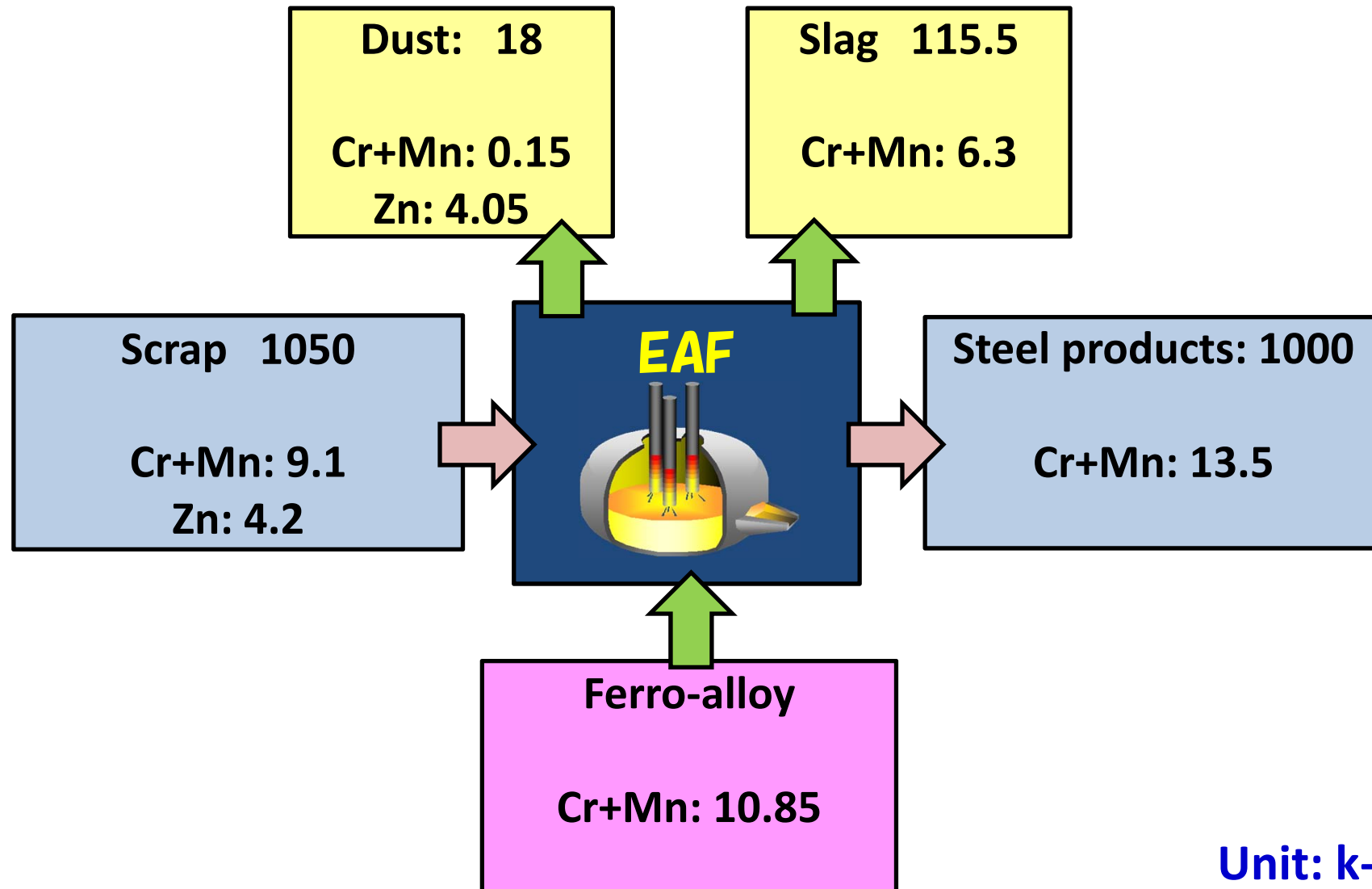
Rare metals in the life-cycle of steel products

Present situation of steel recycling



Rare metals (Cr+Mn+Zn) balance in EAF process

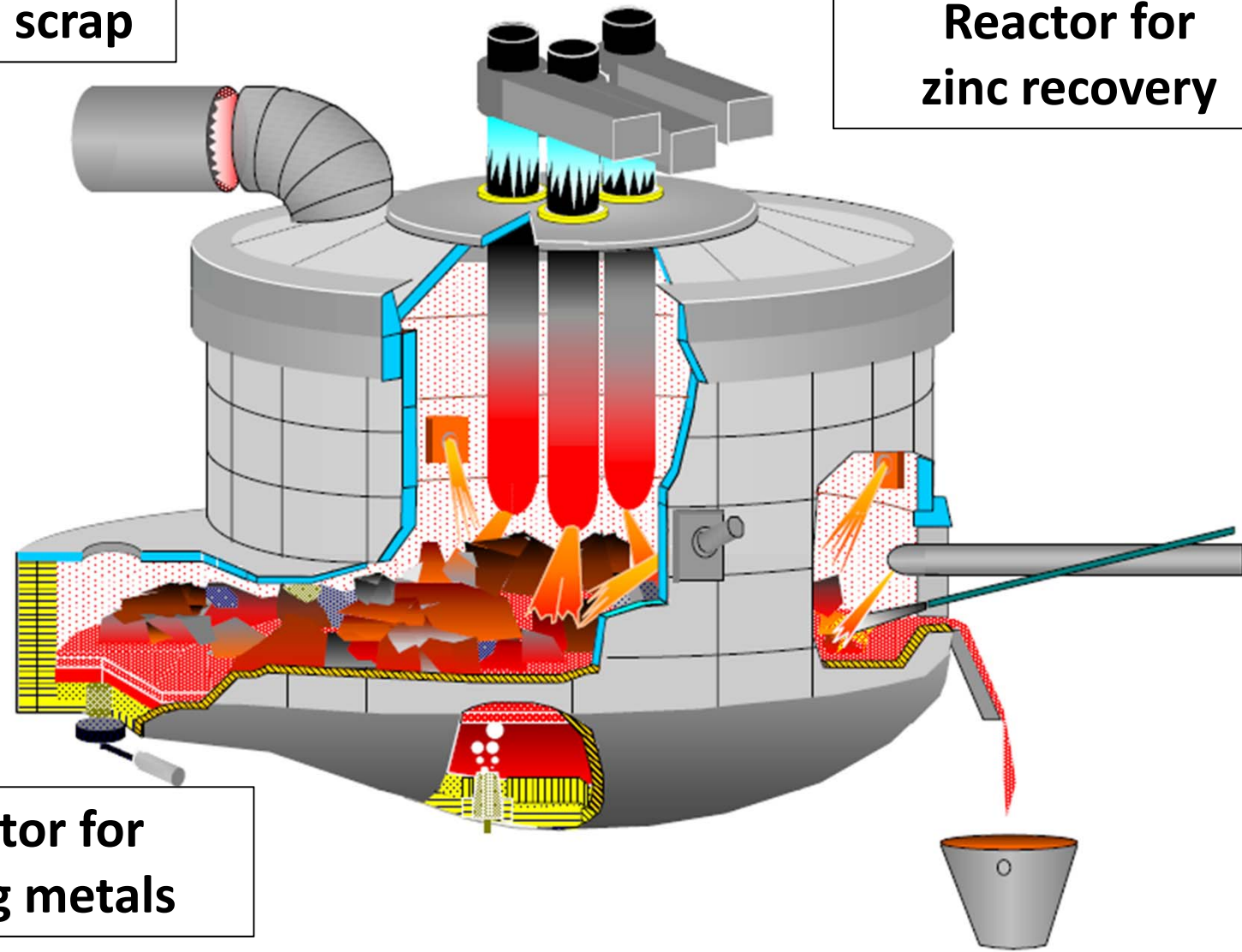
Average of three steel works which produce about 1000 k-ton/year



EAF process

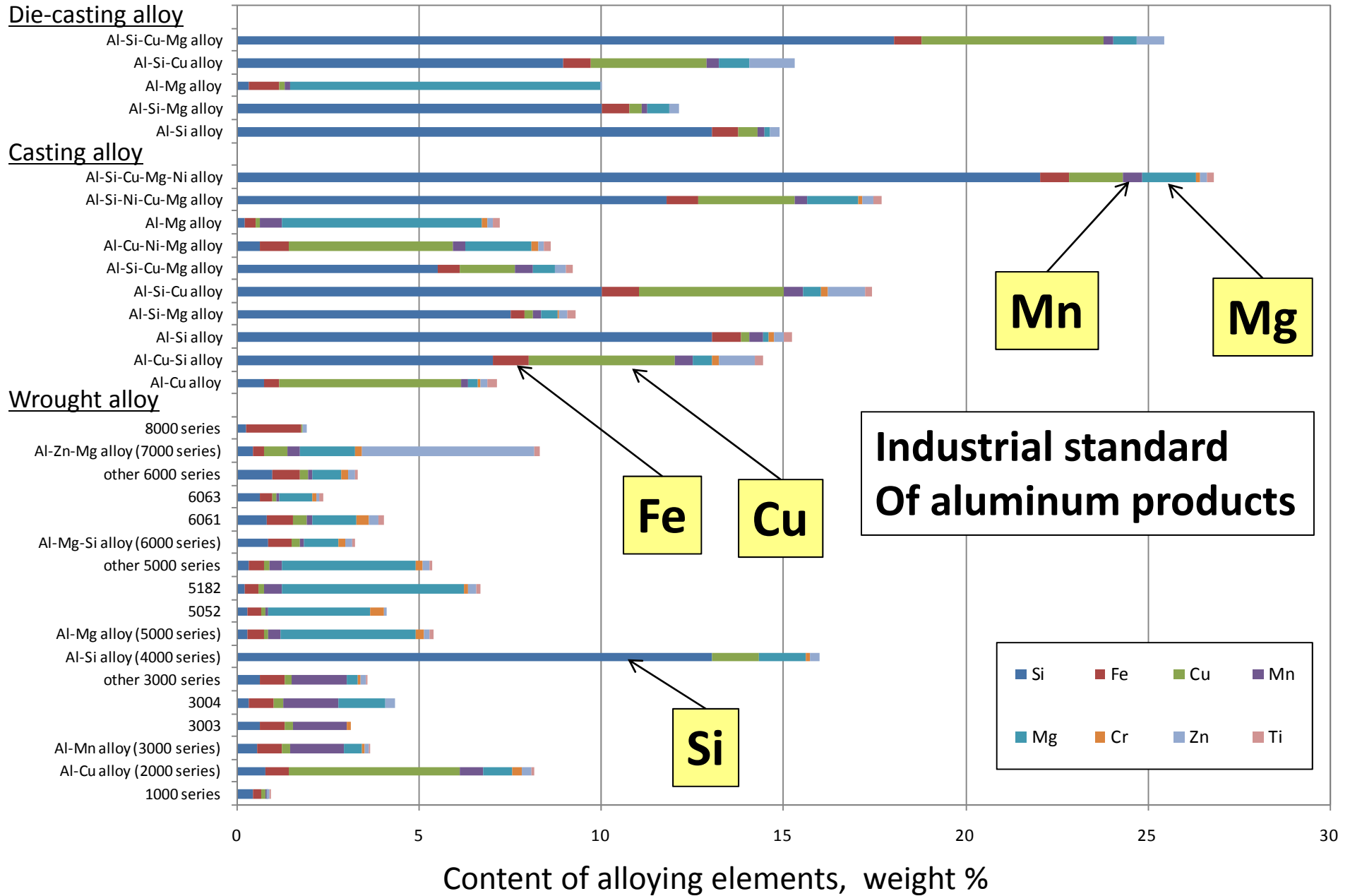
Melting reactor
for steel scrap

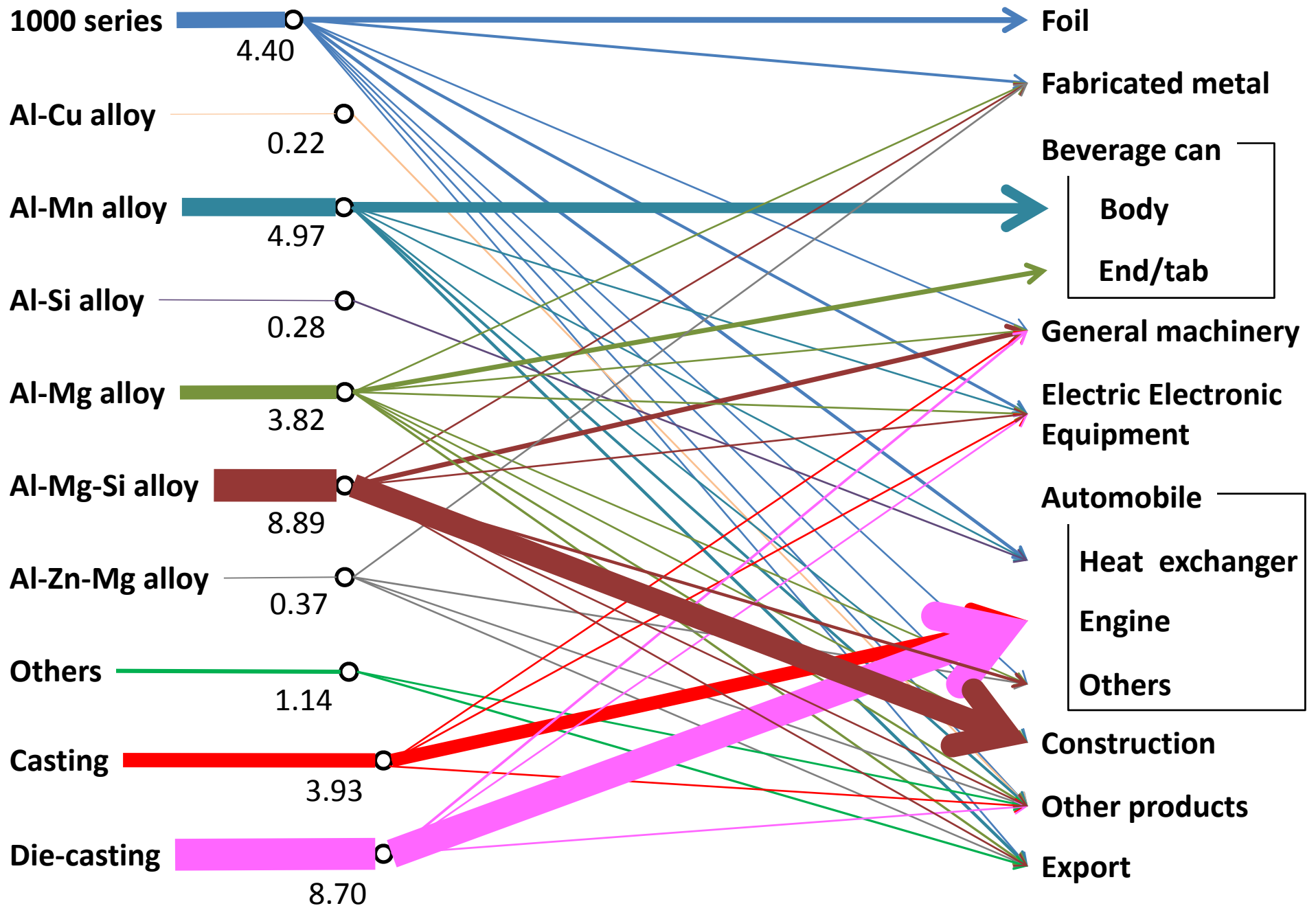
Reactor for
zinc recovery



Reactor for
mixing metals

We have similar problem in the recycling of other metals



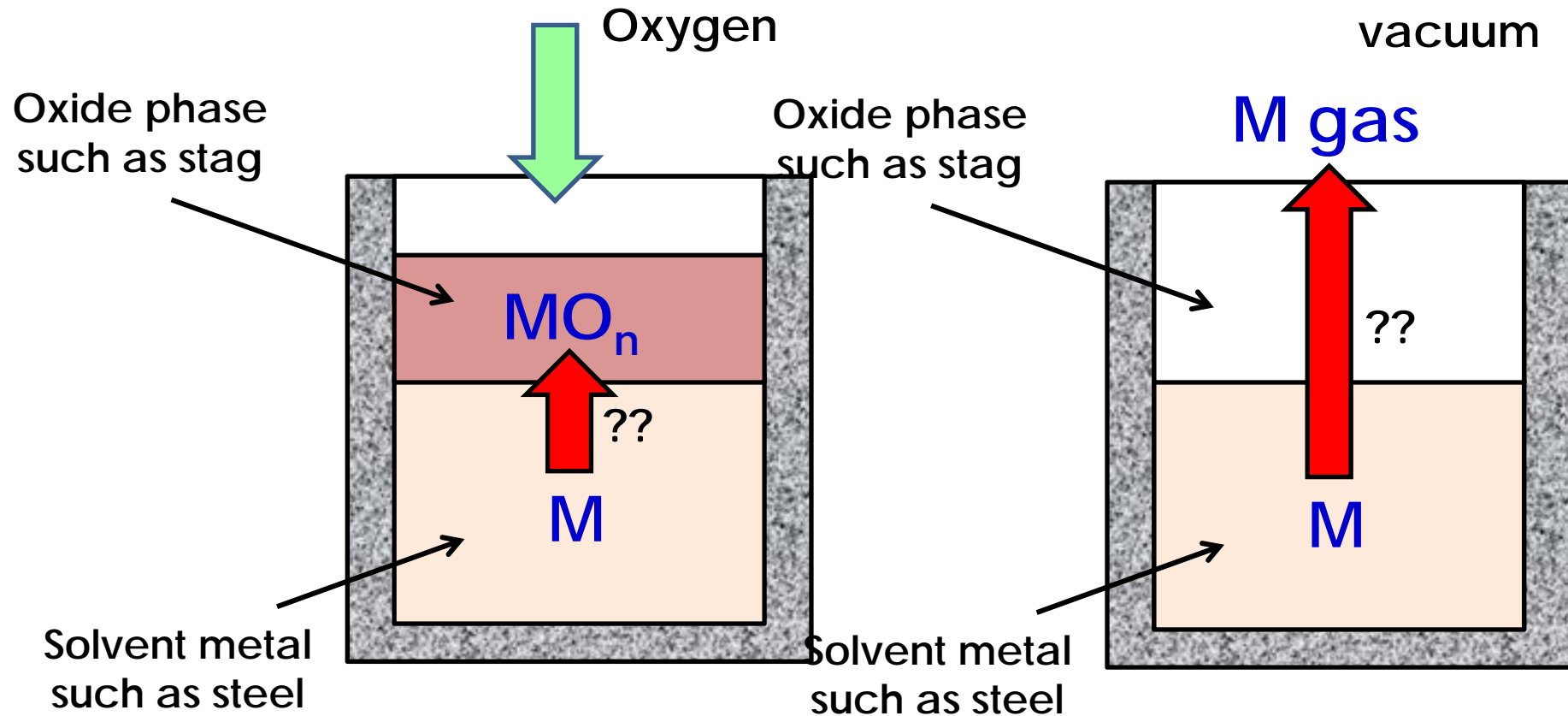


Units: $\times 10^5$ ton

アルミのカスケード利用形態

Nakajima, Nagasaka et al.: Env. Sci. Tech., (2010)

Can we control alloying elements in the recycling (remelting) process?

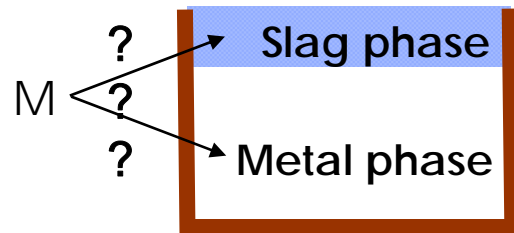


**Refining by oxidation
(Flux treatment or slagging)**

**Refining by evaporation
(vacuum treatment)**

Thermodynamic discussion on the removability of alloying element

Distribution between oxide/metal



Where is impurity element, M ??

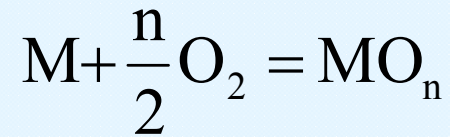
$$L^{\text{slag/metal}} = \frac{x_{\text{MO}_n}}{x_{\text{M}}}$$

Molar fraction of M's oxide

Molar fraction of M in metal

.....

Metal - Oxide



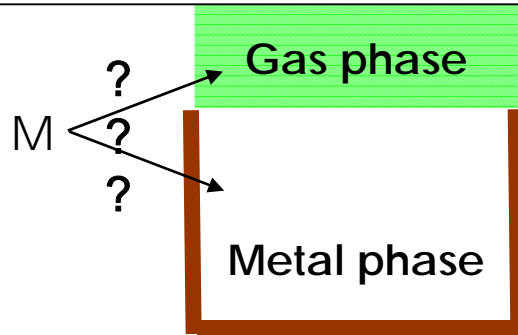
$$K_1 = \frac{a_{\text{MO}_n}}{a_{\text{M}}(p_{\text{O}_2}/p^\circ)^{n/2}} = \frac{\gamma_{\text{MO}_n} x_{\text{MO}_n}}{\gamma_{\text{M}} x_{\text{M}} (p_{\text{O}_2}/p^\circ)^{n/2}}$$

$$\frac{x_{\text{MO}_n}}{x_{\text{M}}} = \frac{K \gamma_{\text{M}} (p_{\text{O}_2}/p^\circ)^{n/2}}{\gamma_{\text{MO}_n}}$$

- Equilibrium constant of oxidation
- Activity coefficient of M and its oxide
- Partial pressure of oxygen

Thermodynamic discussion on the removability of alloying element

Distribution between gas/metal

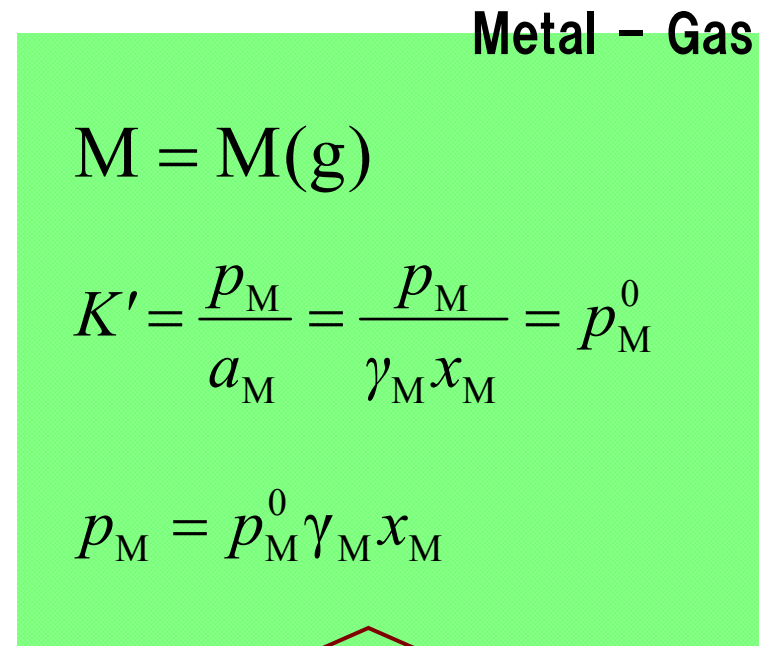


Where is alloying element, M ??

$$L^{\text{gas/metal}} = \frac{p_M}{p_{\text{Base metal}}}$$

Partial pressure of M

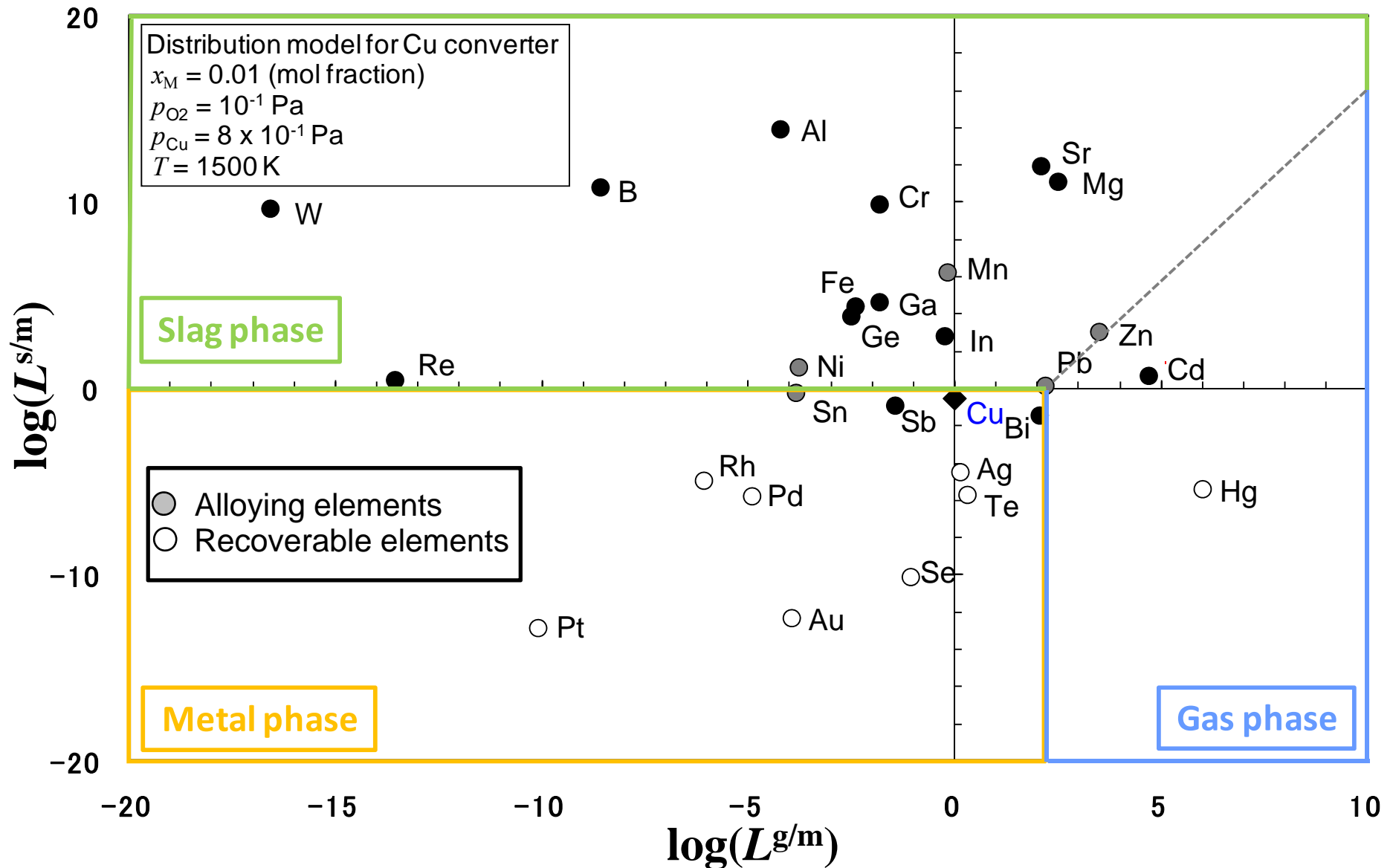
Partial pressure of base metal



- Equilibrium constant of evaporation
- Activity coefficient of M
- Partial pressure of M

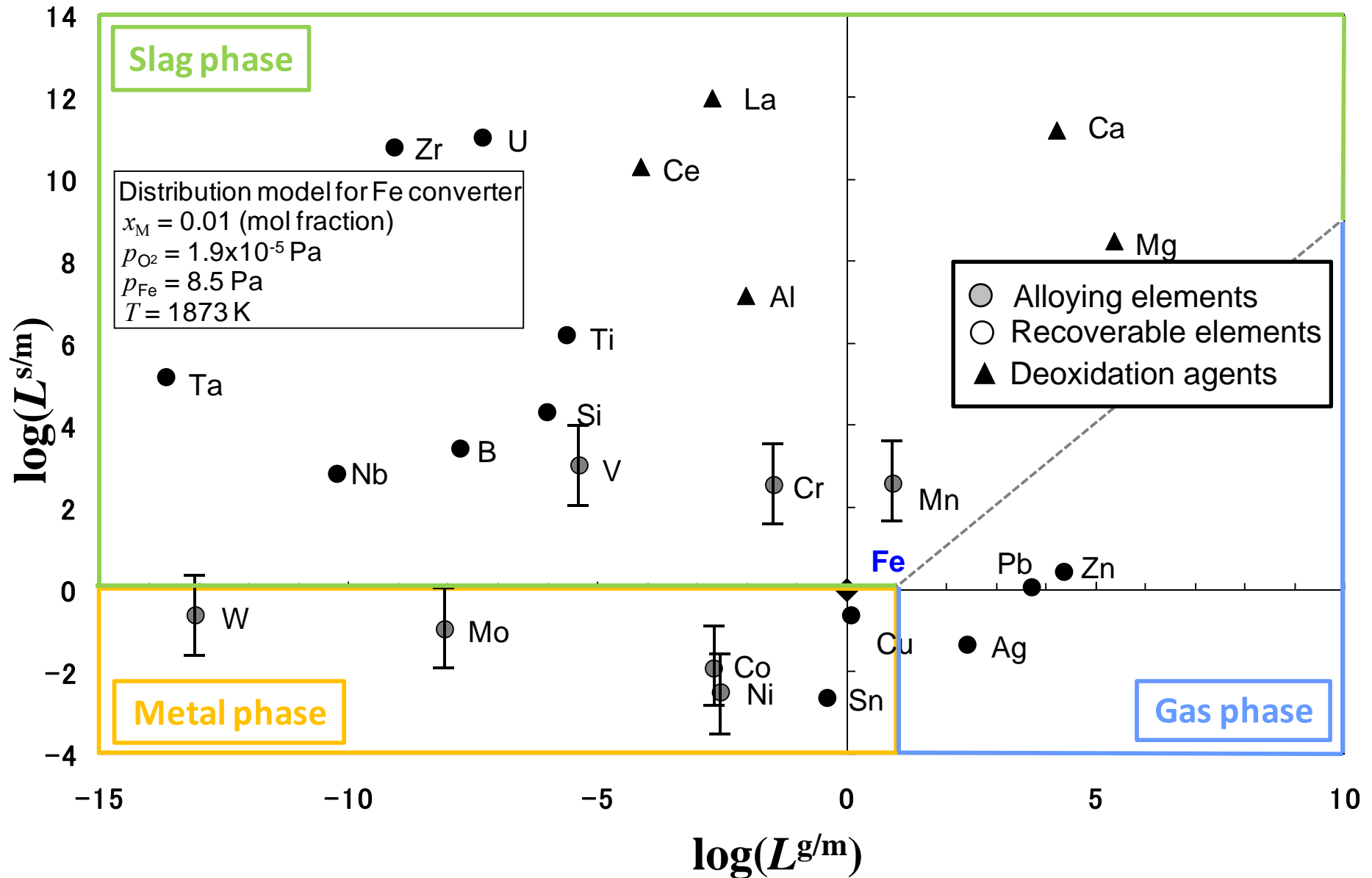
Element distribution during remelting of copper scrap

Nakajima, Matsubae, Takeda, Miki, Nagasaka: Env. Sci. Tech., (2011)



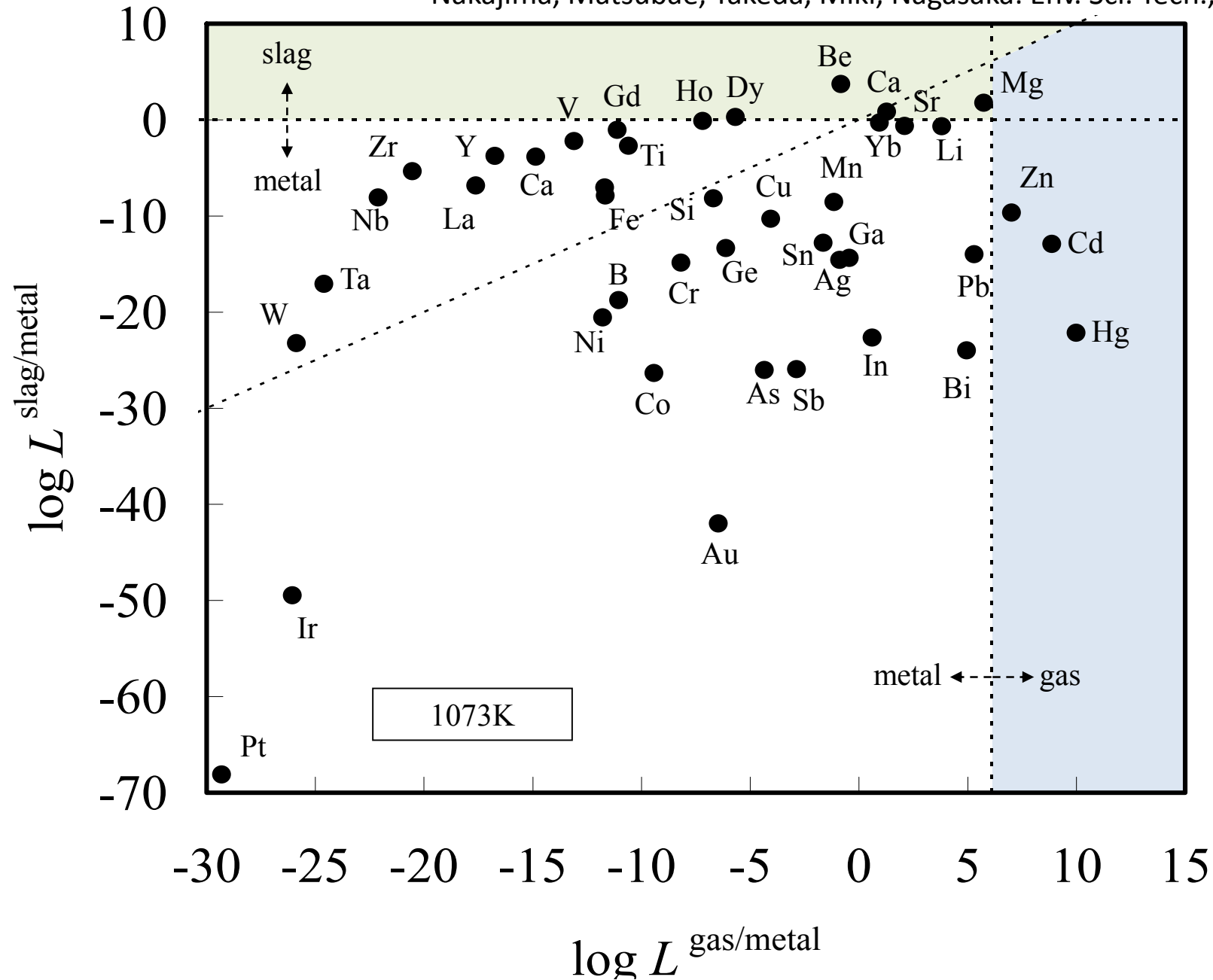
Element distribution during remelting of steel scrap

Nakajima, Matsubae, Takeda, Miki, Nagasaka: Env. Sci. Tech., (2011)



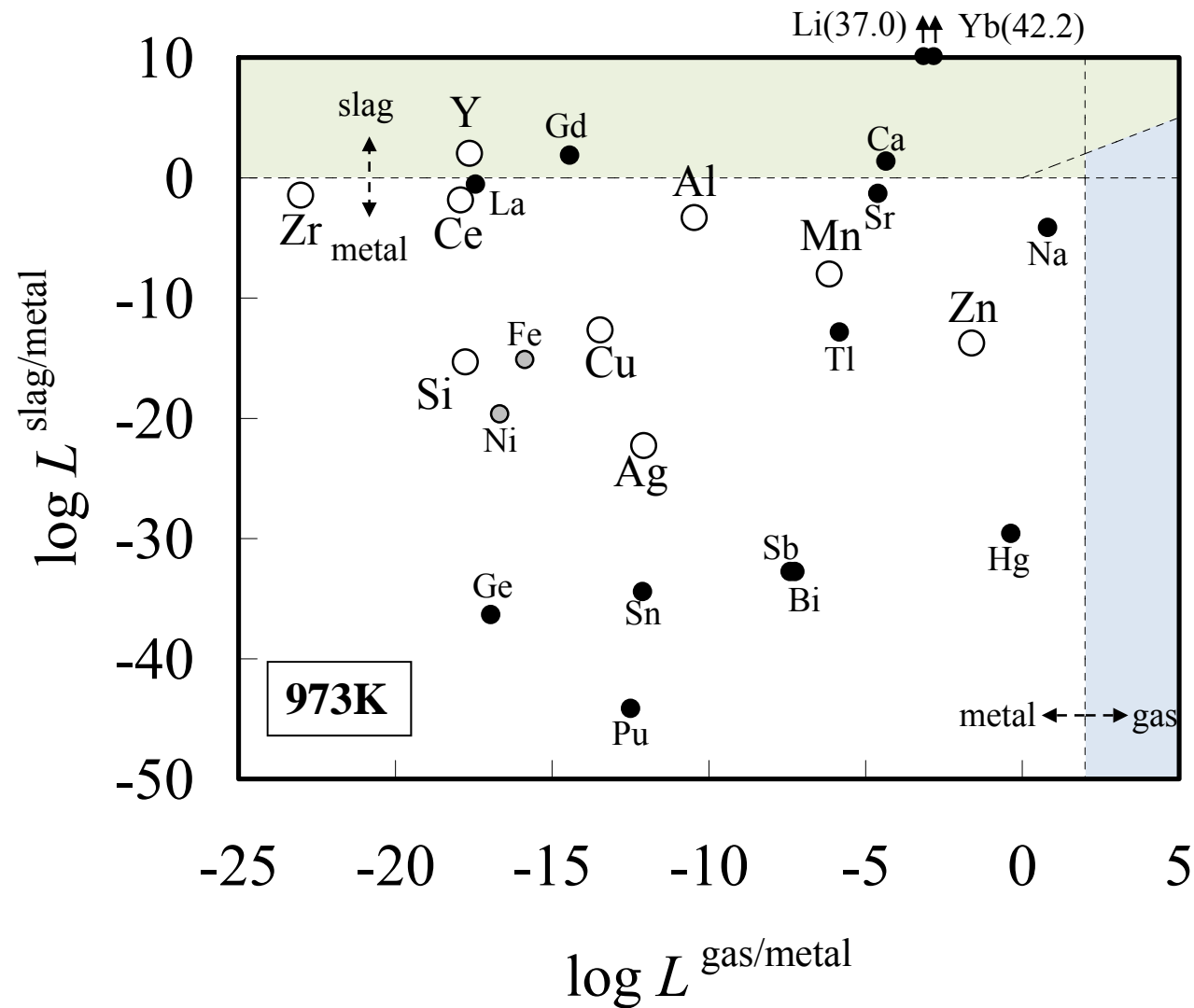
Element distribution during remelting of aluminum scrap

Nakajima, Matsubae, Takeda, Miki, Nagasaka: Env. Sci. Tech., (2009)

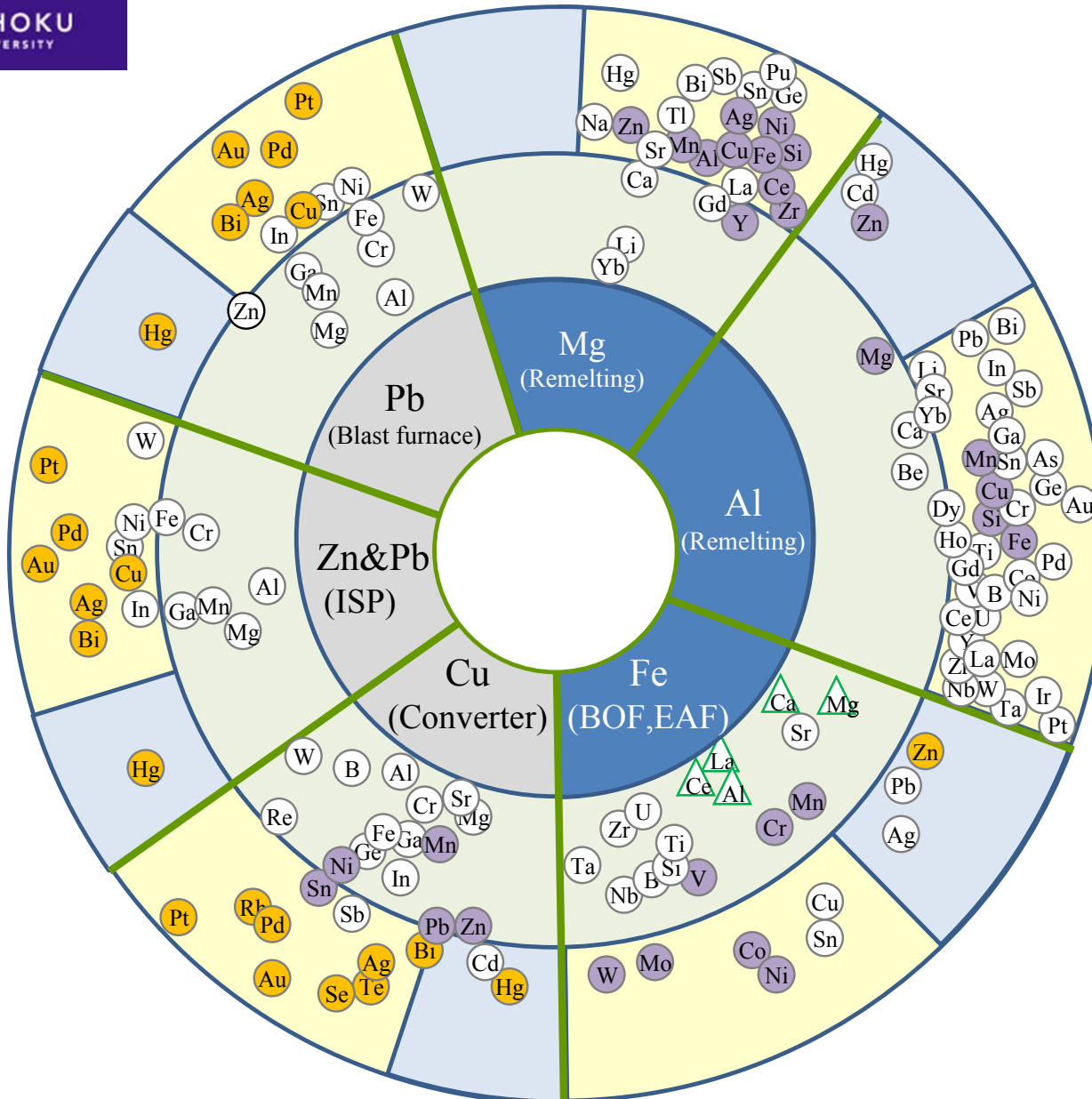


Element distribution during remelting of magnesium scrap

Hiraki, Nakajima, Takeda, Matsubae, Nakamura, Nagasaka: Sci. Tech. Adv. Mater., (2011)



Element Rader Chart



to Metal phase

Elements that have distributed among the metal phase as a solid or liquid metal

to Slag phase

Elements that have distributed among the slag phase as oxide

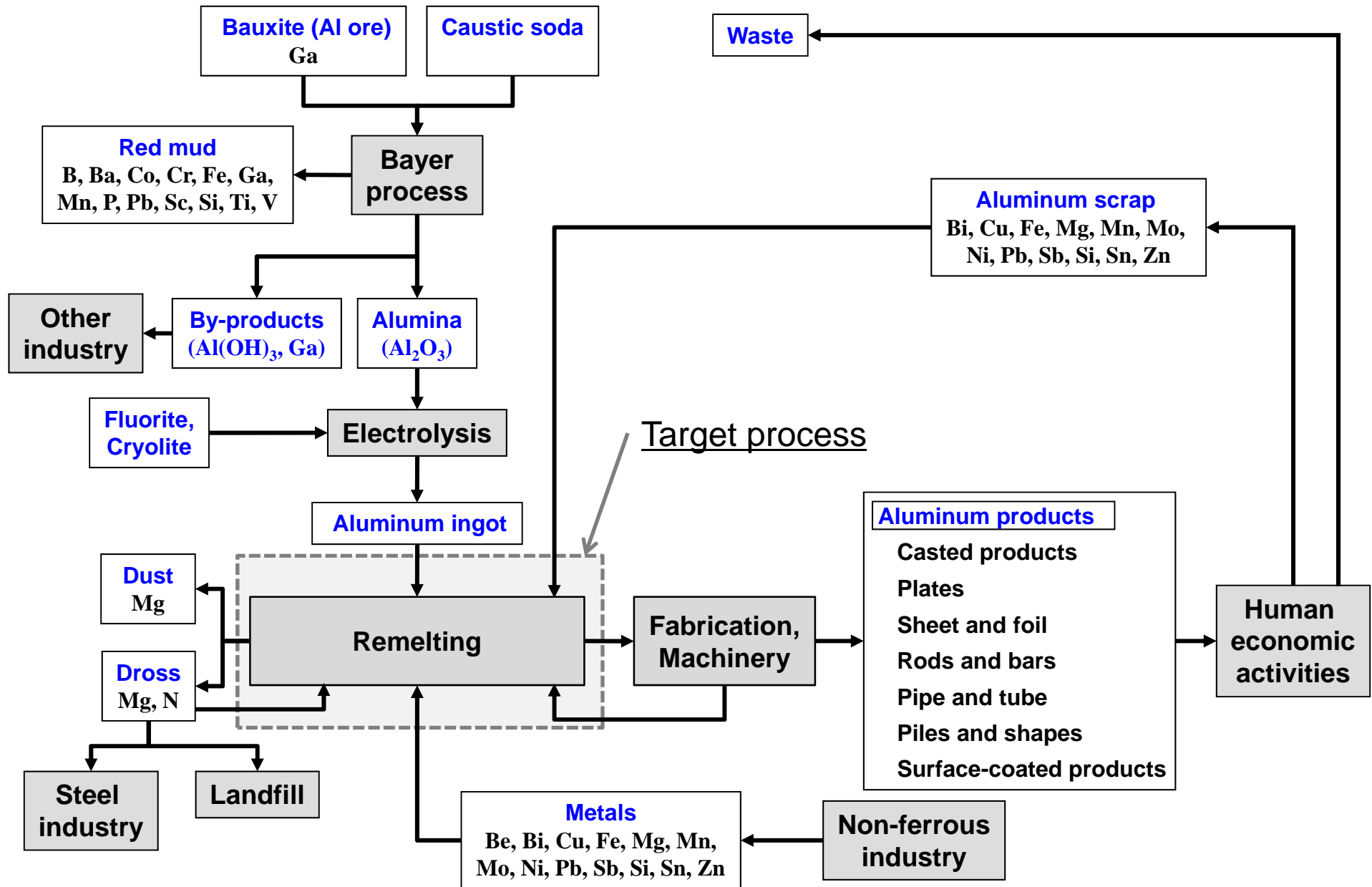
to Gas phase

Elements that have evaporated and distributed among the gas phase .

- Recoverable element (as pure metal)
- Alloying element
- △ Deoxidation agents

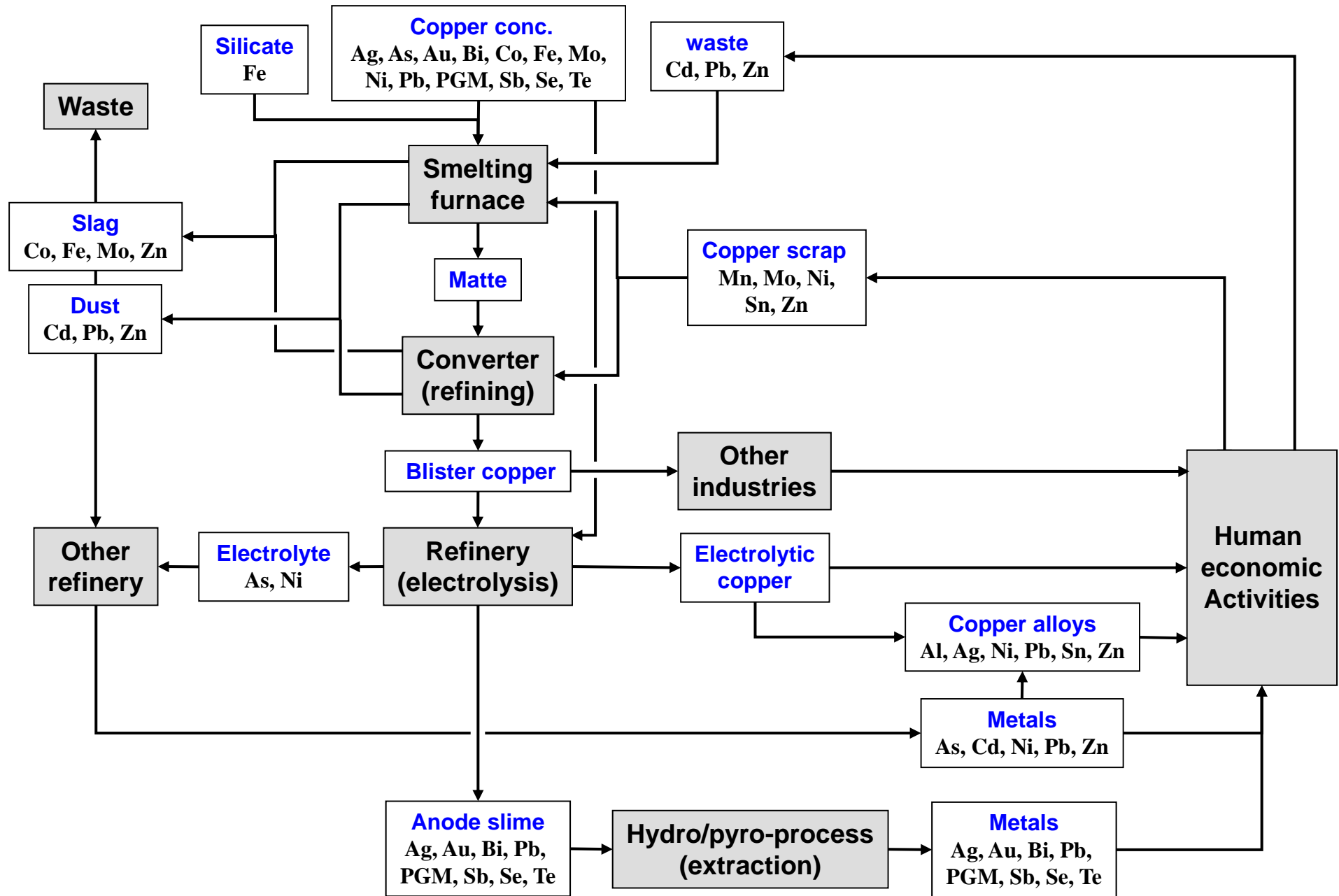
Life cycle of aluminum products and substance flow of alloying elements

Nakajima, Matsubae, Takeda, Nakamura, Nagasaka: Env. Sci. Tech., (2010)



Life cycle of aluminum products and substance flow of alloying elements

Nakajima, Matsubae, Takeda, Miki, Nagasaka: Env. Sci. Tech., (2011)



Conclusion

It is generally understood that metals, such as aluminum, copper, steel, etc., are well recycled in our society.

However, in the view point of quality, the current recycling system makes the quality of regenerated metals worse because metal products used in our society are mostly in the form of alloy rather than pure metals and they are mixed in the present recycling process.

Conclusion

Therefore, understanding and control of substance flow of alloying element through the life-cycle of steel products are extremely important.

Scrap sorting based on the composition and slag-making technology will result in great saving of rare metal consumption in base metals recycling.

**Thank you very much
for your kind attention!**

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Really recycle??



High Moon

I think we should close the valve first...

By Prof. Takatsuki