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Full Paper

EVALUATION OF ADVANCED LOOP-CLOSING SYSTEM OF STEEL RECYCLING

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Abstract

Current system of cascade recycling degrades reusability of materials in the future, therefore it is indispensable for construction of advanced loop-closing system in order to maintain original level of function of materials. This study constructed the simulation model to estimate the effect of an approach to separate copper from scrap and to produce steel sheet through scrap melting process. The model proposed has two sub-models, one is the economic model of steel industries activities and another is the model of material flow of steel. As the result, the approach was revealed to contribute to reduce environmental load in the future and also contribute to enforce global competition of steel sheet products.

KEYWORDS: *loop-closing system, tramp element, scrap melting process, economic model, material flow*

1. Introduction

The basic recycling plan towards sustainability in Japan includes achievement of recycling targets for containers and packages, construction materials, food products, electric appliances and vehicles. These recycling targets are based on the weight-volume index of the circulating material. However, every production process has its own recycling targets, and these achievements are mostly based on a quantitative cascade recycling type which in general is not expensive. In the case of steel, for example, the recovery has turned into cascade recycling that high quality level of steel sheet is taken back to lower level of bar and section steel. The reason is that a lot of electrical wiring harnesses including copper are used in electric appliances and vehicles and the contamination of copper, which is the tramp element for steel in the recycling process, degrade the level of quality of steel. If this current cascade recycling system continues in the future, the contamination level of copper in recycled steel will increase and finally exceed the limit of acceptable contamination.

Thus, this study constructed the simulation model to estimate the effect of an approach to separate copper from scrap and to produce steel sheet through scrap melting process. The model has two sub-models, one is the economic model of steel industries activities and another is the model of

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material flow of steel. We proposed the means and evaluation scheme by setting alternatives to maintain original level of function of materials.

2. Problem identification

2.1 Utilization of steel scrap

In Japan, blast furnace and electric furnace steel manufacturer mainly produce steel products. In 2000, blast furnace steel manufacturers produced 76 million ton of steel and electric furnace steel manufacturers produced 30 million ton of steel. Converters and electric furnaces produce crude iron from pig iron and steel scrap, then final products are manufactured through processes using crude iron. Converter, caster and hot mill system produce high quality products such as steel sheets mainly from pig iron, on the other side, electric furnace and mini-mill system produce low quality products such as bar and section steel mainly from steel scrap.

Steel scrap is divided into discharge scrap generated from loss in steel manufacturing and purchase scrap generated from outside of steel manufacturers, Furthermore, purchase scrap is divided into processing scrap generated from loss in manufacturing and heavy scrap generated from demolished buildings, abolished machinery and others. There is no statistic data of the quantity of heavy scrap generation, and there is only estimated data calculating from the quantity of scrap purchased by steel manufacturers and the quantity of imported and exported scrap. In 2000, 12.63 million tons of discharge scrap and 34.75 million tons of heavy scrap were generated (Hayashi S, 2002).

2.2 Issues of utilization of steel scrap

Contamination of copper in steel scrap is the important issue. The contamination embrittles steel and it is necessary to put pig iron into electric furnace as diluent in order to decrease the level of copper concentration in steel. The quantity of scrap generation has increased recently, but the demand for bar and section steel by construction sectors has decreased, therefore the market has lost the supply-demand balance and falling in the price of scrap has impacted recycling industries. If this situation continues into the future, it could be less efficient for environment to import virgin materials with resource mining in order to dilute the level of copper concentration in steel recycled.

There are two approaches to prevent the above situation. One is to extract copper from crude steel recycled after copper contamination, but JRCM (2000) showed the difficulty to realize at this present moment. Another is the realistic approach to separate copper from scrap in order to avoiding copper contamination. Thus, this study selected the latter approach and analyzed as followings.

3. Methodology

The objective of this study is to construct an evaluation scheme to estimate the effect of the approach to separate copper from scrap steel in order to achieve advanced-loop closing system.

It is necessary to prospect material recycling in the future and estimate stakeholders' economic activities after the impact of recycling issues. This study assumed that steel industries activities to

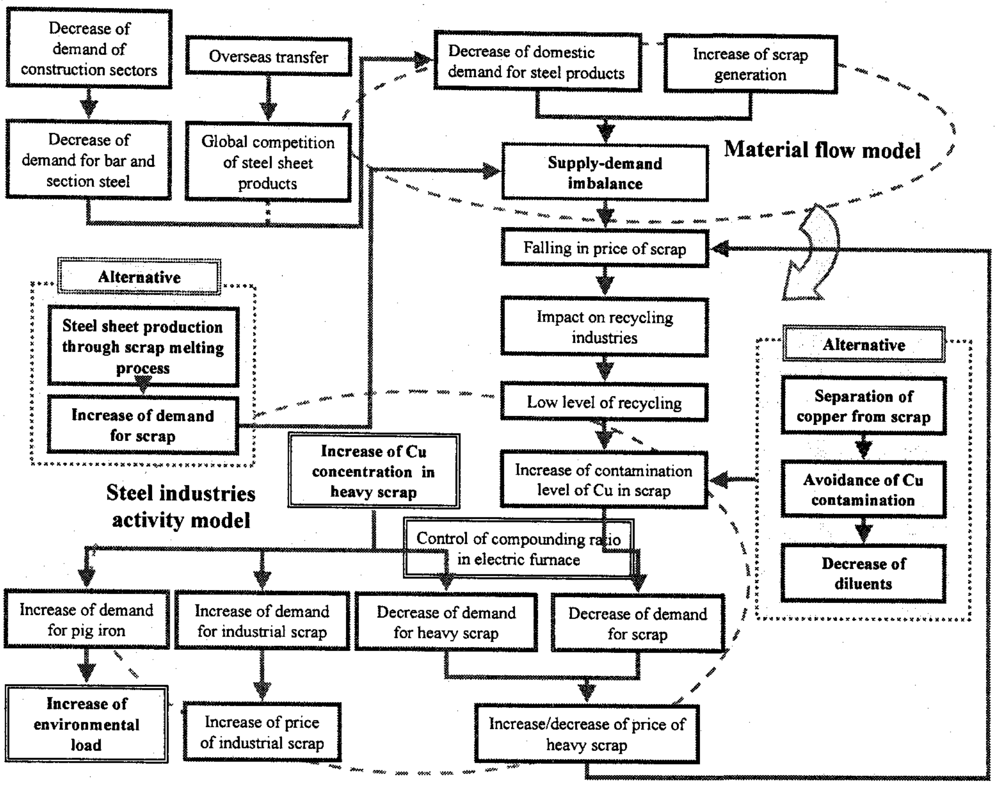


Figure 1. Simulation model with two sub-models, one is the economic model of steel industries activities and another is the model of material flow of steel.

purchase materials that depend on CES type production function on the theory of composite commodity goods by Armington. This analysis indicates industrial activities with cost minimization as partial equilibrium model under circumstances of steel scrap generation and copper contamination.

Material flow model according to the demand for steel products and generation of steel scrap was also constructed in this study and this is independent on equilibrium model. One model accepts a result of another model as an exogenous variable each other as figure 1. In the calculation, we used the data mainly as Table 1.

Table 1. Main data in the calculation

Life cycle stage	Year of data	Data source
Steel production	1950-2000	The Japan Iron and Steel Federation
Price of steel product	1985, 1990, 1995	Management and coordination agency government
Scrap generation	2000	Hayashi S., 2002
Price of scrap steel	1975-2000	Japan ferrous raw materials association

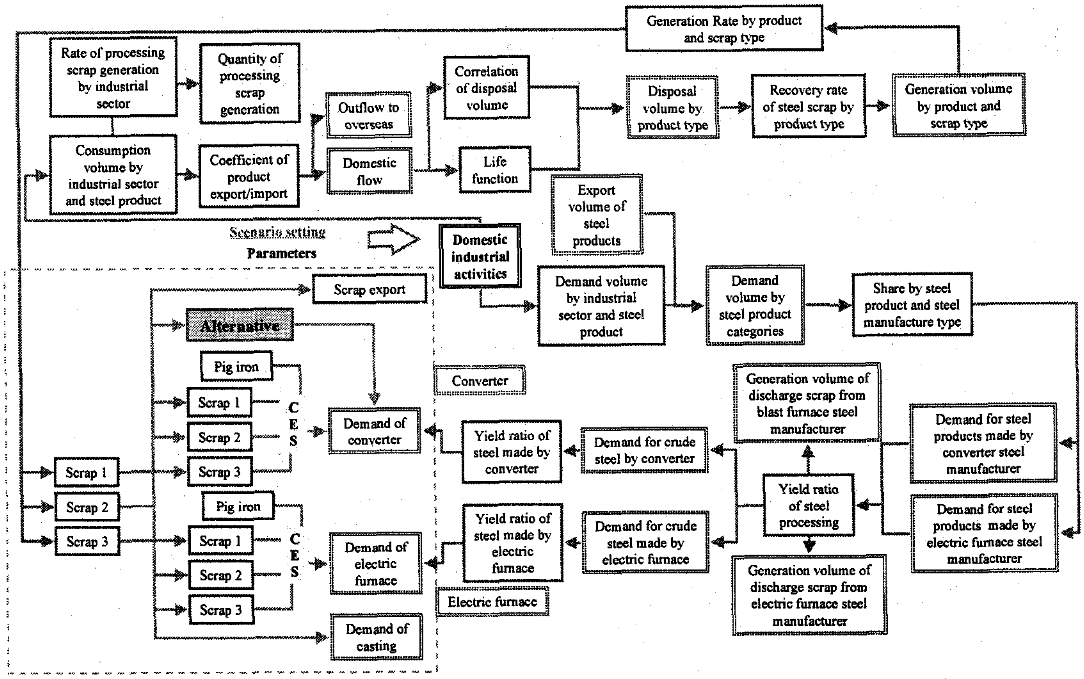


Figure 2. The flowchart of material flow analysis.

4. Material flow analysis

4.1 Outline of material flow analysis

This study analyzed material flow of steel from production to disposal and identified the structure of the relationship between supply-demand for steel and generation of steel scrap. Some parameters were set in order to predict the quantity of steel scrap generation in the future. (Hayashi S., 2003)

4.2 Calculation process for material flow analysis

(1) Production

The amount of domestic steel production was subtracted from export volume and was added to import volume to give the amount of annual domestic utilization of steel products. The production volume was classified into either the volume of converter furnace and of electric furnace. Production volume of each furnace was obtained by multiplying the amount of domestic steel production with the share by steel product and steel manufacture type.

(2) Consumption by industrial sector

Consumption by industrial sector was obtained by multiplying the rate of consumption volume with the estimation of final demand (Committee on Iron and Steel Statistics, 2001).

(3) Industrial scrap

The amount of discharge scrap was obtained by subtracting the quantity of crude steel from the quantity of final products. The difference between the material input volume and the quantity of crude steel was assumed to flow out of the steel cyclic system with slag. The amount of processing scrap generation was referred from the existing questionnaire survey (Hayashi S., 2002).

(4) Inflow and outflow in Japan

It is necessary to identify the inflow and outflow of the steel cyclic system in Japan in order to analyze steel material flow. The export volume of steel contained with domestic final products was calculated using coefficient of inverse matrix for input-output analysis.

(5) Generation of end of life products and recovery of scrap

The normal distribution with average product lifetime was assumed to be fitted for the generation volume of end of life products. However, this method does not reflect the actual generation volume according to industrial economic activities accurately. Thus, this study used the stock method that the amount of stock last year was added to new products in the year and was subtracted from the amount of stock in the year to give the disposal volume in the year. In this case, the stock method was applied to the products of construction and vehicle sectors which had the stock data, and the method of product lifetime was applied to other products.

(6) Estimation of steel production in the future

The production volume after 2001 was assumed to continue the ratio of steel production of each industrial sector in 2000.

4.3 Estimation by model

The amount of scrap generation was estimated as figure 3 according to the above calculation process. The construction sector had much effect on scrap generation, and secondary sectors were vehicle and machinery sectors. It should be noted that these sectors also have much effect on copper

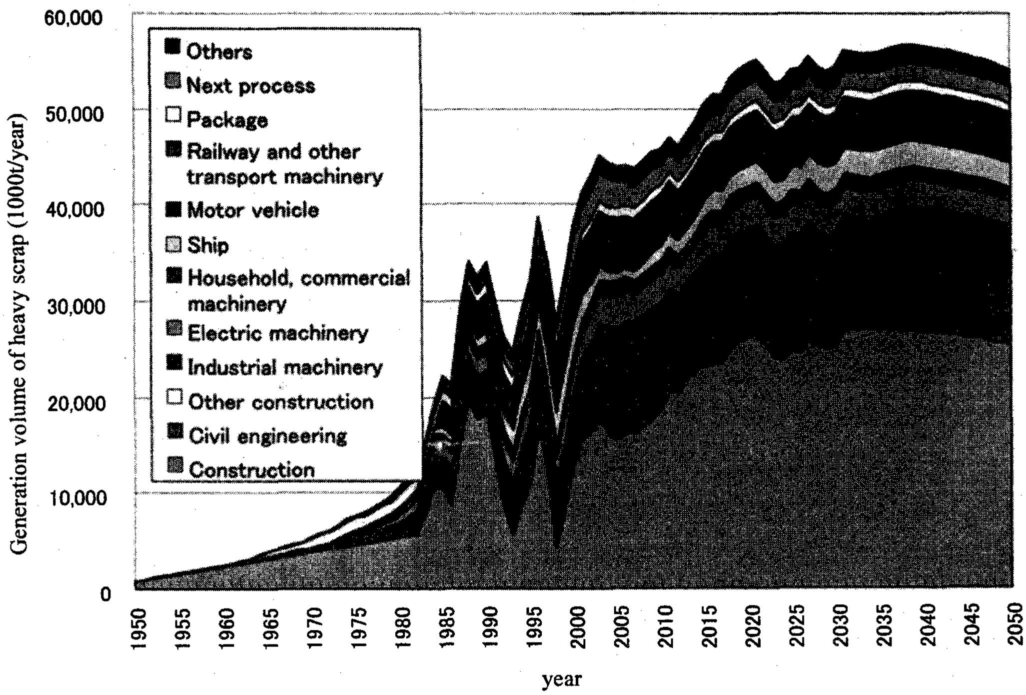


Figure 3. Estimated generation volume of heavy scrap.

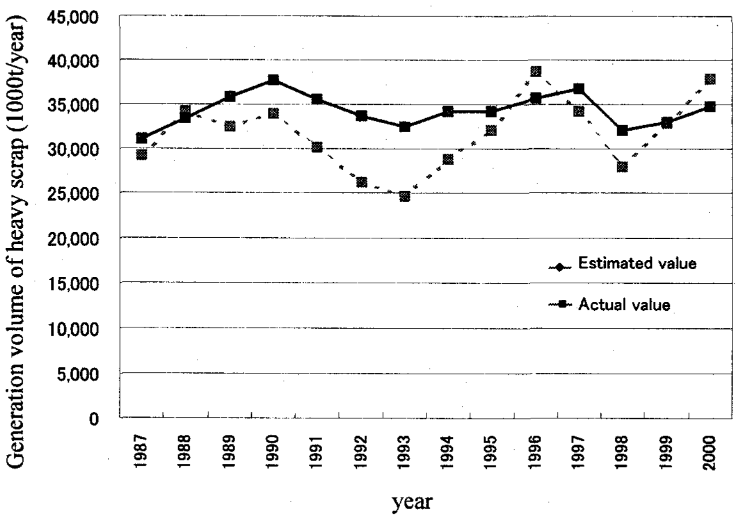


Figure 4. Comparison of estimated and actual generation volume of heavy scrap.

contamination in steel scrap because a lot of electrical wiring harnesses including copper are used in their products. Although the economic bubbles around 1990 promoted to dispose end of life products, this estimation by product lifetime reflected only the production volume in former years, therefore, almost estimated values were lower than the actual values as figure 4. Since the method of product lifetime to estimate generation volume of end of life products could not reflect the change of the generation volume according to economic activities, the estimation were below the actual values at the peak of economy from 1980 to 2000.

5. Activity model of steel manufacturers

5.1 Procedure of analysis

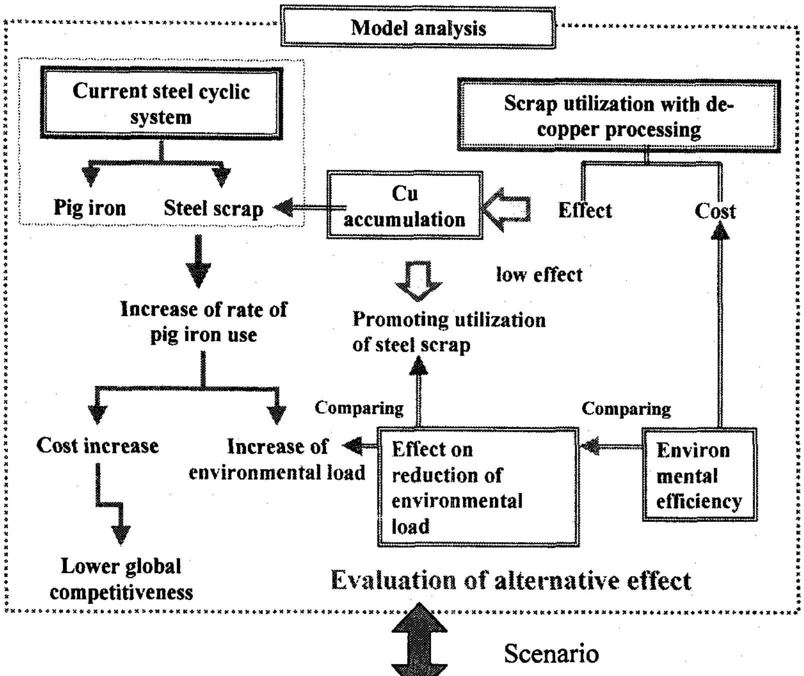
Steel industries were simply classified into blast furnace and electric furnace manufacturers. This study constructed a model of future prospects of steel recycling system with their economic activities with cost minimization. Furthermore, several alternatives were set with their probabilities in society and the significance of alternatives and their conditions were considered.

5.2 Scenario setting

In this study, overseas transfer of production sites and policy measure for environment were identified as two elements for scenario setting. Several scenarios were set by the combination of the conditions of these elements.

(1) Business movement in domestic industries

Recent overseas transfer of production sites has much effect on domestic demand for steel products and generation volume of processing scrap. Thus, this study applied logistic curve to the trend of the number of sites which transfer overseas and analyzed three patterns such as the pattern of continuing current situation, the pattern of predicted situation and the middle pattern.



		Overseas transfer of production sites		
		Change situation as prediction	Change situation as half of prediction	Continuing current situation
Environmental tax	15,000 yen/t-C	Scenario A	Scenario B	Scenario C
	3,000 yen/t-C	Scenario D	Scenario E	Scenario F
	0 yen/t-C	Scenario G	Scenario H	Scenario I

Figure 5. The scheme of steel industries activity model.

(2) Environmental policy

In this study, environmental tax was assumed to administer according to emission volume of CO_2. Three tax rates were set such as 15,000 yen, 3,000 yen, 0 yen/t-C (Ministry of the Environment, 2001) in order to estimate the effect of tax administration.

5.3 Cost minimization model for steel manufacturers

(1) Overview of model

This study constructed the whole structure of cost minimization activities of blast furnace and electric furnace manufacturers according to generation volume of steel scrap and copper contamination level that estimated the price and import volume of steel scrap. Copper concentration in steel and the reduction quantity of environmental load under scenarios and patterns were estimated and the effect of alternatives was analyzed.

The types of steel scrap and their routes should be identified to consider the contamination of steel scrap and dissolution of crude steel. The scrap 1 was identified as discharge scrap generated

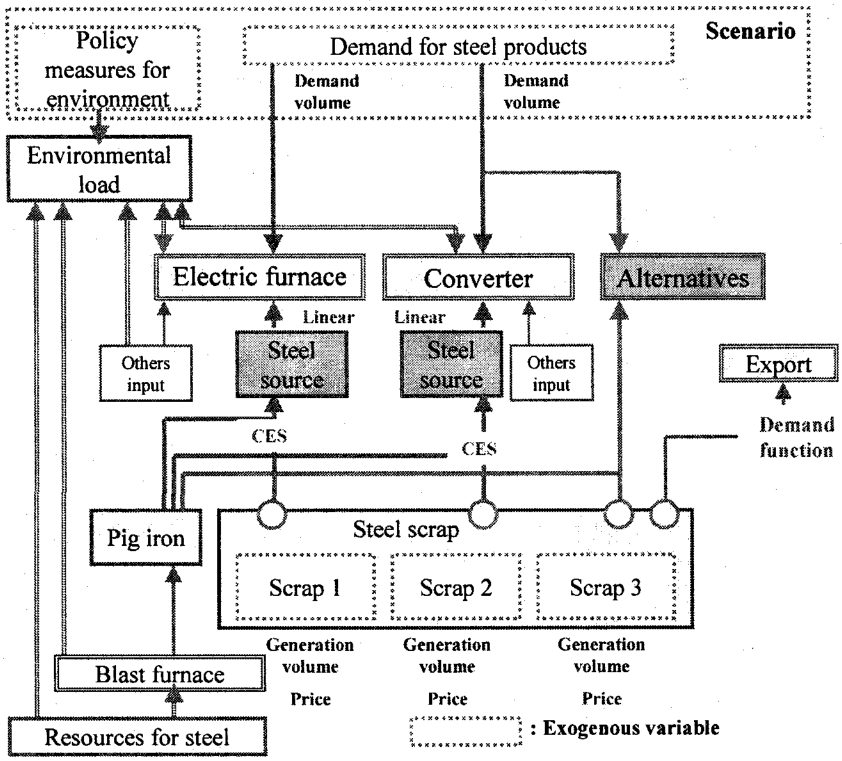


Figure 6. The scheme of economic activities of steel manufacturers with cost minimization.

from processes in steel industries and processing scrap from other industries. The scrap 2 was identified as heavy scrap or press scrap above H2 level of scrap (Japan ferrous raw materials association). The scrap 3 was identified as automobile press steel, shredder dust and others below H2 level of scrap.

(2) Calculation process

The demand for steel source by steel making process was obtained by multiplying domestic industrial activities as scenarios with actual production volume in 2000, demand coefficient by steel products and share of steelmaking process by steel products. The share was assumed to continue in the future according to the current situation of steel industry.

The economic activity to purchase steel resource such as pig iron, steel scrap was assumed to be accordance with CES type production function. The import volume of steel scrap was simply assumed to estimate by overseas demand function of steel scrap.

5.4 Scheme of estimation

(1) Element of estimation

The measurement of environmental load like LCA is not able to estimate the quality of recycling. In this case of avoiding copper contamination in steel scrap, it is simple to estimate the reduction volume of pig iron consumption as diluent. However, the contamination level of copper is not

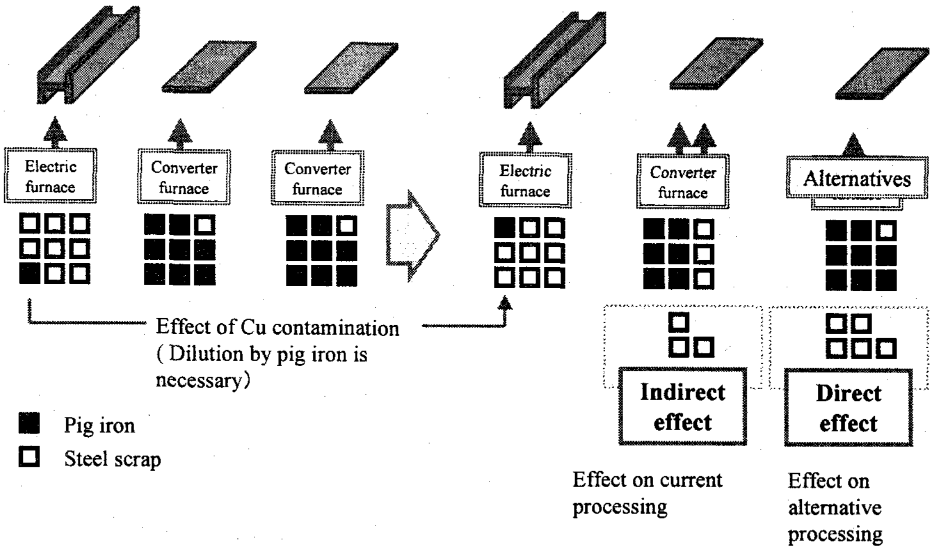


Figure 7. Definition of direct effect and indirect effect.

estimated.

Therefore, this study defined direct effect and indirect effect in order to estimate the quality of recycling. Direct effect means the reduction of virgin materials through recycling of steel scrap in the year. Indirect effect involves complicated elements, such as the long-term effects avoiding copper contamination in steel scrap, the effect of supply-demand imbalance of scrap by increase of steel scrap generation.

(2) Alternative setting

Currently, steel sheet products are usually produced from pig iron with a small amount of discharge scrap steel. In this study, producing steel sheet from mainly purchase scrap though scrap melting process (SMP) was set as an alternative of converter in blast furnace manufacturing and this equipment enforced separation of copper from scrap steel before SMP.

(3) Unit of environmental load

Steel production system should be evaluated with various environmental aspects, such as emission of air pollutant, energy consumption, plastic recycling by blast furnace. In this study, CO_2 emission was taken up as an environmental indicator which became the opportunity to consider future system of steel production and utilization.

We estimated CO_2 emission from steel production processes using embodied emission intensity data (Nansai K. *et.al.*, 2002) and that from alternative processes using data partly from a collaboration business sector. We also estimated CO_2 emission from steel scrap recycling partly using power cost data (Nikkan Shikyou Tsushinsha). Figure 8 showed the result of estimation that CO_2 emission from alternative was approximately the half of that from current processing.

5.5 Results

The result of model simulation is showed as Figure 9. The ratio of steel source from SMP to that from crude steel was set 10, 20 and 30 percentages in order to compare direct and indirect effects.

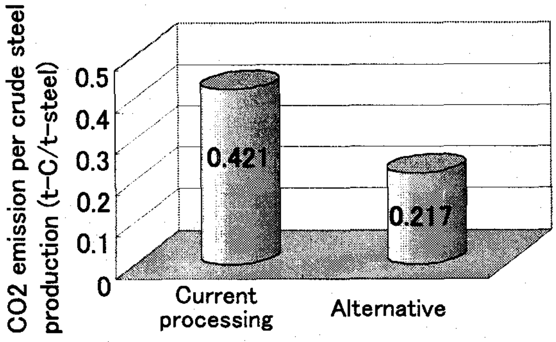


Figure 8. Comparison of CO_2 emission between current processing and alternative.

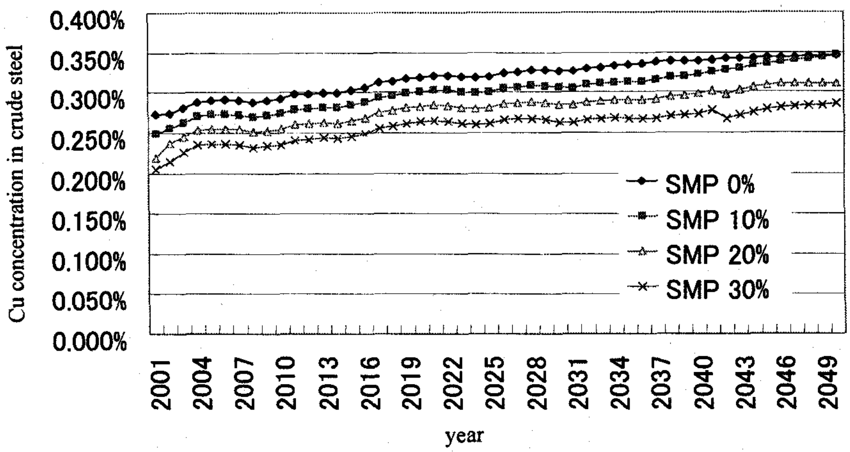


Figure 9. Estimation of Cu concentration in crude steel produced by electric furnace (Scenario A).

Figure 10 shows these effect under 10 percentage of steel source from SMP.

As the result, the reduction volume of CO_2 emission was revealed to increase, because indirect effect increased progressively, and alternative approach to separate copper from steel scrap would provide benefit in the future. Thus, it was cleared that crude steel production from steel scrap by SMP had much effect on reducing environmental load.

Figure 11 shows the effect of each scenario obtained by dividing the summation of reduction of total CO_2 emission from 2001 to 2050 by the production total volume of SMP. The result could be interpreted as followings:

- The change of industrial structure has much effect on reducing CO_2 emission;
- Environmental tax has a little effect on reducing CO_2 emission;
- The change of demand for steel scrap is more effective in reducing CO_2 emission than the change of environmental tax charge;
- The increase of ratio of steel source from SMP to that from crude steel reduces the effect of reduction of CO_2 emission per 1 ton of crude steel production.

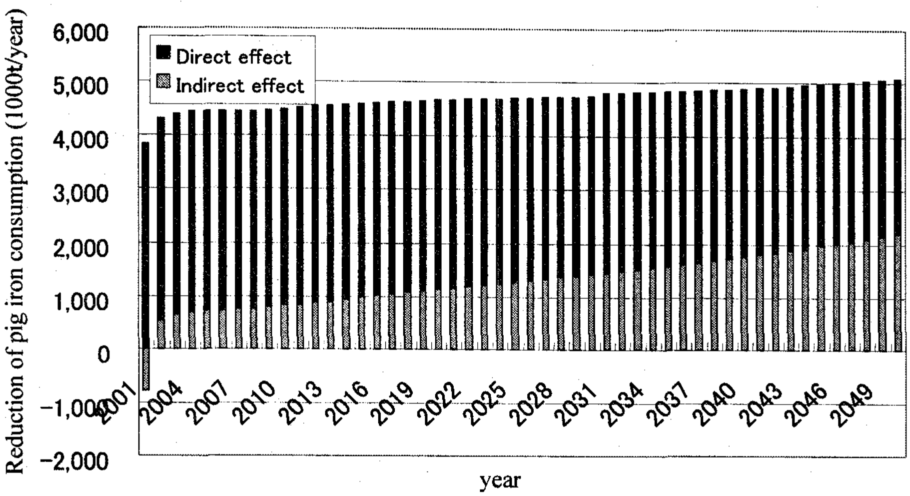


Figure 10. Estimation of reduction of pig iron consumption, 10% of steel source is scrap through SMP (Scenario A).

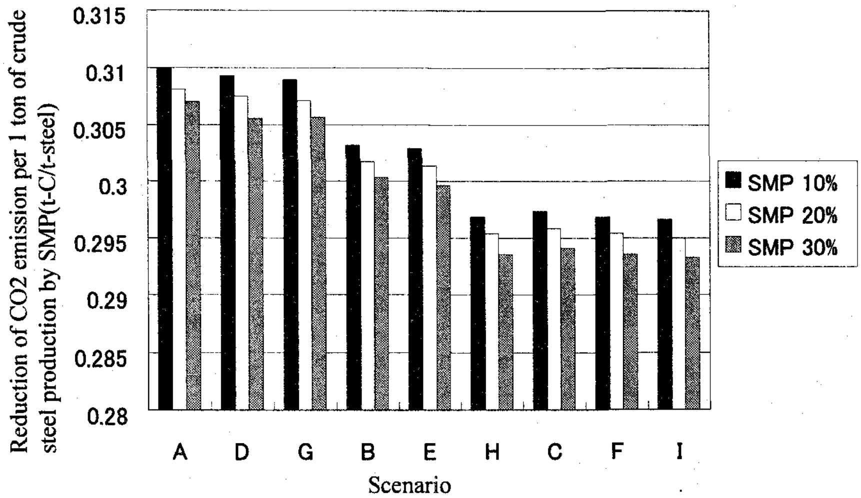


Figure 11. The effect of reduction of CO_2 emission per 1 ton of crude steel production by SMP.

6. Conclusion

In this study, it was revealed by material flow analysis that estimated generation volume of heavy scrap would increase over 45 million ton/year after 2020, and heavy scrap would be the main iron source in the future in Japan. It was also revealed by economic analysis that when SMP was set as the alternative of converter in blast furnace manufacturing, the level of cupper concentration would be almost the same as the level in the current situation, thus continual advanced loop-closing system is able to be constructed. Furthermore, this alternative was revealed to reduce CO_2 emission effectively with cost minimization of environmental tax.

This study constructed the simulation model to estimate the effect of the advanced steel loop-closing system to separate copper from scrap and to produce steel sheet through scrap melting process. As the result, steel sheet production through scrap melting process with de-copper processing was revealed to contribute to reduce environmental load in the future and also contribute to enforce global competition of steel sheet products. The analysis model with cost minimization as partial equilibrium enabled to evaluate not only direct effect but also indirect effect involving the long-term effects avoiding copper contamination in steel scrap and the effect of supply-demand imbalance of scrap by increase of steel scrap generation.

The target of this study was steel industry. Furthermore, the concept of this model is able to apply other materials, therefore, expansion of this model could contribute to construction of cycle-oriented society.

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