Life Cycle Assessment on Newly Developing Steel Recycling System by using I/O Table

Kenichi Nakajima¹*, Yohji Uchiyama¹ and Kohmei Halada²

¹Institute of Mechanics and System Engineering, Tsukuba University, Tsukuba 305-8577, Japan
²National Institute for Materials Science, Tsukuba 305-0047, Japan

According to increase in a waste scrap, a process is noticed in which a waste scrap is consumed for sheet steel production within severe restriction of impurities concentration. In this study, evaluation of the effect on environmental load decline by LCA is applied to this new recycling technology. Target of this study is not for closed loop recycling system like aluminum can for drink but for open loop recycling system in which many industries are concerned. Authors suggest taking the interindustry-relations table for open loop recycling system. Evaluation made in this research is based on it. By setting up I/O boundary, though increase of environmental load is predicted to be high comparing to those which are assumed as non-open recycling system, still there is a sufficient effect for it. As the result of the analysis, curtailment was estimated that energy consumption and CO₂ emission are 16.8 GJ per ton waste scrap and 1.2 t per ton waste scrap, respectively.

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1. Introduction

Japan has stepped foreword to recycled-base non-materialized society. In 2000 new law of “The Basic Law for Establishing the Recycling-based Socieity” was enacted, followed by “Electric Household Appliance Recycling Law” and so on. In the situation, it is important to consider ecomaterials and eco-design that play effective role in life cycle. An evaluation method of life cycle thinking, such as LCA (Life cycle assessment) attracts attention. LCA is used as a tool to make quantitative evaluation of the environmental loads and impacts on “a product system”. And now, LCA is expected not only to assess “a product” but also to give the guideline of designing products and the social systems such as recycling system and energy system.

Several studies of evaluating direct and indirect environmental loads using I/O table have been conducted as an application of LCA. Evaluation such as by Hondo et al.¹ and by Kawashima et al., are for instances² However, these conventional I/O analysis, environmental waste load and by-products, such as process-scraps steel, could not be evaluated, whereas authors proposed a method to evaluate waste and a by-product using an I/O table.³ In the method, consider wastes and by-products as a product, and place them in independent sections to treat them equally.

The purpose of this study is to construct a tool for evaluating the effect of environmental loads reduction of new technology at development stage. In this work, new steel recycling system was taken for evaluation as a case study. continuously rise till 2010 and will saturate after that. In this situation, the waste scrap cannot be used only as bar steel materials whose concentration of impurities is loosely regulated. And surplus scraps will increase if it is not used for steel material with strictly regulation of that, such as sheet steel. On the other hand, newly developed steel recycling system by mechanical separation following shredding (include cryogenic processing) is examined. The system consists of de-copper processing in which steel scrap is cooled to −100°C or lower with coolant such as liquid nitrogen, and produce sheet steel at the small electricity furnace called mini-mill.

Cryogenic processing is performed by the cryogenic heat which reuse the energy of liquefaction of a natural gas. By the de-copper processing, the copper concentration in a scrap becomes about 0.1%, which enable material for hot-rolled sheet steel. At present, cryogenic of LNG is not used at all, however, this system also enables to make an effective utilization of it.

A flow of the present system for steel production is shown in Fig. 1. In the present condition, crude steel for hot rolling steel plate and cold rolling steel plate is produced at a converter furnace, and crude steel for steel bar and section steel is produced at an electric furnace. Waste scraps are mainly used at electric furnace. In the future, the increase of waste scraps generation is assumed. Two scenarios are set in this study. Figure 2 shows scenario (a) without an object system (waste scraps turn into surplus scraps.). Figure 3

2. Evaluated System

It is empirically known that the waste scraps are generated in proportion to the social amount of steel accumulation.⁴,⁵ In 2010, increase of the waste scrap will reach as much as 4800 × 10³t. Consequently, The volume of waste scrap will continuously rise till 2010 and will saturate after that. In this situation, the waste scrap cannot be used only as bar steel materials whose concentration of impurities is loosely regulated. And surplus scraps will increase if it is not used for steel material with strictly regulation of that, such as sheet steel. On the other hand, newly developed steel recycling system by mechanical separation following shredding (include cryogenic processing) is examined. The system consists of de-copper processing in which steel scrap is cooled to −100°C or lower with coolant such as liquid nitrogen, and produce sheet steel at the small electricity furnace called mini-mill.

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![Fig. 1 The material flow of steel production in the present condition.](image-url)
shows scenario (b) with an object system (sheet steel production is attained by mini-mill that consumes waste scraps. And this makes the sheet steel production in converter furnace unnecessary).}

The following assumption is set up for analysis. (1) The amount of waste scraps will increase about $4800 \times 10^3$ t. (2) Demand of steel material will be constant to the present condition in time of evaluation. (3) Amounts of energy consumption and CO$_2$ emission of de-copper processing are neglected. (4) Since an amount of recovered copper by de-copper processing is very small quantity, the effect of recycling is disregarded. Moreover, rolling process is common to all scenarios, so it is removed from the evaluation system.

### 3. Method for the Environmental Load of Scraps

As shown in the Figs. 1–3, pig iron, process scrap, and the waste scrap are carried into a system from outside of the system boundary. And an object system is not the closed loop recycling like an aluminum can but open loop recycling in which many industries are related. If those production of sheet steel and bar steel are set up as a constant function unit, then the amount input, such as scraps, cannot be fixed. Allocation of environmental loads to pig iron and the scrap or the expansion of a system has a big influence on the result of evaluation. Authors have already proposed “Expansion of a system by a material”$^6$ where “expansion of a system” is performed by allocating system reflecting value to material. Based on this method, in case of pig iron, the total environmental load of a system can be calculated to the amount of pig iron unit, and it can be corresponded to “expansion of a system”. And it gives a boundary defined by the I/O table, $i.e.$, an I/O boundary. However, the system that generates a scrap consists of many industrial fields, not only steel industry but a car production, a construction, a shipbuilding, etc., so the possibility of the system expansion is nearly infinite. Therefore, an I/O table is used in this system for expansion.

A general application of the I/O table to LCA is already established, where direct or indirect environmental load calculated value reflects linkage among industries, and it is used for a certain materials ‘or products’ environmental load. It can be also considered that “Expansion of a system by a material” is equivalent not only for a single industrial system but for a country or global level of linkage. However, fresh extension is needed to evaluate scraps using I/O table because it is made in order to understand only the flow of goods. A method to evaluate environmental load of process scrap using I/O table has been already discussed by authors. This method is applied in this study. In case of Japanese I/O table, it is expressed as a row of the minus notation called the Stone method in a input table, although the steel scrap does not exist in an input coefficient matrix. In this research, the steel scrap is treated as products from each section, and the steel scrap section is separated from each production section. The extension is illustrated in Fig. 4.

Regarding the input-column from each section, the same technical model where each element has same input coefficients is assumed. Regarding the production-row to each section, an extension of a row is needed in order to
secure a non-singular matrix. However, since the element of the row is not obtained from an I/O table, data based individual material flow is needed to investigate. In calculation, each process-scrap section is integrated into general process-scrap section that material flow is clear. It is estimated on the basis of the data of the Japan Ferrous Raw Materials Association. Environmental loads of a process-scrap are calculated using the new extended I/O table with the separated process-scrap section. Direct and in direct environmental loads: \( \varepsilon_j \) is obtained from the following formula.

\[
\varepsilon_j = E_j + \sum_i \varepsilon_i A_{ij}
\]

Here, direct environmental loads in j-section for a production of j-goods per unit of money is shown as \( E_j \) and indirect environmental load in other sections for a production of j-goods per unit of money is shown as \( \sum_i \varepsilon_i A_{ij} \). A vector of direct and indirect environmental loads \( \varepsilon \) is expressed in the following matrix notation.

\[
\varepsilon = E' (I - A)^{-1}
\]

Here, A is matrix that has \( A_{ij} \) as a factor and E is vector that has \( E_j \) as a factor, respectively. Direct environmental load is referred from Mr. Kawashima’s paper. “Expansion of the system by the material” is able to allocate these values to each material as if the material has environmental load itself.

This method is equivalent to an allocation between main goods and process-scrap based on economic value in LCA. “I/O table”\(^8\) in 1995 is used in this study. Amount of energy consumption and \( \text{CO}_2 \) emission of process-scrap steel by using extended I/O table were calculated with 55.7 GJ and 6.1 t-\( \text{CO}_2 \) per a million yen, respectively. These values correspond to 0.4 GJ and 0.1 t-\( \text{CO}_2 \) per ton of process-scrap. In regard to waste-scrap, direct and indirect environmental loads are assumed to be zero.

### 4. Result

Based on the above method, the environmental effect prediction of a newly steel recycling system is analyzed. I/O table is used for an inventory of each process and “Yearbook of Ferrous Raw Materials” and “Steel Statistics”\(^9\) are used for the basic material flow. The crude steel volumes of production in the 1995 fiscal year are about \( 100 \times 10^6 \) t, and the 67.3% is the production of converter steel. Calculated result using I/O table is shown Table 1. Assuming if there is no de-copper technology in future (scenario (a)), then processing of a surplus scrap is needed. \( \alpha \) is environmental load to treat surplus scrap steel, waste matters from transportation and storage, for example. On the other hand, with the prospectus de-copper technology (scenario (b)), the environmental effect of energy consumption and \( \text{CO}_2 \) emission is predicted to be 16.8 GJ per ton of waste scrap and 1.2 t per ton of waste scrap.

### 5. Conclusions

Target of this evaluation is not for the closed loop recycling like an aluminum beverage can but open loop recycling in which many industries participate. In this research, the system boundary corresponding to open loop recycling is given by using I/O table. It enables to set up the system boundary defined by the I/O table, i.e., an I/O boundary, in this method. Although it is predicted by setting up I/O boundary compared with the result at the time of assuming non-open loop recycling that environmental load becomes high, the result of LCA is definite. The result shows that the mini-mill process currently developed for recycled-base dematerialized society is an excellent mean also in LCA.

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### REFERENCES