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Life Cycle Inventory for Steel in Taiwan

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ABSTRACT

This paper summarizes the results of a comprehensive research work done on the life cycle inventory of steel in Taiwan.Under a contract with the Ministry of Economic Affairs; the environmental research team at the Industrial Technology Research Institute has undertaken a life cycle assessment (LCA) project since 1997. Among many others, life cycle inventory (LCI)-steel is one of the major tasks within the scope of this project. The bulk of the project work has been completed by the end of year 2000. The functional unit and system boundary of LCI-steel, unit processes within LCI-steel for integrated steel mill and electric arc furnace have been established. Compiled LCI data have been verified agaist operating steel mills and are to be updated on an on-going basis, to ensure their completeness and accuracy. For integrated steel mill, the material and energy balances based on 1 kilogram of carbon steel product have been calculated. Inputs include : ore, scrap, coal, alloy, flux, total energy, and water consumption. Outputs include : solid wastes, wastewater, carbon dioxide, dust emissions, SOx and NOx. LCI data summaries for steel products, based on both integrated steel mill route and electric arc furnace route, are also presented in this paper. The data obtained from this work have been checked against the results of the International Steel Institute LCI study and they are found to be in good agreement when comparing the two sets of data within the same context.

Key words: life cycle inventory, steel, Taiwan

INTRODUCTION

While accelerating industrial activities are adding a significant pollutant burden to the environment as well depleting available resources at an alarming rate, cleaner production and green design of processes and products obviously are the best preventative measures to ensure the sustainability of further industrial development. To effect these measures, however, one needs to make use of a life cycle assessment (LCA) approach to verify or improve the cleanness or greenness of the concerned industrial processes and products. Life cycle inventory (LCI) of these processes, involving material and energy balance checking throughout the entire life cycle of the target products, then emerges as a necessary research effort that every nation has to carry out, aiming to provide an indigenous and user-friendly database for industries to facilitate their LCA work and hence pursuit of green design.

Within this framework and under a contract with the Department of Industrial Technology of the Ministry of Economic Affairs (DOIT/MOEA) in Taiwan, the environmental research team of Industrial Technology Research Institute (ITRI) has undertaken the LCA work since 1997. The LCA work include: compiling 18 common and base-industry databases on energy, water, transportation, steel, petroleum, alkaline chlorine, cement, rubber, PVC, PS, glass, etc.; building LCI module; and completion of an integrated design-for-environment (DfE) and LCA module. Four case studies have been carried out, namely on refrigerators, soft drink containers etc., for demonstration purpose. In every case, the scope covers more than five (5) contaminants, ten (10) raw materials, and three (3) energy resources.

PROGRESS OF LCI-STEEL WORK IN TAIWAN

LCI-steel is no doubt one of the major sub-tasks within the overall LCA work. In total, an integrated steel mill and twenty-nine (29) electric arc furnaces have been surveyed since 1997 [1]. Out of the latter 29, only the data from 5 such furnaces are of consistency and reliability and therefore are used in the eventual LCI-steel study. These results have been verified against the operating data of concerned still mills.

The bulk of the above work has been completed by the end of December 2000. Compiled data are given in the Industrial Technology Research Institute report [1].

These data are to be continuously updated and verified by joint effort of ITRI team and relevant industries on an on-going basis.

At the same time, China Steel Corporation (CSC), being a key member of the International Steel Institute (ISI), is also active in coordinating with the ISI LCA Task Force and participating in its LCI survey and updating project. The ISI survey has started in 1995, of which the data has been updated until 1999. This project involves 12 steel-related products; its results are presented either by grouping or region [2]. The main purpose of this project, needless to say, is to provide a benchmark and thus a guidance for the steel industries to make their products “greener”.

The LCI-steel results of the MOEA/DOIT/ITRI work have been checked against those of the above-mentioned ISI/CSC study; they are found to be generally compatible with each other and within the acceptable accuracy while putting the two into the same context.

SYSTEM BOUNDARY OF STEEL LCI

Two types of steel-making processes exist in Taiwan, i.e. integrated steel mill and electric arc furnace. While addressing steel LCI, however, it is normally discussed in terms of a functional unit described as follows.

Functional Unit of Steel LCI

Depending on the subject of the steel product under assessment, the functional unit of steel LCI can be one of the following three items, which are major products from an integrated steel mill or an electric arc furnace:

- per kilogram (kg) of slab
- per kilogram (kg) of bloom
- per kilogram (kg) of billet

System Boundary of Steel LCI

It is a general practice to use a cradle-to-gate approach to set the system boundary for steel LCI. This normally covers : raw material and energy production including their extraction from the earth and further processing and refining; consumables production; transportation of all above plus ferrous scrap to the site boundary of steel works; steel works processing; by-products recovery processes; steel products and recovered materials delivery at the gate of the steel works; and discharge of water, air and solid emissions to the earth. The saved external operations, i.e. equivalent by-product functions, however, should be deducted from the system boundary LCI, to avoid double counting.

Figure 1 depicts the system boundary of steel LCI.

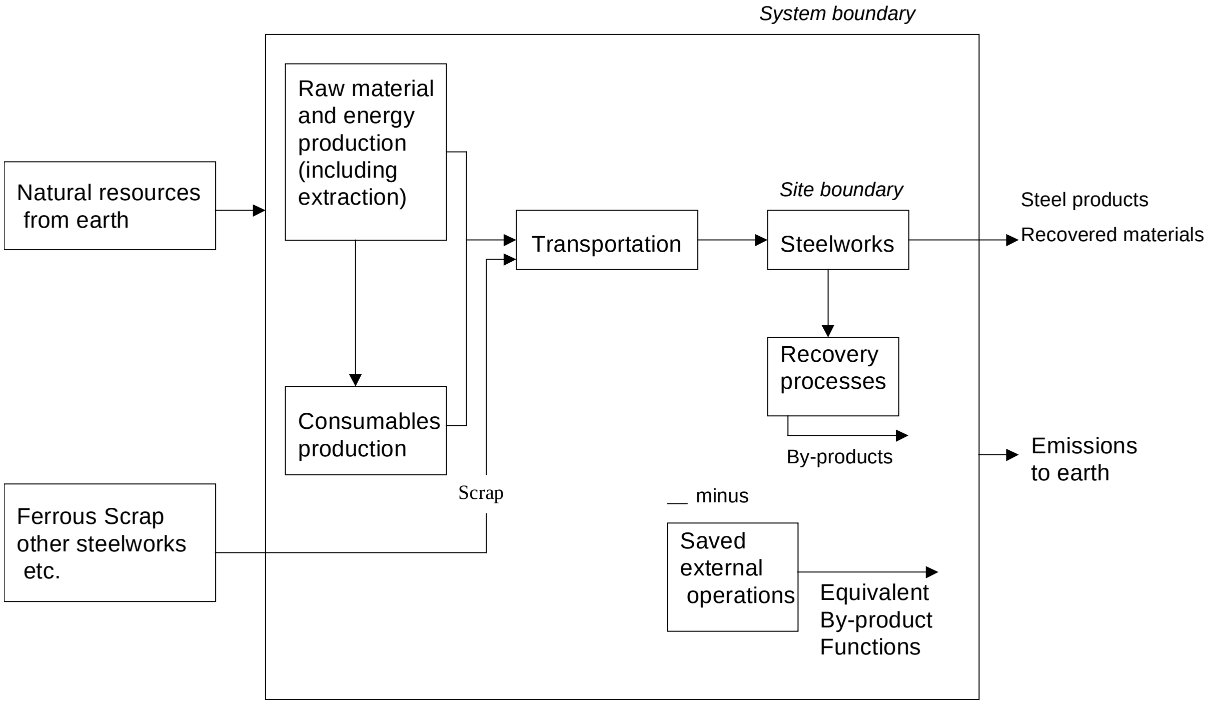

Figure 1. System Boundary of Steel LCI [1]

Unit Processes Within Steel LCI System – Integrated Steel Mill

Steel-making in an integrated steel mill generally follows a blast furnace (BF) route. Iron ore, feldspar and limestone are fed into a sintering plant to produce graded sinter, which is fed together with coke produced from coal in a coke oven, into a BF for pig iron (hot metal) production. Other material inputs to the BF include iron ore and ferro-manganese. The hot metal, with other materials such as dolomite, fluorspar and magnesium oxide, are then fed into a basic oxygen furnace (BOF) for making liquid steel, which then is made into slab, bloom and billet through continuous casting.

The slab, bloom and billet are then processed through section rolling, rod and bar rolling, hot strip mill, heavy plate rolling, and UO pipe making, to produce sections, rebar engineering steel wire rod, hot rolled coil, and plate.

Needless to say, energy is provided to all unit processes involved.

This process system is illustrated in Figure 2. Steel-making : Blast Furnace Route.

As described above, the unit processes are numerous within an integrated steel mill, however, from the viewpoint of LCI study the key ones are : raw material and energy delivery to the steel work; coal mining and delivery to the coke oven; iron ore, feldspar and limestone mining and delivery to the sintering plant; iron ore and ferro-manganese mining and delivery to the BF; sand production and delivery to the BF; coke and iron ore sinter delivery to the BF; BF for pig iron making; dolomite production, fluorspar mining, magnesium oxide production, and their delivery to the BOF; calcine procedure; hot metal and calcium oxide delivery to the BOF; BOF for steel making; liquid steel delivery to the continuous casting plant; production of slab, bloom, and billet; and discharge of air and water emissions

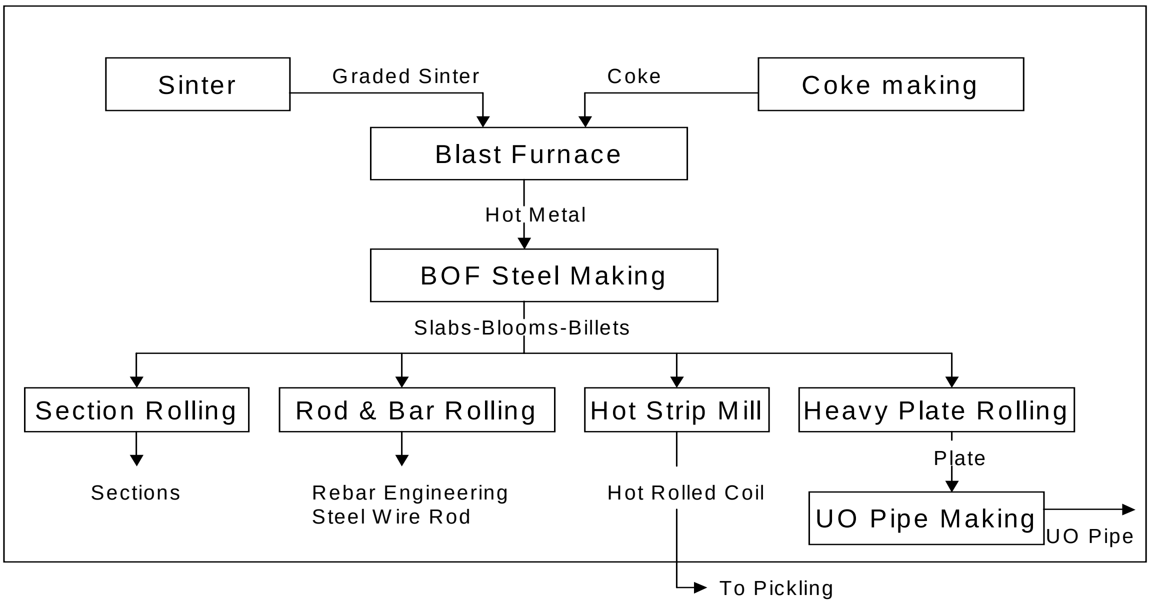

Figure 2. Steelmaking : Blast Furnace Route

and solid wastes from the steel works.

Figure 3 shows graphically the unit process flow within the steel LCI system for an integrated steel mill.

For the purpose of LCI-steel study on an integrated steel mill, major unit operations with relevant information are listed in Table 1.

Unit Process Within Steel LCI System – Electric Arc Furnace

Steel-making via electric arc furnace (EAF) route is basically a re-melt and cast primary ingot process. Raw materials, primarily ferro-alloy scrap collected from recycling practice, and energy are fed into an electric arc furnace, followed by MRP process and a vacuum degasser, to produce slab and billet as steel products. Also included as part of the output in the LCI system are : air and water emissions discharge and solid wastes generated from the steel plant.

Figure 4 illustrates the unit process flow within steel LCI system for an electric arc furnace.

Steel Making and Products Life Cycle

The steel-making and products life cycle basically consists of two parts of sharing interest, i.e. resource (raw material) countries and consumer (market) countries. See Figure 5. Included in the former "resource" part are : origin of resource materials such as coal, iron, etc.; steel-making by using the delivered resources; production of slab, bloom, billet, and slag; and delivery of these products to the following mills for further processing. Inputs to this part consist of resources, technology and capital, while outputs include slab, bloom, billet, air, water, solid and carbon dioxide emissions. In average, in producing 1 tonne of slab, 2.6 tonnes of raw materials are used in the steel-making plant, which in addition to the production of slab also generates 0.45 tonnes of slag and 1.6 tonnes of carbon dioxide.

The slab, bloom and billet are transported to the subsequent mills for further processing into steel products, which is the starting point of the so-called "market" part. In average, for I tonne of slab/bloom/billet, 0.9 tonnes of mill products are produced, resulting in 0.8 tonnes of consumer products delivered to the hand of end users, which after use become scraps waiting for recovery. During the process of making mill products and consumer products, 0.2 tonnes of residues are generated, which together with 0.45 tonnes of recovered scrap are sent to the EAF for making 0.5 tonnes of slab/bloom/billet. The EAF uses an average of 500 kwh of power in producing 1 tonne of steel.

RESULTS OF STEEL LCI

The results of the LCI-steel study are summarized in three forms, i.e. material and energy balance of integrated steel mill (BF-cold rolling), LCI data for steel products - blast furnace route, and LCI data for steel products – EAF route.

These data are extracted from a comprehensive database compiled from various sources, including the 1997-1998 ITRI survey[1], further verification in a time span of three years with various integrated steel mill and EAFs, and aforementioned CSC's study related to ISI LCI work[3]. These data have been checked against each other and found to be in general agreement.

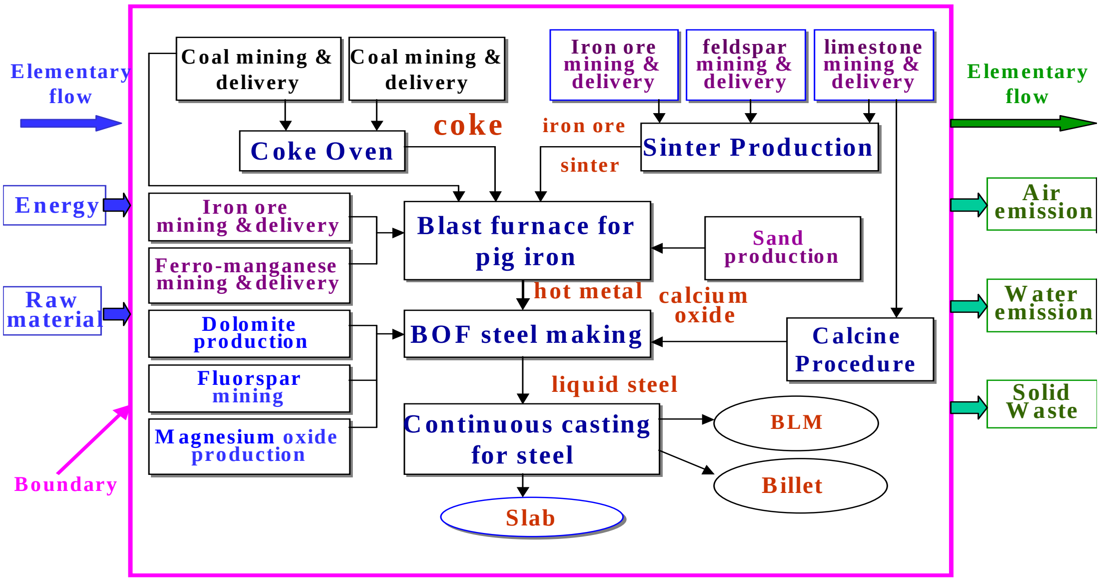

Figure 3. Unit process within Steel LCI System - Integrated Steel Mill[1]

Material and Energy Balance of Integrated Steel Mill (BF-Cold Rolling)

There is only one integrated steel mill in operation in Taiwan, i.e. China Steel Corporation. This integrated mill, while enjoying one of the highest per capita yield worldwide, produces approximately 10 million tonnes of steel per year. Table 2 represents a summary of the material and energy balance based on 1 tonne of carbon steel produced, up until BF-cold rolling[2].

In average, for every one (1) tonne of carbon steel produced, 1,400 kg of ore, 30 kg of scrap, 783 kg of coal, 20 kg of alloy and 370 kg of flux are used.

Total energy consumption, including coal, is23 GJ while the water consumption is 5.5 cubic meter. It is noted that energy recovery and water recycle are practiced widely in CSC, resulting in very efficient use of limited energy and water resources

On the output side, for every one (1) tonne of carbon steel produced, 530 kg of solid waste, 1.5 cubic meter of wastewater, 2.1 tonnes of carbon dioxide, 1.0 kg of dust, 1.3 kg of sulfur oxides and 1.2 kg of nitrogen oxides are emitted from the steel mill. These figures are reasonably low, comparable to those of other well-managed steel mills

LCI Data Summary for Steel Products – Blast Furnace Route

Based on the blast furnace route, Table 3 and Table 4 list the inflow and outflow data per 1 kg of steel product, respectively.

Material inflows include coal, dolomite, iron, limestone, zinc, ferrous scrap, natural gas, oil, and water. Energy inflows are expressed in the forms of total primary energy, non-renewable energy, renewable energy, fuel energy and feedstock energy

Table 1. Unit Operations of Integrated Steel Mill

Code	Operation	Unit
7201	Coke oven products	MJ
7202	Sinter production	kg
7203	Blast furnace for pig iron	kg
7204	Calcine Procedure	kg
7205	BOF steelmaking	kg
7206	Continuous casting for steel	kg
7207	Slab Conditioned procedure	kg
7208	BLM Production	kg
7209	Billet Production	kg
7210	Oxygen Production	m3
7211	Compressed air production	kg
7213	Steelworks power plant	MJ
7214	Coke oven gas production	MJ
7215	Coke oven gas use	MJ
7216	Blast furnace gas production	MJ
7217	Blast furnace gas use	MJ
7218	LDG production	MJ
7219	LDG use	MJ
7220	Electricity generation-Coke oven process	MJ
7221	Electricity generation-Sinter process	MJ
7222	Electricity generation-Blast oven	MJ
7223	Steelworks power plant-Electricity generation	MJ
7224	Steelworks electricity generation	MJ
7225	Steelworks electricity use	MJ
7228	Coal delivery	MJ
7231	Steelworks power plant-Mid press steam	MJ
7232	Steelworks power plant-CBA production	MJ
7233	Internal steel scrap recovery	kg input
7234	External steel scrap recovery	kg
7235	Nitrogen production	m3
7236	Argon production	m3
7240	SLAB PRODUCTION (ARC FURNACE) ROC	kg

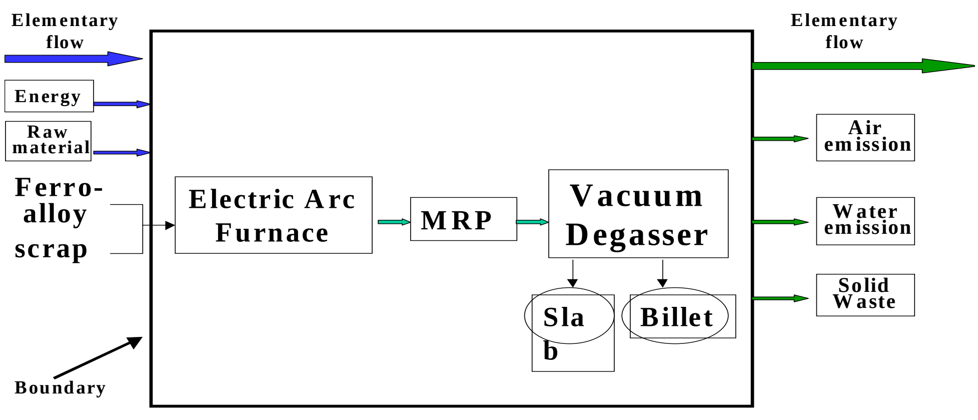

Figure 4. Unit process within Steel LCI System
—Arc Furnace: Remelt and cast primary ingot —[1]

Outflows include carbon dioxide, carbon monoxide, nitrogen oxides, particulate matters, sulfur oxides, ammonia, chlorides, fluorides, COD, cyanides, phenol, chromium, iron, nickel, zinc, total nitrogen (except ammonia), phosphates, phosphorous matter, sulfides, total suspended solids, water, recovered matter, and solid waste.

It can be seen that the data of Tables 3 and 4 compare favorably with those of Table 2, while putting the two sets of data in the same context.

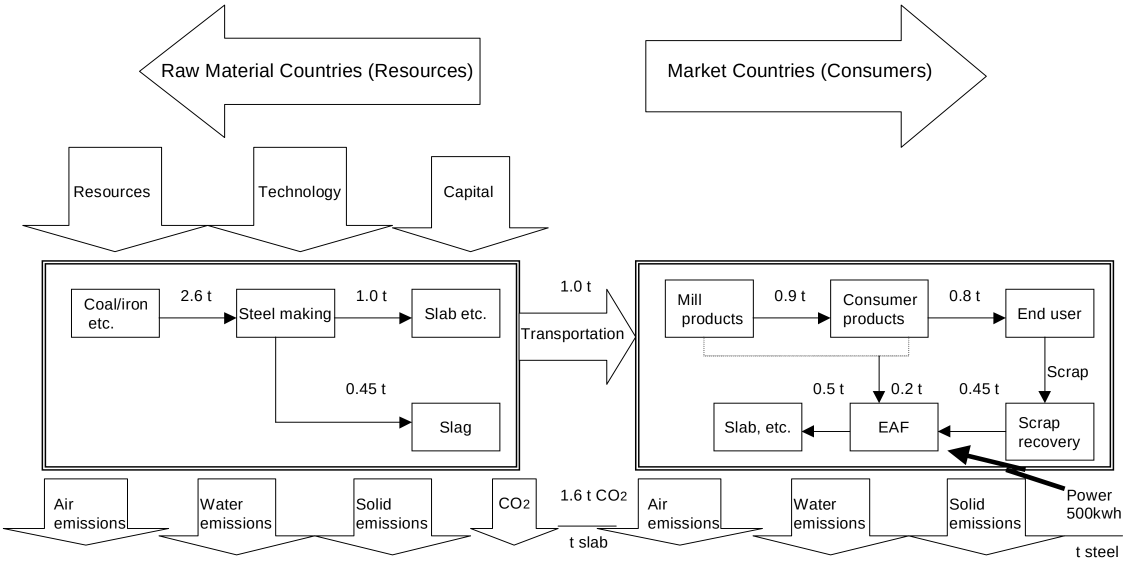

Figure 5. Steel Making and Products Life Cycle

Table 2.
Material and Energy Balance of Integrated Steel Mill (BF-Cold Rolling)[1,3]

Input:	
Ore	1,400kg/t-CS
Scrap	30kg/t-CS
Coal	783kg/t-CS
Alloy	20kg/t-CS
Flux	370kg/t-CS
Total Energy(including coal)	23GJ/t-CS
Water consumption	5.5m^3/t-CS
Output:	
Solid Wastes	530kg/t-CS
Waste Water	1.5m^3/t-CS
CO2	2.1t/t-CS
Dust-cmission	1.0kg/t-CS
SOx	1.3kg/t-CS
NOx	1.2kg/t-CS

LCA Data Summary for Steel Products – EAF Route

Based on the EAF route, Table 5 and Table 6 list the inflow and outflow data per 1 kg of steel product, respectively.

Material inflows, like those in Table 3, include coal, dolomite, iron, zinc, ferrous scrap, limestone, natural gas, oil and water. Energy inflows include total primary energy, non-renewable energy, renewable energy, fuel energy and feedstock energy.

Outflows, on the other hand, include carbon dioxide, carbon monoxide, nitrogen oxides, sulfur oxides, particulate matters, ammonia, chlorides, cyanides, fluorides, sulfides, chromium, iron, lead, nickel, zinc, total nitrogen (except ammonia), phosphates, phosphorous matter, COD, total suspended solids, water, recovered matter, and solid waste

As described previously, only the data from 5 of the 29 EAFs being surveyed are of consistency and therefore used in the compilation of Tables 5 and 6. These data are considered of reasonable quality and good as a reference for further study or other purposes.

Table 3. LCI Data Summary：Inflows for Steel Production (per kg of steel product) under Blast Furnace Route [1,3]

Description	Unit	Sum
Coal（in ground）	kg	0.678
Dolomite（CaCO3, MgCO3, In ground）	kg	0.026
Iron（Fe, ore）	kg	1.485
Limestone（CaCO3, in ground）	kg	0.006
Natural Gas（in ground）	kg	0.059
Oil	kg	0.054
Zinc（Zn, ore）	kg	0.006
Water Used（total）	kg	31.588
Ferrous Scrap-total	kg	0.126
E Total Primary Energy	MJ	29.381
E Non Renewable Energy	MJ	28.833
E Renewable Energy	MJ	0.548
E Fuel Energy	MJ	28.976
E Feedstock Energy	MJ	0.406

CONCLUSIONS

The LCI-steel study for both integrated steel mill and electric arc furnace routes in Taiwan has been completed with data updating to be continued on an on-going basis.

The obtained data of this work have been verified with the operating steel mills and checked against the results of the ISI LCA Task Force study. These data are found to be in relatively good agreement while comparing them within the same context.

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Table 4. LCI Data Summary：Outflows for Steel Production （per kg of steel product）under Blast Furnace Route [1,3]

Description	Unit	Sum
Carbon Dioxide（CO_2, fossil and mineral）	g	2175
Carbon Monoxide（CO）	g	32.141
Nitrogen Oxides（NOx as NO_2）	g	2.743
Particulate Matters - total	g	1.616
Sulfur Oxides（SOx as SO_2）	g	3.238
Ammonia（NH_4^+, NH_3, as N）	g	0.114
Chlorides（$C1^-$）	g	0.873
Chromium（Cr III, Cr VI）	g	1.077E-03
COD（Chemical Oxygen Demand）	g	0.276
Cyanides（CN^-）	g	0.001
Fluorides（F^-）	g	0.023
Iron（Fe^{++}, Fe^{3+}）	g	0.024
Lead（Pb^{++}, Pb^{4+}）	g	5.322E-04
Nickel（Ni^{++}, Ni^{3+}）	g	2.723E-04
Nitrogen-TOTAL（except Ammonia）	g	0.157
Phenol（C_6H_6O）	g	8.886E-03
Phosphates（PO_4^{3-},HPO^{4-}, H_2PO^{4-}, H_3PO_4, as p）	g	-0.002
Phosphorous Matter（unspecified, as P）	g	0.001
Sulfides（$S^=$）	g	0.133
Total Suspended Solids（unspecified）	g	0.297
Zinc（Zn^{++}）	L	0.005
Water（unspecified）	kg	12.459
Recovered matter（total）	kg	0.082
Waste（total）	kg	0.211

Table 5. LCI Data Summary ： Inflows for Steel Production

（per kg of steel product）under EAF Route [1,3]

Description	Unit	Sum
Coal（in ground）	kg	0.088
Dolomite（CaCO3, MgCO3, In ground）	kg	0.001
Iron（Fe, ore）	kg	0.008
Limestone（CaCO3, in ground）	kg	0.073
Natural Gas（in ground）	kg	0.054
Oil	kg	0.046
Zinc（Zn, ore）	kg	-0.004
Water Used（total）	kg	8.023
Ferrous Scrap-total	kg	1.118
E Total Primary Energy	MJ	11.509
E Non Renewable Energy	MJ	10.380
E Renewable Energy	MJ	1.125
E Fuel Energy	MJ	10.965
E Feedstock Energy	MJ	0.553

Table 6. LCI Data Summary ：Outflows for Steel Production

（per kg of steel product）under EAF Route [1,3]

Description	Unit	Sum
Carbon Dioxide（CO2, fossil and mineral）	g	523.378
Carbon Monoxide（CO）	g	1.654
Nitrogen Oxides（NOx as NO2）	g	1.398
Particulate Matters – total	g	0.224
Sulfur Oxides（SOx as SO2）	g	1.767
Ammonia（$NH4^{+}$, NH3, as N）	g	0.000
Chlorides（$C1^{-}$）	g	0.242
Chromium（Cr III, Cr VI）	g	2.18E-05
COD（Chemical Oxygen Demand）	g	0.069
Cyanides（CN^{-}）	g	0.000
Fluorides（F^{-}）	g	0.015
Iron（Fe^{++}, Fe^{3+}）	g	0.005
Lead（Pb^{++}, Pb^{4+}）	g	6.33E-05
Nickel（Ni^{++}, Ni^{3+}）	g	6.13E-05
Nitrogen-TOTAL（except Ammonia）	g	-0.001
Phenol（C6H6O）	g	5.56E-06
Phosphates（$PO4^{3-}$, HPO^{4-}, $H2PO^{4-}$, H3PO4, as p）	g	9.67E-03
Phosphorous Matter（unspecified, as P）	g	6.67E-02
Sulfides（$S^{=}$）	g	0.001
Total Suspended Solids（unspecified）	g	0.057
Zinc（Zn^{++}）	L	2.60E-04
Water（unspecified）	kg	7.290
Recovered matter（total）	kg	0.106
Waste（total）	kg	0.067