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Professional paper

EXAMPLES OF LCA METHODOLOGY IMPLEMENTATION IN STEEL INDUSTRY

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Abstract

Steel industry kept pace with actual trends for environmental protection in many ways – through different technological improvements considering environment protection, important share of recycling in the steel production, design of so called “eco-steels”, materials designed according to recent environmental directives and legislatives, etc. In the frame of steel production monitoring, LCA methodology is very important for obtaining an accurate environmental picture of a process, due to the fact that the process should be evaluated over its entire life cycle. A number of tools and methodologies have been developed in recent years to assess the potential environmental impacts associated with a product, process or activity during its entire life cycle. The examples of Life Cycle Assessment (LCA) are used by large steel industrial companies as potentially helpful tool for improving the production processes, efficiency of resource utilization and significantly reduction of waste generation and emissions are presented in this paper.

Key words: *steel industry, Life Cycle Assessment (LCA), environmental protection.*

1. PREFACE

At the beginning of the 21st Century it is thought to be very hard for the world economy to continue developing. Iron and steel are two of the most popular materials on the Earth and will remain so in future. Therefore, the development of such materials into an eco-material will greatly affect both issues - resources and environment. In producing iron and steel, a lot of resources such as electricity, water, fossil fuels, iron ore, limestone, refractories and metallic elements like molybdenum, cobalt, vanadium, niobium, nickel, chromium, zinc, aluminum, manganese and silicon are consumed, and further technological progress and development is required to save resources and energy from a viewpoint of ongoing depletion of resources [1].

Steel production is an energy- and CO₂- intensive activity, as much of the production process takes place at high temperatures. Besides, iron ore is converted in metallic iron by using carbon

as reducing agent. As global warming due to CO₂-emissions is considered one of today's main environmental problems, publications about the environmental impact of steel production mainly focus on reduction of energy use. For example, ArcelorMittal Gent decreased its energy use from 25 GJ/ton hot rolled coil in 1980 to 17,9 GJ/ton in 2005. The reduction of specific energy demand is the result of important process-integrated measures such as the switch from ingot casting to continuous casting (realised during 1989-1996), the reduction of material losses in the various production steps, as well as of good company management practices. Next to CO₂, large industrial steelworks also emit pollutants that may have other environmental impacts [2].

Steel, as a construction material, provides many beneficial and essential services to society. However the processes linked to the production, transportation, use, maintenance, deconstruction, reuse, recycling and ultimate disposal of steel construction products contribute to the global environmental pressures being exerted on our planet. It is essential to understand how, where and why these environmental impacts occur and to quantify them. This will allow strategies to be implemented so that steel can continue to provide benefits to society but at a reduced or acceptable environmental cost. LCA is increasingly gaining acceptance as the most useful and relevant decision-support tool when assessing the environmental impacts of the built environment [3].

To obtain an accurate environmental picture of a process, it is essential that the process will be evaluated over its entire life cycle. A number of tools and methodologies have been developed in recent years to assess the potential environmental impacts associated with a product, process or activity during its entire life cycle. Life Cycle Assessment (LCA) is one such tool, and is sometimes referred to as "cradle-to-grave" analysis.

2. LIFE CYCLE ASSESSMENT METHOD – IMPLEMENTATION IN STEEL INDUSTRY

LCA is an environmental assessment method for evaluation of impacts that a product, process or technology has on the environment over the entire period of its life – from the extraction of the raw material through the manufacturing, packaging and marketing processes, the use, re-use and product or technology maintenance, to its eventual recycling or disposal as waste at the end of its useful life. LCA can assist steel plants in the environmental management. LCA is a method of the evaluation of environmental aspects and potential impacts associated with all stages of the life of product, process and technology. The LCA method consists of four phases defined by the Society of Environmental Toxicology and Chemistry (SETAC) and more recently by the International Standards Organization (ISO):

- 1. Goal Definition and Scoping** lays out the rationalization for conducting the LCA and its general intent, as well as specifying the product systems and data categories to be studied,

2. **Life-Cycle Inventory (LCI)** involves the quantification of raw material and fuel inputs, and solid, liquid, and gaseous emissions and effluents,
3. **Life-Cycle Impact Assessment (LCIA)** characterizes the environmental burdens identified in the LCI and assesses their effects on human and ecological health, as well as other abiotic effects, such as smog formation and global warming,
4. **Improvement Assessment or Interpretation of Results** uses findings from the analysis to identify and evaluate opportunities for reducing life-cycle environmental impacts of a product, process, or activity, or to reach conclusions and provide recommendations.

LCA evaluates the life-cycle environmental impacts from each of five major life-cycle stages: raw materials extraction/acquisition, materials processing, product manufacture, product use, and final disposition/end-of-life. Figure 1. shows the steel life cycle.

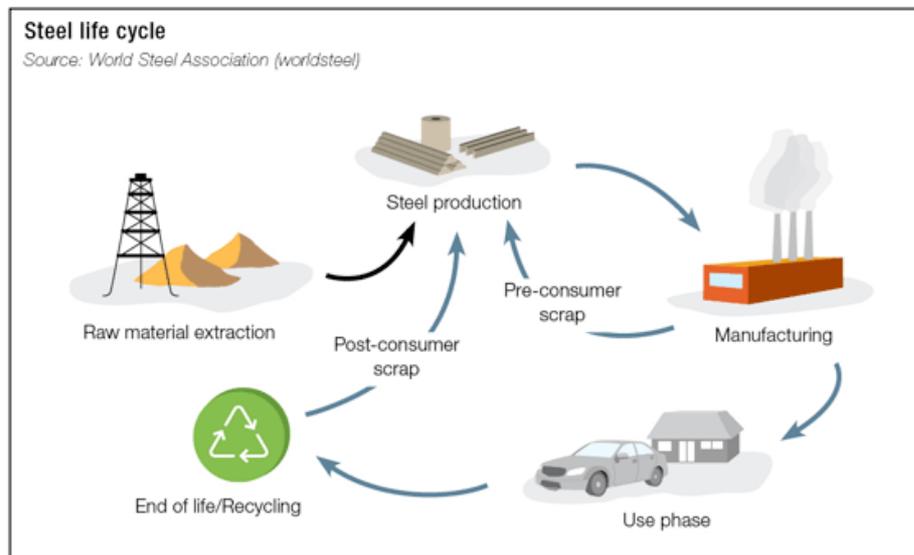


Figure 1. Steel life cycle

World Steel Association leads perform of LCA analyses in the metallurgical sector. Life Cycle Assessment (LCA) is undertaken as the most holistic approach for evaluation environmental impact and selecting new technologies to reduce emissions for iron and steel industry.

3. EXAMPLES OF LCA IMPLEMENTATION IN STEEL INDUSTRY

LCA methodology is being used by large industrial companies as potentially helpful tool for improving the production processes, efficiency of resource utilization and significant reduce of waste generation and emissions.

3.1. Nippon Steel Corporation

Nippon Steel has developed various environmentally compliant products eco-products by making the most of the excellent properties and functions of iron as a member of the steel industry and will greatly contribute to global environmental protection also in the 21st Century as an eco-company manufacturing eco-products by ecoprocesses and eco-technologies.

Steel can contribute to the environment from the standpoints of steel manufacture and products in the following four main stages:

1. steel manufacture (from raw materials to finished steel products),
2. fabrication and assembly of final products using steel,
3. use of final products,
4. scrapping or recycling for reuse.

The first stage is concerned with the steel manufacturing process itself. It is essential to establish steel production processes with small energy and low environmental loads, or ecoprocesses. The steel industry is a large energy consumer. Two successive oil crisis in the 1980's prompted the Japanese steel industry to implement positive energy-saving measures. Japanese steel production is one of the most energy-efficient processes in the world now [4].

The second stage is concerned with the contribution to the manufacturing processes of customers using steel. The user can improve or reduce its environmental load by using a given type of steel. For example, the use of appropriate steel helps the customer to enhance manufacturing efficiency in its fabrication process, eliminate some of its fabrication steps, or simplify its fabrication process itself.

The third stage is concerned with contribution to the environment when end products made by using steel are actually used. For example, better steel products contribute to the fuel mileage improvement of automobiles and the efficiency enhancement of motors.

In the fourth stage, the used products are scrapped or recycled for reuse. In this stage, steel scraps are returned to the steel industry, normally. In the stages after the second stage, steel products contribute to the environment when they are utilized as commercial products by customers and end users. These steel products can be called environmentally conscious steel products or eco-steel products [5].

3.2. LCA of automobiles and steel

In considering the LCA of automobiles, the energy consumption concerned can be roughly divided into two areas: one for the manufacturing of the vehicles; and the other for driving them. For the lifetime energy consumption for passenger cars, energy for motion accounts for 75-80%, while the percentage for material energy is only 15-20%. It is evident from this that priority should be given to the development of materials to reduce the vehicle weight for the purpose of energy consumption for producing motion rather than pursuing reduction of the energy consumption for manufacturing materials. The ratio of each material for passenger cars 2000cc class, in terms of weight, accounts for 75% of all the materials for passenger cars. Although steel products, used to ensure safety of automobiles, cannot be reduced, if the strength of

hightensile steel can be improved, the weight of the steel products used can be decreased, thereby enabling contribution to improving fuel economy for producing motion [6,7].

As for the relationship between vehicle weight and fuel economy of Japanese, a 10% decrease in the vehicle weight corresponds to a 10-12% improvement in fuel economy. Present passenger cars have achieved some 5% decrease in weight by the use of high-tensile steel, compared with those in and around 1970. Furthermore, in the future, nearly 10% reduction in weight is expected by increasing the use ratio of high-tensile steel.

As refining technologies improve and advance, steel products become purer, resulting in the improvement of corrosion resistance. It is well known, for instance, that ferritic stainless steel corrosion resistance is improved sharply when its carbon plus nitrogen content is reduced to 100 ppm or less. Recently, this knowledge has been applied in Japan. In addition, recently surface-treated steel sheets for automobiles that remain corrosion resistant for 10 years of service have been developed.

3.3. LCA between a steel-framed house and a conventional wooden structure

The iron and steel industry has just launched a drive to promote steel-framed houses. At a recent academic meeting, the results of a study carried out at a correlative iron-making course at Tokyo University on the comparison of the carbon dioxide emission in terms of LCA between a steel-framed house and a conventional wooden structure were reported. Metaphorically, steel products are masses of energy. This means that the emission of carbon dioxide in building a steel-framed house is greater than that of a wooden house. However, when viewed by the method of disposal at the end of their service life the wooden house is burned and produces carbon dioxide, while the CO₂ emission from the steel-framed house can be held to one-quarter of the wooden house's as the waste steels are scrapped and recycled. Furthermore, when the longer service life of the steel framed house is taken into account, the results obtained show that the total carbon dioxide emission from the steel-framed house is reduced to as low as some 20% of that of the wooden house.

3.4. CSIRO Minerals

A Life Cycle Assessment (LCA) of stainless steel production, including nickel, ferronickel, ferrochromium and iron feedstocks was carried out using inventory data derived from the literature. The environmental impact categories considered in the study were Global Warming Potential (GWP), Acidification Potential (AP) and total (or full cycle) energy consumption. The effects of different sources of electricity (black coal, natural gas and hydroelectricity) were also examined in the study.

While other environmental impact categories are also important in LCA studies, the data necessary to evaluate these impact categories are often not available in the literature. In the case of toxicity impact categories (human toxicity and eco-toxicity), there are also concerns that even when such data are available, they do not truly reflect what occurs in the environment [8].

The functional unit for the study was 1 kg of refined stainless steel, with all impacts being expressed per kg of refined stainless steel.

The following processing routes were considered in the LCA study:

- iron and steel production by the integrated steel route (Blast Furnace and Basic Oxygen Furnace),
- nickel metal production by flash smelting and Sherritt-Gordon refining,
- ferrochromium and ferronickel production by the rotary kiln/arc furnace process,
- stainless steel production by the electric arc furnace/argon-oxygen decarburization (EAF-AOD) process.

The feedstocks to each process and their compositions as used in the LCA study are given in Table 1.

Table 1. Processes and feedstocks included in LCA study

Metal	Feedstock	Process
Iron/steel	Iron ore (64% Fe)	Blast furnace & Basic Oxygen furnace
Nickel	Sulphide ore (2.3% Ni)	Flash smelting & Sherritt-Gordon refining
Ferrochromium	Chromite ore (27.0% Cr, 17.4% Fe)	Pelletising/sintering/pre-reduction/ submerged arc furnace
Ferronickel	Laterite ore (2.4% Ni, 13.4% Fe)	Rotary kiln / electric furnace
Stainless steel	Pig iron (94% Fe, 4.4% C)	Electric arc furnace / argon oxygen decarburization
	Ferrochromium (55% Cr, 30% Fe)	
	Ferronickel (23% Ni, 69% Fe)	
	Nickel (100% Ni)	

Stainless steels are typically produced by a two-stage process. Raw materials (including scrap) are melted together in an electric arc furnace, with the composition of the molten metal used corresponding approximately to that of the desired steel product, apart from the carbon content. The molten metal is then transferred to a refining vessel (most commonly an argon-oxygen decarburization (AOD) vessel) which reduces the impurities (especially the carbon content) to the low levels required in the final product.

A schematic flowsheet of stainless steel production by the electric furnace-argon/oxygen decarburization (EAF-AOD) process is shown in Figure 2. The compositions of the various metal inputs into this process given in Table 1 were used to estimate the required amounts of the various metal inputs to produce 304 stainless steel (which accounts for more than 50% of all stainless steels produced) with a composition of 68,6% Fe, 19,0% Cr, 9,3% Ni and 0,08% C.

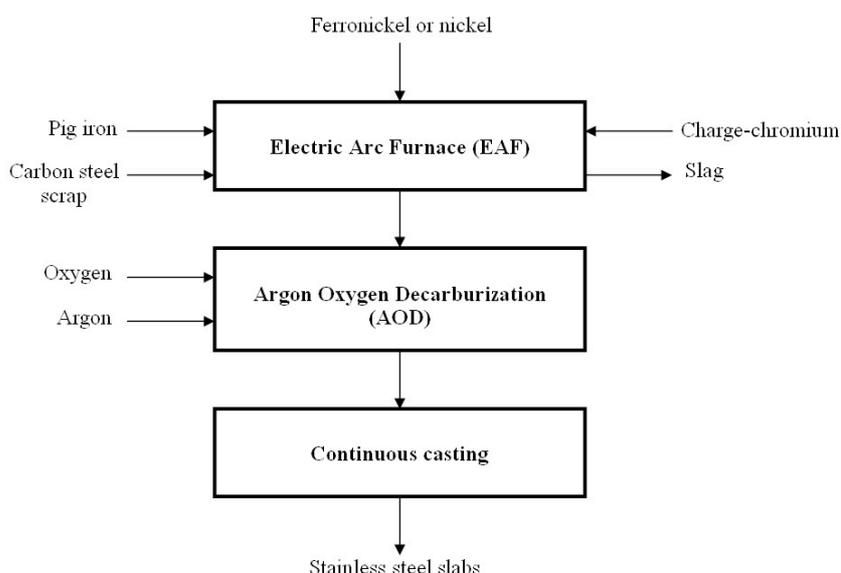


Figure 2. Schematic flowsheet of stainless steel production

Individual LCA spreadsheet models of the various metal production processes outlined in Table 1 were set up using the CSIRO Minerals in-house LCA software LCA-PRO (Excel-based). The relevant inventory data were incorporated into the respective models and the results generated by the models are summarised in Table 2.

Table 2. LCA results for stainless steel production

Environmental impact	Feedstock materials for stainless steel production				304 Stainless steel	
	Iron	Nickel	Ferrochrome	Ferronickel	From nickel	From ferronickel
Total energy (MJ/kg)	22	114	56	110	49	75
Gaseous emissions						
CO ₂ (kg/kg)	2.0	11.1	5.1	8.9	4.8	6.6
CO (g/kg)	1.9	2.9	5.4	5.6	3.4	4.7
N ₂ O (g/kg)	0.02	0.05	0.06	0.07	0.04	0.06
CH ₄ (g/kg)	2.6	16.6	6.2	18.4	6.0	10.8
NO _x (g/kg)	12.6	44.6	29.6	70.6	24.8	44.1
NMVO ^{**} (g/kg)	0.20	2.7	0.17	1.6	0.4	0.8
SO ₂ (kg/kg)	0.007	0.107	0.018	0.026	0.022	0.020
GWP (kg CO ₂ e/kg)	2.1	11.4	5.3	9.3	4.9	6.8
AP (kg SO ₂ e/kg)	0.015	0.138	0.039	0.075	0.039	0.051

** Non-Methane Volatile Organic Compounds

The results of the LCA showed that when ferronickel is used as the nickel source, the total energy consumption for stainless steel production is approximately 50% higher than when nickel metal is used as the nickel source (75 MJ/kg cf. 49 MJ/kg). This result comes about largely because the Fe units in ferronickel have a much higher energy intensity than do the Fe units in pig iron, and the greater the use of the former at the expense of the latter, the greater is the total energy consumption.

The results also showed that the production of ferronickel made by far the largest contribution (59%) to the total energy consumption for stainless steel production when this feedstock is used as the nickel source, but when nickel metal is used as the nickel source the contributions of the various stages are more evenly distributed. It was also observed that the electricity consumption of the electric furnaces used in the production of ferronickel, ferrochromium and stainless steel contributed approximately 50% to the total energy consumed in stainless steel production. Given the relatively low efficiencies associated with electrical power generation, significant reductions in the total energy of stainless steel production could be anticipated if more direct use of thermal energy was made in the ferronickel, ferrochromium and/or stainless steel smelting stages, for example by utilising bath smelting processes.

The energy intensity of stainless steel production relative to the production of a number of other metals is shown in Figure 3. where the results from this LCA study are compared with the results from previous LCA studies by the authors [9-11].

It can be seen from this figure that the energy intensity of stainless steel is comparable with that for copper and zinc, lower than that for aluminium and nickel, but higher than that for steel and lead. Toxicity concerns often associated with copper and lead and the generally shorter life span of steel compared to stainless steel due to its lower corrosion resistance, means that when all three factors (energy intensity, toxicity and lifespan) are considered together, stainless steel is probably the most suitable candidate of all the metals shown in Figure 2. for meeting sustainable development goals.

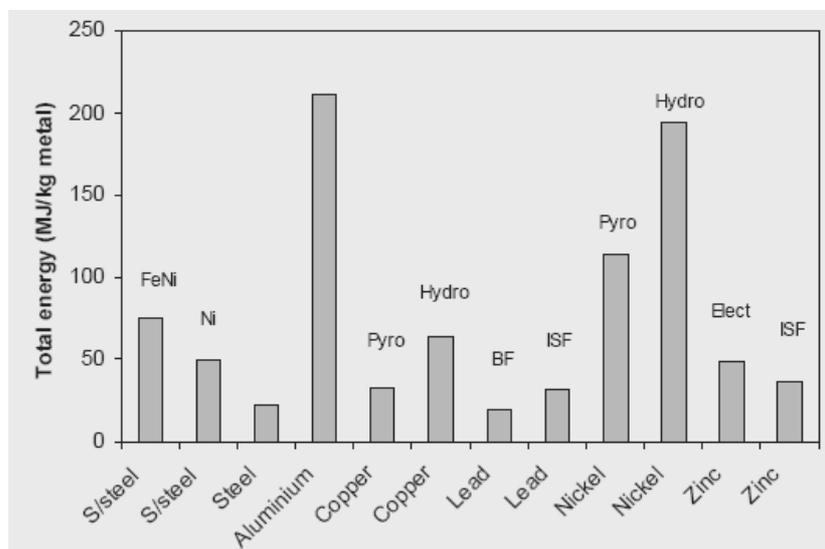


Figure 3. Total energy consumption for stainless steel production compared to other metals

The energy intensity of the pyrometallurgical processes in Figure 3. can potentially be reduced in a number of ways, including:

- eliminating the need to reheat the feed materials into the process,
- recovering the thermal energy contained in the slag products and utilising this energy within the process.

Using the stainless steel LCA model in conjunction with process simulation software, it was estimated that 1,4 MJ/kg stainless steel (400 kWh/t) would be saved by removing the need to reheat the feed materials shown in Figure 2. This saving constitutes two-thirds of the electricity input, with the total energy consumption and GWP being reduced by approximately 6% to 71 MJ/kg and 6,4 CO₂ e/kg respectively (with ferronickel feedstock), bearing in mind the electricity generation efficiency of 35% [12].

If the energy intensity of stainless steel production relative to the other metals in Figure 3. could be reduced even further, it would enhance stainless steel's attractiveness from a sustainable development viewpoint. As mentioned earlier, this may be possible by more direct use of thermal energy in the smelting stages used to produce the various metallic feedstocks. Work is currently in progress at CSIRO Minerals to investigate the use of bath smelting processes for more direct routes to stainless steel.

3.5. ArcelorMittal Gent (Belgium)

ArcelorMittal Gent with a production capacity of $5 \cdot 10^6$ ton of steel per year, it is one of the major production sites of the ArcelorMittal Group, which is the largest steel producer in the world. ArcelorMittal Gent represents a fully integrated steelwork, meaning that every step of the production process, from the supply of raw materials to the production of finished products such as coated steel sheets and laser-welded blanks, takes place on site.

By using LCA method, a detailed evaluation of the evolution of the environmental impact of the ArcelorMittal Gent site was done.

In order to evaluate the evolution of the environmental impact of ArcelorMittal Gent over the period 1995–2005, six partial ecoefficiency indicators or “eco-intensities” taking into account the evolution in production were proposed.

For the impact category acidification, the eco-efficiency improved between 1995 and 2005 with 45% as a result of improved production efficiency and by a number of process-integrated measures.

The impact of emissions contributing to photo-oxidant formation was 4% lower in 2005 than in 1995, despite a relative increase in own sinter production (which is the main source of photo-oxidants).

The partial eco-efficiency indicator for emissions to air contributing to human toxicity decreased with 52% between 1998 and 2005 (1998 was chosen as reference year for this theme, since for 1995 and 1996 there exists no accurate emission data for some pollutants). This decrease is the result of both process-integrated and end-of-pipe measures leading to a significant reduction of PAH- and PCDD/F-emissions.

The emissions to water only accounted for less than 0,3% of the total impact (of all the emissions to air and water) in the impact category human toxicity. The partial eco-efficiency indicator for freshwater aquatic ecotoxicity (only emissions to air) decreased with 9% between 1998 and 2005.

The impact of the pollutants in the discharged wastewater is in the same order of magnitude as the impact of the emissions to the air. In some years the impact was negative because the concentration of heavy metals e.g. vanadium and nickel in wastewater discharged in the canal was lower than the concentration in the canal water used.

NO_x is the major contributor to eutrophication; its emission decreased with 11% from 1995 to 2005 as a result of improved production efficiency and because of the switch to certain types of anthracite as fuel in the sinter plant.

As for ecotoxicity, the concentration of eutrophyng pollutants is lower in the wastewater than in the canal water. The (negative) impact of N- and P-containing substances in the wastewater is 10 times lower than the impact of NO_x-emission to air. ArcelorMittal's water use per ton of liquid steel produced decreased by 33% as a result of the realisation of an intelligent recycling system.

The extraction of non-phreatic groundwater was stopped in 2002. For the impact categories acidification, human toxicity (emissions to air) and water use, ArcelorMittal Gent succeeded in an absolute decoupling of environmental impact and steel production.

For photo-oxidant formation, freshwater aquatic ecotoxicity and eutrophication, the decoupling of environmental impact and steel production was relative [13-15]

4. CONCLUSIONS

The technology of ferrous metals is well established. The use of iron and steel, in particular, is considerable and widespread. However, the processing of these materials is resource intensive and generates considerable pollutants, despite continual development. To maintain the use of these popular and versatile materials in the future will necessitate an increased attention to reductions in the consumption of natural resources and power, and greater sensitivity to the environment. As human civilization advances, it is inevitable that iron and steel will increase in quantity on the global scale. Therefore, in production and application processes of such materials, their eco-material-oriented. i.e. to take ecology into consideration development is a serious issue that is indispensable for the world economy to continue growing. This involves a lot of engineering and industrial issues and requires rapid development in the future. Furthermore, by releasing the implementation results of LCA correctly and having consumers utilize it, consumers can chose more eco-friendly products and whether a company's product development is eventually considered environmentally friendly can be evaluated. LCA has been a topic of growing interest to the steel industry. Several steel companies and associations have already independently carried out LCA studies, each different in purpose, system boundary and methodology, and some of the examples are shown in this paper. The challenges posed by a competitive market are forcing steel makers to switch over to cleaner production by adopting the best practices at each stage in the life cycle of steel making. This shift may be gradual but is unmistakable. Heavy investment programmes, top management support, employee education and

training are all contributing towards enhanced environmental performance. It is hoped that in the coming years, the use of new and innovative management tools such as LCA will be increased.

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Stručni rad

PRIMERI PRIMENE LCA METODOLOGIJE U INDUSTRIJI ČELIKA

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Izvod

Industrija čelika je uhvatila korak sa najnovijim trendovima u oblasti zaštite životne sredine na nekoliko načina- kroz različita tehnološka poboljšanja u pogledu zaštite životne sredine, preko značajnog udela recikliranja u proizvodnji čelika, kao i proizvodnje takozvanog “eko-čelika”, materijala nastalih prema najnovijim ekološkim direktivama i zakonskim odredbama itd. U okviru monitoringa proizvodnje čelika LCA metodologija je veoma važna za dobijanje precizne ekološke slike nekog procesa, zbog činjenice da se taj process mora evaluirati tokom čitavog svog životnog ciklusa. Poslednjih godina je razvijen niz oruđa i metodologija kako bi se procenili potencijalni ekološki uticaji u vezi sa nekim proizvodom, procesom ili aktivnošću tokom čitavog životnog ciklusa. U ovom radu su predstavljeni primeri procene životnog ciklusa (LCA) koje velike kompanije koje se bave proizvodnjom čelika koriste kao korisno oruđe u poboljšanju proizvodnih procesa, efikasnosti korišćenja resursa i značajnom smanjenju količine nastalog otpada i emisije.

Ključne reči: *Industrija čelika, procena životnog ciklusa (LCA), zaštita životne sredine*