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GREEN MANUFACTURING BASED ON LIFE CYCLE ASSESSMENT (LCA)

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Abstract: This paper presents Green Manufacturing (GM) in Life Cycle Assessment (LCA) approach and application of LCA in production logistic. This paper provides an overview of the current status of LCA methodology and its applicability for Green Manufacturing evaluating and improving. Life Cycle Assessment is one of the pollution prevention methods, which are used primarily for increase environmental and economic efficiency of product or technology. According to the sustainable development, pollution should be prevented or reduced at the source whenever feasible. LCA demonstrates the elements of technology or product which generate the highest environmental burdens. This is particularly important for material - and energy - intensive sectors. Green Manufacturing based on LCA is presented on the example of chosen manufacturing process.

1 INTRODUCTION

Many production management methods is used to assessment and improving the quality of product or technology. However, less of these methods able to evaluate environmental influence. Author of this article proposed integration of environmental and economic aspects of product or technology in whole life cycle and suggested eco-efficiency analysis (EEA) as a new criterion for production system assessment (instead of productivity). In article [1,2] was presented the importance of economic and environmental aspects assessment in the logistics process and the essence of eco-efficiency analysis in the production logistics. Eco-efficiency analysis allows to find the most effective solution taking into account economic aspects and environmental compatibility of products or technologies. The concept of eco-efficiency (EE) was first introduced by Schaltegger and Sturm (1990) [3], the concept only became popular after adoption by the World Business Council for Sustainable Development (WBCSD) in 1992. Although, there is as yet no unambiguous and generally accepted definition of eco-efficiency, consensus seems to be growing that an eco-efficiency indicator expresses the ratio between an environmental and a financial variable [4]. The methodology of eco-efficiency calculation is known for almost twenty years. According to WBCSD "Eco-efficiency is achieved by the delivery of competitively-priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level at least in line with the earth's estimated carrying capacity". In short, it is concerned with creating more value with less impact [5]. Eco-efficiency tools (including Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) are related with Green Manufacturing tools. All of them are used for pollution prevention and increase environmental and economic efficiency.

In this paper case study of LCA and eco-efficiency application in iron ore sinter production for improve GM system is presented. Reducing environmental emissions from the sintering process is one of the most important steps for improving the environmental aspects in iron and steel industry

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towards to Green Manufacturing [6].

2 GREEN MANUFACTURING AND LCA IN PRODUCTION LOGISTIC

Green Manufacturing deals with maintaining sustainability's environmental, economical and social objectives in the manufacturing domain. Reducing hazardous emissions, eliminating wasteful resources consumption and recycling are examples of sustainable green manufacturing activities. A.M. Deif [7] proposed the relation between sustainability as a concept and green manufacturing as a methodology in the following definition of Green Manufacturing: GM is a sustainable approach to the design and engineering activities involved in product development and/or system operation to minimize environmental impact. The term Green Manufacturing was coined to reflect the new manufacturing paradigm that employs various green strategies and techniques to become more eco-efficient. This strategies include creating products/systems that consumes less material and energy, substituting input materials, reducing unwanted outputs and converting outputs to inputs (recycling) [8].

Green Manufacturing is a conception of production which connects the design of products and processes that reduce waste, eliminate costly end-of-the-pipe treatments, provide safer products and reduce use of energy and resources. Green Manufacturing is also known by plethora of different names: Clean manufacturing, environmentally conscious manufacturing, environmentally benign manufacturing, environmentally responsible manufacturing and Sustainable manufacturing. Irrespective of the various acronyms, the primary goal remains the same - designing and delivering products that minimize negative effects on the environment through their production, use, and disposal. The fundamentals of Green Manufacturing are relate to minimizing the use of resources and the environmental impact of a product. This philosophy is extended to all the elements of its life cycle - from its design to its end of life [9]. The main objectives of Green Manufacturing include:

- pollution prevention
- reduce waste
- reduce materials and energy
- increase of eco-efficiency

In order to implement a comprehensive environmental performance assessment of production system can be used holistic technique - life cycle assessment LCA. In order to analyze the environmental LCA technique should first define the production system, system boundaries and identify environmental factors. In Fig.1 is presented production system in terms of the full life cycle. The prospect of life cycle assessment LCA covers the entire product life cycle from extraction of raw material and its acquisition, the production of energy and materials and manufacturing, the exploitation and processing after the operation and demolition.

LCA is used as a means to comprehensively evaluate processes, material choices and their effects on life cycle greenhouse gases (GHGs) emissions. It is important to integrated economic assessment and results of LCA into product design at an early stage to improve eco-efficiency of the product or technology [2,10]. LCA can be used for Green Manufacturing evaluating. The LCA approach enables the calculation and comparison of energy used and environmental impacts for different products across the supply chain. It also provides the opportunity for companies and policy-makers to consider the organization and influences on an entire system rather than a single link within the supply chain. This may result in company decision- and policy-making about environmental impacts that leads to system-wide benefits [11].

Production management includes all issues for the design of production systems, organization of production processes, plan and control. It should be stressed that so far little attention was put on environmental influence of the production system in the field of production management and production logistic. Also in the definition of the production system in the traditional sense emphasizes the economic aspect, while environmental aspects are missing. The main purposes of the production system are [12] :

- quality and innovation of products,
- increase of productivity,
- decrease of production costs.

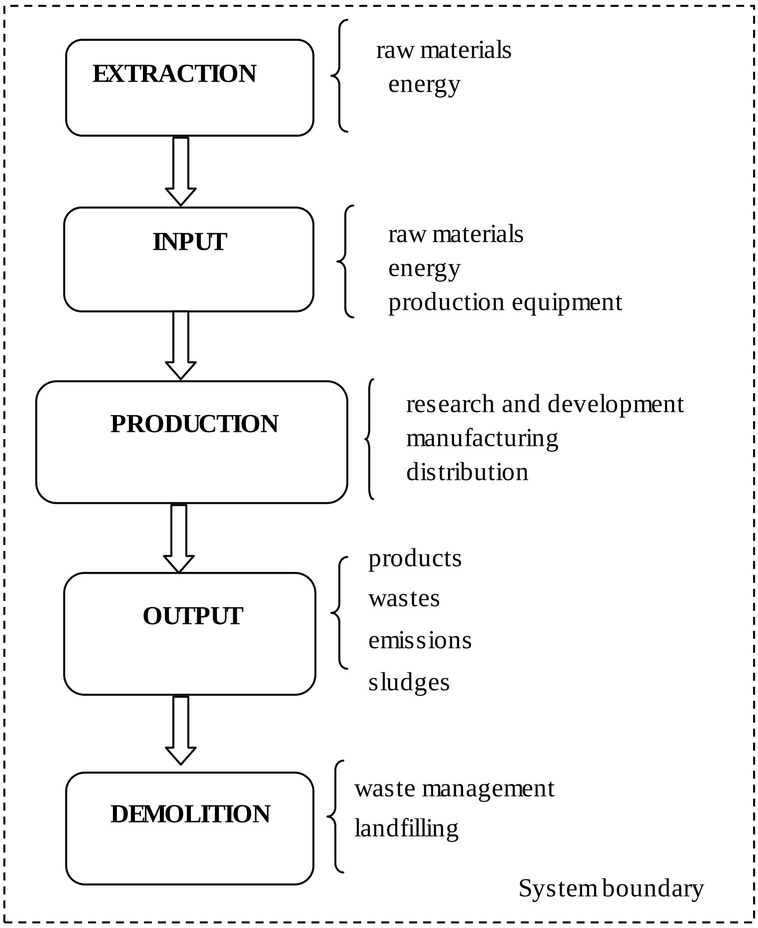

Figure 1: Production system in terms of the full life cycle

Sustainability means that manufacturing processes are considered from the perspective of all the sustainable development factors – environmental, economic and social aspects - in whole life cycle. Therefore, the author of this paper proposes to include environmental aspects in the production system and suggests to take into account the next new purpose of production system - increase eco-efficiency of product or technology. This is associated with a simultaneous increase economic and environmental performance of specific technologies or products. Taking into account the environmental performance in the operation of the production system is the effect on the criterion of the production system. Currently, this criterion is usually - productivity. Proposed new criterion - eco-efficiency - taking into account both economic and environmental aspects. This criterion is a measure of productivity and also includes a new element - an environmental indicator. LCA can have many applications in production logistic and Green Manufacturing. It can be a tool for comparative analysis of different technological scenarios related to the use of different:

- input materials (biomaterials, renewable raw materials),
- energetic factors (such as alternative fuels),
- production technology.

3 CASE STUDY

The concept of LCA application for the eco-efficiency evaluating is discussed with the use of a case study which shows application of LCA in the sinter plant which is the most polluting steelmaking process. This paper was based on a case study of iron ore sinter production system in Poland. In paper [2] eco-efficiency analysis was done for alternate fuel used in raw materials. In that paper was presented LCA application in sinter production system and the results of LCA study comparing used common fuel (coke breeze) in process and alternative fuel (anthracite).

3.1 Methods

It was presented [2] eco-efficiency analysis of three scenarios of iron ore sinter production system:

- Scenario A – solid fuels: coke breeze 100% (basic scenario)
- Scenario B – solid fuels: coke breeze 85% + anthracite 15%
- Scenario C – solid fuels: coke breeze 70% + anthracite 30%

Life Cycle Assessment was carried out in accordance with the requirements of ISO 14040 by four stages: goal and scope definition, inventory analysis LCI (Life Cycle Inventory), impact assessment LCIA (Life Cycle Impact Assessment) and interpretation. Life Cycle Assessment of sinter production was carried out using LCA software package SimaPro 7.3 (Pre Consultants B.V), with database in the program (ecoinvent). The impact assessment was performed according to the IPCC GWP 100a (Intergovernmental Panel on Climate Change, Global Warming Potential, 100 years). In accordance with ISO 14040:2006, set the objective, scope, system boundaries and limitations of LCA and the analysis of inputs and outputs of LCI. The system boundary was defined as cradle to factory gate production of sinter including all inputs, raw material, energy, emissions and waste. For comparative purposes, all data were determined in relation to the same functional unit, 1000 kg of sinter. The cost indicators were calculated according to the environmental life cycle costing methodology.

3.2 Results and discussion

The analysis was performed using IPPC assessment method. Environmental impact assessment of iron ore sintering process were shown in Table 1. The highest impact on CO_2 equivalent in iron ore sinter production is related to fuel consumption. Fossil fuels constitute only 5% of raw materials and fossil fuels cause 38,4% global warming. The results of the analysis show a reduction of greenhouse gas emissions through the use of anthracite. For sinter production only with coke breeze (scenario A) the average indicator value is 640,50 kg CO_2 equivalent and the lowest rate is for scenario C (with 30% anthracite) – 521,57 kg CO_2 equivalent, in 1Mg of sinter. The relative contribution for all scenarios are shown in Figure 2 for the three most important environmental aspects relative to the value performance.

Table 1: Environmental impact assessment of iron ore sinter production system, in Mg of sinter

Impact category	Scenario A	Scenario B	Scenario C
Greenhouse gases (kg CO_2 equiv.) include:	640,50	582,38	521,57
Direct CO_2 emissions	310,00	260,00	210,00
Indirect CO_2 emissions:	330,50	322,38	311,57
- from coke breeze	245,62	208,78	157,19
- from anthracite	-	30,92	74,21
- other	84,88	82,68	80,16

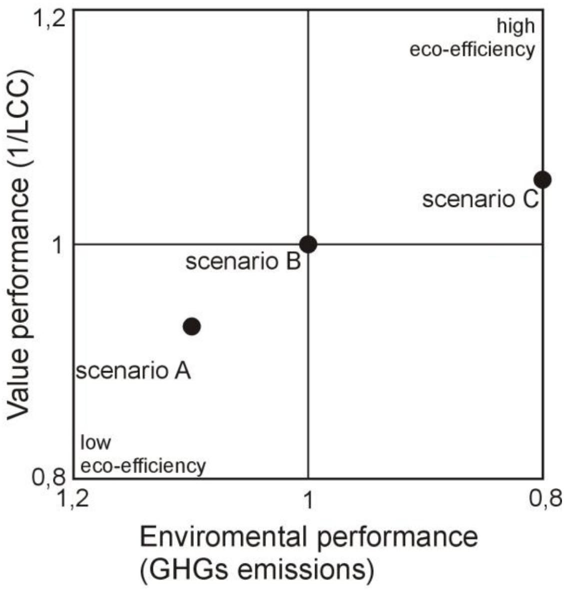

Figure 2: Relative eco-efficiency with emissions of greenhouse gasses as a indicator of environmental performance

The most eco-efficiency scenario of iron ore sinter production system has simultaneously the lowest cost and the lowest environmental score. Scenario C has the best performance in both aspects (environmental and economic), so it is the most eco-efficiency scenario and this scenario is the closest concept of Green Manufacturing.

4 CONCLUSIONS

To achieve sustainable development in the whole production logistic in iron and steel industry, there is a need assessment of the eco-efficiency of used alternative raw materials and fuels in conventional technologies and to assess the eco-efficiency of alternative technologies. LCA is used in iron and steel industry as a means to comprehensively evaluate processes, material choices and their effects on life cycle GHG emissions.

On the basis of eco-efficiency analysis, Life Cycle Assessment and Green Manufacturing it was found the these methods have many similar purposes: pollution prevention, waste reduction and reducing the consumption of raw materials and energy. LCA is the first step of pollution prevention toward principles of sustainable development. Further broadening LCA allows for eco-efficiency evaluation. Eco-efficiency is a tool for cleaner production and achieve Green Manufacturing, where in the design process develops the most eco-efficiency product. It is important to integrated economic assessment and results of LCA into product design at an early stage to improve eco-efficieny of the product or technology.

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