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ASSESSMENT OF THE ENVIRONMENTAL PERFORMANCE EFFECTS ASSOCIATED WITH THE REPLACEMENT OF ETHYLENE FROM FOSSIL BY RENEWABLE RESOURCE IN GPPS PRODUCTION

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ABSTRACT

This study analyzed the environmental effects associated with the replacement of ethylene produced from natural gas by an equivalent asset obtained by sugarcane in the processing of chain General Purpose Polystyrene (GPPS). The analysis was performed through Life Cycle Assessment (LCA) technique, which considered a cradle-to-gate approach for the production of 1.0 ton of GPPS according to the Brazilian operational condition. It was used ReCiPe – Midpoint (H) for the impact assessment. Consumptions of natural gas and crude oil influence significantly the environmental profile of fossil GPPS. Nevertheless, the agricultural activities required to renewable GPPS production resulted into increased environmental impacts of Climate Change, Agricultural Land Occupation, Human Toxicity, Freshwater Eutrophication and Terrestrial and Freshwater Ecotoxicity.

INTRODUCTION

The consequences of unregulated use of natural resources have mobilized humanity to design mechanisms that result in minimizing the impacts from the production of goods to improve their quality of life. The industry is directly involved in the issue as an important resource consumer and waste generator. The petrochemical industry stands out in this context because its products reduce global reserves of fossil resources. In this scenario fossil fuels play an important role in maintaining the expectations in the development of modern society due to current economic model which is based on power consumption. Despite that, the social awareness about the preservation of the environment has increased on the last three decades. This controversial condition led the petrochemical industry an uncomfortable standoff situation. The scenario in Brazil is not different. So, in order to coordinate the issue and present itself to the market more proactively, the segment has been researching for different alternatives. Regarding the production of polymeric derivatives, the main strategy is to replace the fossil resource by raw materials obtained from renewable resources, in order to rationalize crude oil and natural gas extractions and balance CO_2 emission.

This study discusses the validity regarding the environmental dimension of the same approach on the perspective provided by Life Cycle Thinking. Therefore, it was analyzed the effects of substitution of ethylene produced from natural gas by ethylene obtained by sugarcane ethanol dehydration in the production of General Purpose Polystyrene (GPPS). The objective was achieved by using the Life Cycle Assessment methodology. This analysis follows a cradle-to-gate approach for the production of 1 ton GPPS, according to average technology practiced for Brazilian companies.

METHODS

This LCA was carried out to comply with the patterns defined by ISO standards 14040:2006 and 14044:2006. The goal of the study consists in evaluate the effect of the introduction of an asset of renewable origin in the production of GPPS. This evaluation was developed comparing fossil GPPS with a homologous obtained from ethylene of bioethanol. Regarding to Scope Definition it was established as Reference Flow: “*to produce 1 ton of GPPS*”. The Product System of fossil GPPS comprises the unit process of crude oil extraction, oil refining for naphtha production, ethylene and benzene obtaining and GPPS manufacture. The product system for renewable GPPS replaces the petrochemical processes for the ethylene production by an agricultural route. This case study considers cultivation of sugarcane, hydrous, and ethylene production via dehydration technic. Figures 1 and 2 detail both product systems.

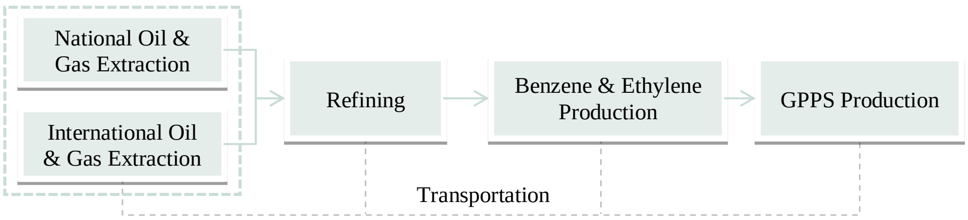

Figure 1: product system of GPPS produced from petrochemical derivatives

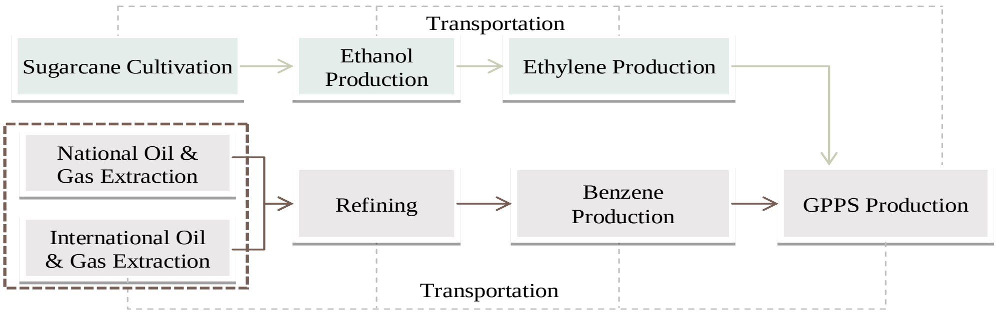

Figure 2: product system of GPPS obtained from ethylene from renewable origin

Regarding Geographical Coverage, all the processes in both product systems are carry out in Brazil. Exception occurs for the oil purchased overseas from Nigeria, Libya, Iraq, Saudi Arabia, Algeria and the natural gas from Bolivia (BEN, 2012). Temporal Coverage includes the period from 2008-2011. Finally, for Technological Coverage it was admitted the average technology practiced in the country by companies that operate in the polymers sector. Concerning Data Quality, secondary data were used to describe the environmental performance of GPPS production in Brazil. The procedures applied allowed to measure the uncertainty degree of the data set used in the preparation of the Life Cycle Inventory to make the results consistent. The allocation among petrol derivatives was done according energy criterion. The distribution of environmental aspects in ethanol and sugar production occurred from commercial criterion. Other cases where this kind of procedure is necessary, mass criterion was adopted. The application of cut-off criteria is aligned with ISO 14044 (2006) guidelines and considered 1 wt. % of the total material input for each elementary process. Life Cycle Impact Assessment was carry out by the method ReCiPe – midpoint (H) version 1.07. This analysis included only relevant environmental impact categories: Natural and Agricultural land occupation (NLT and ALO); Terrestrial and Freshwater Ecotoxicity (TEc and FEc); Fossil depletion (FD), Freshwater eutrophication (FEu) and Climate change (CC).

Description of the processes

Offshore oil production represents about 91% of the total Brazilian oil prospected. Furthermore, about 20% of the crude oil processed in the country is imported (BEN, 2012). The average refining technology employed in the country consist of crude-oil desalting, atmospheric and vacuum distillations, catalytic cracking, coking and hydrotreating processes (ANP, 2012). In 2010, over 70% of the natural gas produced in Brazil was from conventional oil fields. This amount corresponds to 42% of the total demand for the period. The remaining 58% came from Bolivia by importation (BEN, 2011). Natural gas and the naphtha produced along refining pass through a steam cracking stage in order to obtain ethylene (Antunes, 2007). In addition, naphtha is heated and fed into the catalytic reforming reactor to produce benzene (Netzer, 2005). Dehydration of sugarcane ethanol has emerged as an alternative to obtain ethylene. The potential advantage of the process is the renewability of the agricultural resource. Sugarcane is mainly cultivated in Central and Southeast zones from Brazil. The Stade of São Paulo leads the national production. This state accounted for 58% of total production in the country in the 2010-2011 harvest, with an average agricultural productivity of 83 ton/ha. The production of ethanol by fermentation occurs via *Saccharomyces cerevisiae* under controlled conditions. Distilleries makes use bagasse for cogeneration of electricity. The surplus energy is marketed (Sugawara, 2012). The ethanol dehydration occurs in continuous reactors. A temperature of 400°C is needed in order to shift the equilibrium and efficiently produce ethylene with a high conversion. Additionally, γ-Alumina is used as catalyst (Cameron et al, 2012). The alkylation of benzene and ethylene into ethyl-benzene over a synthetic zeolite catalyst starts the GPPS manufacturing. After this process, styrene is produced by the catalytic dehydrogenation of etil-benzene in presence of steam (Burri et. 2008). Free-radical polymerization of styrene monomers, primarily in solution of ethyl-benzene is the final step in the manufacture of GPPS (Martins, 2009).

RESULTS AND DISCUSSION

Table 1 presents the environmental results of the replacement of fossil ethylene by renewable resource in GPPS production. The most significant impacts of fossil GPPS occurs at NLO and FD categories. GPPS obtained by renewable ethylene presents significant environmental impacts at CC, FEu, HT, ALO, TEc and FEc. Sugarcane cultivation contributes for all of these negative effects. This results are related to fertilizers and pesticides used in the agricultural activities emit discharge N and P, plus diuron and ametryn to air, water and soil. These losses are responsible to increase FEu, HT, Tec and FEc. Emissions of CO_2 and CH_4 from biomass burning and N_2O occurred during soil preparing, are responsible for increases of CC. Furthermore, land is required to cultivation enhancing ALO and NLT.

Table 1: Environmental performance of fossil GPPS and GPPS partially made from sugarcane

Impact Categories	Units	Fossil GPPS	Partially renewable GPPS
Climate Change	kg $CO_{2\ eq}$	1,40E+06	3,23E+06
Freshwater eutrophication	kg P_{eq}	2,04E-02	5,50E-02
Terrestrial ecotoxicity	kg 1,4-DB $_{eq}$	9,32E-02	5,78E+06
Freshwater ecotoxicity	kg 1,4-DB $_{eq}$	1,54E+05	3,90E+05
Agricultural land occupation	m^2	7,37E-02	1,97E+06
Natural land transformation	m^2	1,21E-01	1,12E-02
Fossil Depletion	kg oil $_{eq}$	1,05E+06	1,00E+06

Replacing fossil resource by renewable raw material reduces the non-renewable depletion in GPPS production. From this point of view, the petrochemical companies that follow the conduct are acting in a proactive way. The electricity cogeneration in bioethanol industry reduces the overall energy consumption in the whole GPPS life cycle. In addition, a high impact as NLT is assigned to fossil GPPS because the prevalence of hydropower in the Brazilian grid.

CONCLUSIONS

Effective benefits of replacing fossil resource by renewable raw material in GPPS production were identify in two of impacts categories evaluated in the study - NLT and FD. On the other hand, fossil GPPS presented better environmental performance on the other six categories under analysis. This situation indicates that the use of renewable sources to replace fossil derived is valid in specific situations, of little availability of area and imminently scarcity of oil and its derivatives. Efforts in the fields of genetic engineering and cleaner production may improve this situation making feasible from an environmental perspective a route whose technology is already consolidated.

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REFERENCES

BEN-Brazilian Energy Book. (2012). Statistics Yearbook 2011. http://www.brasilcom.com.br/dadosestatisticos

ANP Agência Nacional de Petróleo. (2012). *Esquemas de produção no refino de petróleo.* Brasília. 230pp.

A. Antunes (2007). *Setores da indústria química orgânica*, v1. 242p., Rio de Janeiro. ISBN: 9788576500773.

D. Burri, K. Choi., D. Han, N. Jiang, A. Burri, S. Park. *Oxidative dehydrogenation of ethyl benzene to styrene and CO_2 over SnO_2-ZrO_2 mixed oxide nanocomposite catalysts* (2009) *Ind. Eng. Chem. Res. 48* (23), p 10307-13

G. Cameron, L. Le, J. Levine, N. Nagulapalli (2012). *Process Design for the Production of Ethylene from Ethanol*. University of Pennsylvania. http://repository.upenn.edu/cbe sdr/39

A Martins (2009). *Projeto de um controlador PI-MIMO para uma planta de produção de poliestireno.* Master Thesis. (Chemical Engineering). University of Rio Grande do Sul – UFRS (in Portuguese), 2009.

D. Netzer, (2005). *Benzene supply trends and proposed method for enhanced recovery* http://www.petrochemicals.dnetzer.net/articles/article-3.05.pdf.

Sugawara, E. (2012). *Comparação dos desempenhos ambientais do B5 etílico de soja e do óleo diesel, por meio da ACV.* Master Thesis. (Chemical Engineering). University of Sao Paulo – USP (in Portuguese), 2012.