Energy 36 (2011) 3716–3726

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

A LCA (life cycle assessment) of the methanol production from sugarcane bagasse

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ARTICLE INFO

Article history:
Received 28 February 2010
Received in revised form
25 November 2010
Accepted 7 December 2010
Available online 13 January 2011

Keywords:
LCA
Biofuels
Methanol
Biomass
Thermochemical route
Cogeneration

ABSTRACT

Nowadays one of the most important environmental issues is the exponential increase of the greenhouse effect by the polluting action of the industrial and transport sectors. The production of biofuels is considered a viable alternative for the pollution mitigation but also to promote rural development. The work presents an analysis of the environmental impacts of the methanol production from sugarcane bagasse, taking into consideration the balance of the energy life cycle and its net environmental impacts, both are included in a LCA (Life Cycle Assessment) approach. The evaluation is done as a case study of a 100,000 t/y methanol plant, using sugarcane bagasse as raw material. The methanol is produced through the BTL (Biomass to Liquid) route. The results of the environmental impacts were compared to others LCA studies of biofuel and it was showed that there are significant differences of environmental performance among the existing biofuel production system, even for the same feedstock. The differences are dependent on many factors such as farming practices, technology of the biomass conversion. With relation to the result of output/input ratio, the methanol production from sugarcane bagasse showed to be a feasible alternative for the substitution of an amount of fossil methanol obtained from natural gas.

1. Introduction

The methanol (CH_3OH), also known as methyl alcohol, had proved to be used as fuel, blended with gasoline in internal combustion engines (85% methanol and 15% gasoline) or as pure methanol (100% methanol), but the last is still in the research and development stage. Besides, methanol also serves as a raw material for chemicals products, such as formaldehyde, acetic acid, and a wide variety of others chemicals products, including polymers, paints, adhesives, construction materials, synthetic chemicals and others [1].

At the time being, it is possible to envisage a wide use of methanol as an alternative to diesel fuel and in innovative technologies like the methanol fuel cells. This potential allows to envisage a growing of the demand in the near future [2].

Today in Brazil, methanol is an important raw material for the biodiesel production, because it is the main chemical reagent used in the transesterification process.

The important appeal is that the methanol production from biomass is a clean route, with low dust air pollutants (SO_x, NO_x), and GHG (greenhouse gas) emissions [3]. This is a positive aspect in a world that has serious GHG emissions constrains [4].

At the time methanol is produced from natural gas, and since early 1980s, larger plants, using efficient low-pressure technologies, are replacing the small less efficient ones. A very intensive R&D work is being done to develop a new technology, that could allow to obtain methanol from biomass, through gasification. However, these gasification techniques are still at a relatively early stage, with no units operating commercially yet, but several biomass-to-methanol demonstration projects have been developed recently, such as the Hynol Project in United States, the BioMeet and Bio-Fuels projects in Sweden. In Brazil, there is the Raudi-Methanol Project that proposes the methanol production from sugarcane bagasse [5,6].

The main task of this paper is to carry on an evaluation of the main environmental impacts of methanol production from sugarcane bagasse, using the CML 2001 LCIA (Life Cycle Impact Assessment) method within the framework of LCA (Life Cycle Assessment) methodology. In addition, life cycle energy efficiency indicators, like the LCE (Life Cycle Efficiency) and the FER (Fossil Fuel Energy Ratio) were calculated, as well as a comparison of the environmental impacts results with others LCA studies of biofuel production was made.

The evaluation study was made through a hypothetic case study of a methanol plant annexed to an autonomous distillery, which

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doi:10.1016/j.energy.2010.12.010

Nomenclature

CEST	condensing extraction steam turbine
CFC	chlorofluorocarbon
CSFMB	comprehensive simulator of fluidized and moving bed equipment
E	energy (MJ)
ELCA	exergetic life cycle assessment
FER	fossil fuel energy ratio
GHG	greenhouse gas
HC	Hydrocarbons
IEE	integral environmental evaluation
ISO	international organization for standardization
LCI	life cycle inventory
LCE	life cycle efficiency
LCIA	life cycle impact assessment
LCA	life cycle assessment
LHV	lower heating value (MJ/kg)
PM	particulate materials
PM10	particulate material measuring 10 μm or less
PPM	one part per million
TOC	total organic carbon
UV-B	ultraviolet-B

contains a cogeneration plant. The three installations are connected, since the ethanol plant supply bagasse to the cogeneration plant and methanol plant, while the cogeneration plant supply the methanol and ethanol plant with steam and electricity.

The size of the ethanol plant corresponds to the Brazilian standard units, and the methanol plant capacity was based on the available bagasse amount obtainable.

2. Methanol from biomass

In principle, any carbonaceous material such as coal, lignite, wood waste, agricultural residues and sugarcane bagasse can be used to synthesize methanol. However, in contrast with to methanol production from natural gas, the synthesis of methanol from carbonaceous material needs additional steps to prepare the biomass for gasification process, followed by cleaning and conditioning steps. So, the main stages of methanol production from biomass can be summarizing [3]:

Pre-treatment: The biomass must be pretreated to meet the processing requirements of the gasifier. This process involves drying and a adjusting the material size [7].

Gasification: Biomass gasification starts with the thermal treatment of biomass in the presence of sub-stoichiometric oxygen concentrations in the fluidization gas. At certain temperature the biomass pyrolyzes, giving a gas stream and a solid residue; being the composition of the gas stream influenced by the operating conditions of the gasifier.

In particular, gasification with air produces a syngas stream that contains large quantities of nitrogen. This nitrogen prejudices subsequent processing of methanol; therefore a technology of gasification that uses oxygen as “gasification fluid” is preferred.

Gas cleanup: The syngas produced by the biomass gasification unit contains a wide range of contaminants, so to prevent tar deposition, heat exchanger fouling, catalysts poisoning and deactivation problems a gas cleaning system is required; which includes particulates, and sulfur removal, and also scrubbing for chlorine compounds elimination.

Syngas conditioning: To guarantying an optimum syngas for methanol synthesis, three parameters must be fixed:

a) The CO_2/CO ratio.
b) The $H_2/(2CO + 3CO_2)$ relation that must be approximately 1:1 [8]
c) Inert gases (N_2, CH_4) concentration should be minimized.

The CO_2/CO ratio and the relation $H_2/(2CO + 3CO_2)$ can be adjusted through a water–gas-shift reaction; a catalytic one occurs at 200–475 °C, which converts CO + steam into H_2 and CO_2, through the equilibrium reaction showed on Eq. (1) [9]:

$$CO + H_2O \Leftrightarrow H_2 + CO_2 \quad (1)$$

Another parameter to be controlled is the amount of methane in the syngas. To get it a steam reforming process is performed, converting methane to CO and H_2 by a steam addition usually employing a Ni catalyst at high temperatures, above 830–1000 °C, Eq. (2) [10].

$$CH_4 + H_2O \rightarrow 3H_2 + CO \quad (2)$$

After this, the syngas still have a considerable amount of CO_2, part of which should be removed to get desired value to allow the methanol synthesis. For this partial CO_2 removal, physical and chemical processes are available, the chemical absorption using amines and the physical absorption, using Selexol are two of them [11].

Methanol synthesis: it proceeds by the hydrogenation of the carbon oxides over a suitable catalyst (copper–zinc) at temperatures in the range of 200–280 °C and pressures of 5–10 MPa [12]. Eq. (3) presents the main reactions involved in the methanol synthesis [3]:

$$\begin{aligned} &CO + 2H_2 \leftrightarrow CH_3OH \\ &CO_2 + 3H_2 \leftrightarrow CH_3OH + H_2O \end{aligned} \quad (3)$$

The first one being the so called primary methanol synthesis reaction, where a low amount of CO_2 in the feed (2–10%) acts as an initiator of this primary reaction and helps to maintain the catalyst activity. The stoichiometry conditions of both reactions are satisfied when R (calculated by Eq. (4)) reaches a value not lower than 2.03 [13].

$$R = \frac{H_2 - CO_2}{CO + CO_2} \quad (4)$$

Methanol purification: The crude methanol from the synthesis process contains water produced during synthesis, as well as other minor co-products. So the methanol purification is achieved by distillation [14].

3. LCA

The LCA is a methodology that evaluates the environmental impacts of every stage of a product's life (from cradle to grave), The LCA enables the quantitative estimation of the environmental impacts resulting from all stages in a product life cycle, often including impacts not considered in the more traditional analyses (e.g. raw material extraction, material transportation, ultimate product disposal, and others). The LCA provides a comprehensive view of the various environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product and process selection in order to support the decision-making process [15,16].

The term “life cycle” refers to the major activities in the course of a product's life, from its manufacture, its use, and its maintenance,