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Environmental life cycle assessment of lignocellulosic conversion to ethanol: A review

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ABSTRACT

Bioenergy from lignocellulosic biomass offers the potential to provide a significant source of clean, low carbon and secure energy. In recent years, a number of studies have been carried out to assess the environmental performance of lignocellulosic ethanol fuel. However, the complexity of biofuel systems generates significantly different results due to the differences in input data, methodologies applied, and local geographical conditions. Moreover, much attention has been placed on assessing climate change potential and energy consumption. This study draws on 53 published life cycle assessment of the lignocellulosic ethanol. More than half of the articles reviewed focus on assessing greenhouse gas (GHG) emission or fossil energy consumption or combination of both. All studies but two reviewed conclude that there is a reduction of GHG emission when using lignocellulosic ethanol in comparison to fossil fuel reference system. However, different studies have reported different sources contributing to GHG emission: some reports majority of GHG emissions come from biomass cultivation stage; others argue significant GHG emissions from ethanol conversion process. All articles suggest a reduction of fossil consumption in all cases of ethanol fuel. Contrary results for the impact of acidification and eutrophication potential from lignocellulosic ethanol are also observed—some reports less impact in comparison to conventional gasoline whiles others report significant increase of acidification and eutrophication potential by ethanol production. Studies also show water consumption varies significantly depending on biomass types, irrigation requirement, and regional irrigation practices; with different findings on whether agricultural practices or ethanol conversion being the main sources for water consumption. Contrary findings on emissions contributing to ecotocixity and human health have also been reported with some being favourable while others not. Results from the literature also suggest strong dependency of LCA results on system boundary, functional unit, data quality and allocation methods chosen.

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1. Introduction

Climate change and energy security have, for many nations, become two of the greatest challenges. As a result the production of renewable energy has increased with the aim to reduce our current dependency on fossil fuels. Bioenergy, often with the benefit of little additional point of use infrastructure and non-immediate dependency on weather, offers a unique source of renewable energy. In particular, bioenergy from lignocellulosic biomass offers the potential to provide a significant source of clean, low carbon, and secure energy. Although often regarded as carbon neutral process there are environmental impacts associated with the system production, transportation, and growth of feedstock. As a result, sustainability assessment is now acknowledged to be an important element of development of bioenergy from lignocellulosic material.

One way to determine the impact of bioenergy is to use the environmental management tool, Life Cycle Assessment (LCA). LCA is a methodological tool used to quantitatively analyse the life cycle of a product or an activity within a generic framework provided by ISO 14040 and 14044 [1,2]. It examines the environmental burden of a product or process over its entire life, from production, through use and on to disposal or recycling. It consists of four methodological steps: goal and scope definition, inventory analysis, impact assessment and interpretation. Within the goal and scope the function of the system, its study boundary and environmental issues to be considered are identified. The system boundaries outline which processes and materials will be included and excluded from the system. The functional unit (FU) expresses the function of the system studied in a quantitative manner. The functional unit can therefore facilitate a direct comparison between different systems. The inventory stage is where data about the energy and materials used, and pollutants or wastes released into the environment as a consequence of a product or activity, are gathered. When a process produces more than one output an allocation procedure is used to allocate the environmental burdens between main products and co-products. After the inventory data are gathered an impact assessment is carried out to transform the long list of inventory results into the potential impact upon a limited number of environmental issues. These issues, or indicators, are classified into categories according to their potential long term damage such as climate change and ozone depletion. The indicator scores express the potential relative severity of the product or system examined on an environmental impact category.

By using LCA to examine the system of interest, quantifying the material and energy inputs and outputs to air water and soil, the potential impact on the environment can be determined. To date several studies [3–6]; have examined the environmental impact of bioethanol, with a particular focus on two main categories: greenhouse gas (GHG) emissions and fossil energy efficiency. These studies show, to a varying degree, reduction of fossil fuel use and of GHG emissions in comparison with the use of conventional energy such as gasoline.

Biomass is often considered to be a carbon neutral feedstock but a significant amount of GHG emissions are released during the life cycle, for example as part of the fertiliser production and use, during the transportation of the biomass, as well as in the conversion stages. Additionally, comprehensive sustainability assessment of biofuel is urgently needed to assess economic, social and environmental impacts of biofuel production and consumption [7]. Yan and Lin [8] revealed that the interactions among various sustainability issues make the assessment of biofuel development difficult and complicated. In addition, the complexity of the whole biofuel production chain can generate significantly different results due to differences in input data, methodologies applied, and local geographical conditions.

Lignocellulosic biomass can be converted to ethanol through feedstock handling, pretreatment, hydrolysis and fermentation, ethanol recovery and wastewater treatment [9]. Fig. 1 shows a typical process of the bioethanol conversion system. A typical LCA study of biofuel includes the feedstock growth at farming level, biofuel conversion process, and fuel use in transportation stage. Although LCA work [3] has shown environmental benefits associated with lignocellulosic ethanol, most studies have focused on assessing the farming systems with generic assumption of the ethanol conversion process. Very few have addressed the specific environmental issues related to the conversion process due to process uncertainties and non-availability of commercial scale plant [10]. Despite extensive research on laboratory and small scale within the scientific community, there is not yet a large scale commercial lignocelluloses-to-ethanol facility. Therefore technology uncertainty and potential commercial scale operation parameters also contribute to the gap [10].

The UK and EU is committed to producing 10% biofuel for transportation by 2020 [11]. Therefore the production of bioethanol is of great interest to energy suppliers and vehicle manufacturers. It is important that we meet our targets with the minimal impact on the environment; therefore a review of the current knowledge in this area is desirable. This paper reviews the existing literature of LCA studies for lignocellulosic ethanol processes with an aim to identify research gaps and therefore where future research should focus. The paper starts with a brief statement of study approach, and then provides an overview of the LCA studies reviewed in this paper, and follows a summary of

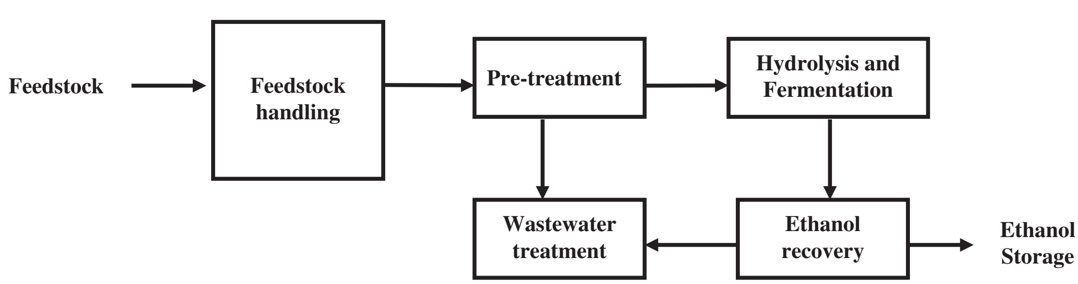

Fig. 1. Typical lignocellulosic ethanol conversion process.