Bioresource Technology 185 (2015) 202–210

Contents lists available at ScienceDirect

Bioresource Technology

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

# LCA of bioethanol and furfural production from vetiver

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## HIGHLIGHTS

- Exploration of non-conventional agricultural crop residues in India is necessary.
- Vetiver leaves are rich in cellulose – 32.6%, hemicellulose – 31.5% and lignin – 17.3%.
- Vetiver leaves could be a potential feedstock for biorefinery in India.
- Significant impact reduction from vetiver system compared to conventional system.

## ARTICLE INFO

*Article history:*
Received 17 December 2014
Received in revised form 16 February 2015
Accepted 24 February 2015
Available online 2 March 2015

*Keywords:*
Biorefinery
Environmental impact
Furfural
LCA
Vetiver

## ABSTRACT

In this study a prospective life cycle assessment of biorefinery system from vetiver leaves was carried out to know the environmental benefits of this system over conventional systems considering the geographical context of India. The composition of vetiver leaves from the experimental analysis revealed that vetiver is rich in cellulose (32.6%), hemicellulose (31.5%) and lignin (17.3%) that could be used as a feedstock for biorefinery. The comparative life cycle assessment results show that the carbon dioxide emission and fossil oil depletion could be reduced by 95% and 23% respectively in case of standalone bioethanol system, and 99% and 17% respectively in case of bioethanol and furfural system compared to that of conventional petrol and furfural systems. The sensitivity study indicates that the impact could be further reduced if vetiver biomass is used as a source of energy in biorefinery plant instead to the coal.


## 1. Introduction

In 2011, around 8500 million tons equivalent of crude oil energy was consumed around the world and the energy demand is forecasted to rise by 56% by 2040 (IEA, 2012). Around 85% of the energy consumed now is from fossil fuels which are blamed for energy insecurity and environmental concerns. However, in the last decade there has been a tremendous improvement and increase in renewable energy production and consumption. Among renewable energy, there have been significant policy changes in transport fuels favourable to biofuels owing to its environmental benign properties. However, the current biofuels produced from food crops such as sugarcane, corn, palm oil etc., in various parts of the world are blamed for food price rise, and therefore non-food alternatives are being studied. In the recent years, there has been a significant improvement in biofuel production technology from non-food sources such as agricultural residues and algae technology for bioethanol and biodiesel production respectively.

Lignocellulosic biomasses are made up on cellulose, hemicellulose and lignin compounds forming a strong bond within each other. Cellulose present in the biomass could be raw material for bioethanol production if they are converted to glucose via saccharification and fermentation. Hemicellulose could be a feedstock for biochemical productions such as furfural whereas the lignin could be a solid fuel for boiler that could generate a partial amount of energy required in the bioethanol and biochemical production process or could be further processed to produce lignin derivative products such as lignosulphates (Stewart, 2008). Year 2013–2014 could be marked as important years in cellulosic ethanol history where three industries started their commercial production in Italy (Betarenewables), Brazil (Granbio) and US (Abengoa) with a production capacity of 50.7 million litres, 82 million litres and 94.6 million litres per year respectively.

With growing concerns over environment, fuel and food security, energy policies would be reformed in favour of cellulosic ethanol in various countries demanding more agriculture residues in near future. The choice of residues would depend on the local agricultural practices and availability in a country. Apart from

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http://dx.doi.org/10.1016/j.biortech.2015.02.096
0960-8524/

conventional agricultural residues generated in arid land, the potential of other agricultural sources that could be cultivated and generated in waste land have to be explored for the reasons such as (1) to improve the soil quality (2) to alleviate soil erosion (3) to generate biomass resources with less fertilizer and water and (4) to generate employment opportunities in such vast waste land available areas. In a developing country such as India, the consumption of transport fuel and its environmental impact are high demanding renewable fuels in near future. The Indian government has already drafted a policy to blend 20% biofuels to fossil fuels by 2017 in transport sector (National Policy on Biofuels, 2009) to reduce the dependency on foreign oil and mitigate climate change.

Several biomass residues such as rice straw, wheat straw, sugarcane tops and leaves etc., are available in India to meet the demand of the current transport biofuels if the policy is implemented (TIFAC, 2009; Bloomberg, 2011). However, all these residues are generated in fertile zones and would be beneficial only to the economic development of these zones. Whereas, a vast area of waste land is available in India and the soil enrichment and economic development of those area also have to be considered. In addition, the non-conventional agriculture residues should also be promoted to fulfill the future's biomass residue demand. Furthermore, there is huge stress for water resources in India demanding low maintenance crop residue for biofuel production. Therefore, agriculture residues that could be cultivated in waste land with minimal water requirement have to be identified and promoted.

Vetiver (*Chrysopogon zizanioides*) native to India is a perennial grass from Poaceae family. Vetiver cultivation system developed by the World Bank in India in the mid-1980s, is now being widely used in many countries for soil and water conservation, land stabilisation and rehabilitation, sediment control and phytoremediation. Vetiver is vegetative and a low maintenance plant with its leaves growing up to 1.5 m high. The roots of vetiver are thick and grow fast deep, binding strongly to the soil downward up to a depth of 2–4 m. It is a drought tolerant plant and could be used for reclamation of salt affected soils (Bank, 1987; Truong et al., 2008; Chaplot, 2014; Yaseen et al., 2014). Vetiver leaves at present have only limited application such as boiler fuel, handicraft products and mushroom cultivation (Danh et al., 2012; Balasankar et al., 2013).

Vetiver grows fast under low maintenance conditions and has the capacity to generate high biomass (leaves) in waste land. Vetiver leaves are rich in cellulose and hemicellulose content that could be used as a feed stock for bioethanol production (Wongwatanapaiboon et al., 2012) and biochemical productions in a biorefinery. However, the life cycle assessment of vetiver system has to be assessed to find the environmental effects of its cultivation, transportation and processing stages. Therefore in this paper, the potential of vetiver leaves as a feedstock for biorefinery concept to produce bioethanol and furfural and the environmental impacts are explored through the compositional analysis of vetiver and a prospective life cycle assessment of vetiver biorefinery system considering different schemes to estimate the greenhouse gas emission and fossil energy demand compared to that of conventional product system. Life cycle assessment of vetiver biomass refinery system has not been reported earlier in literature and therefore the results of this study would be helpful to the research community and policy frame work.

## 2. Method

### 2.1. Scope

The scope of this study is to assess the life cycle impact of vetiver biorefinery system in comparison with that of a conventional system. There are two schemes of biorefinery system studied in the present paper, (1) standalone bioethanol production from vetiver leaves where both C6 and C5 sugars are converted to ethanol and the remaining lignin is used as a solid fuel within the system for energy production, (2) both bioethanol and furfural are produced from cellulose and hemicellulose respectively and the lignin is used as solid fuel for energy production. The life cycle assessments of these two schemes are compared with a reference system: (1) gasoline (2) gasoline and conventional furfural production from vetiver. The processes involved in each scenario are described in the following sections.

### 2.2. Description of the studied and reference systems

*Bioethanol production from vetiver biomass:* Production of bioethanol from vetiver leaves includes process stages such as vetiver cultivation, harvest, transportation, pretreatment, saccharification, fermentation and distillation. Vetiver plant is cultivated in the field by planting the saplings and providing the necessary ingredients such as fertilizer, herbicides and pesticides. After certain growth period the leaves are harvested and transported to the bioethanol production facilities. Initially the biomass is subject to dilute acid pretreatment at (160–170 °C) residence time (10–15 min) to separate the hemicellulose from cellulose and lignin (NREL, 2011; Raman and Gnansounou, 2014). During pretreatment the hemicellulose are hydrolysed to C5 sugars and are removed by filtration after pre-treatment. Later the pH of the liquid fraction is neutralised from acidic condition using ammonia. The solid fraction after pretreatment, rich in cellulose and lignin are saccharified at 50 °C for $\sim$72 h using cellulase and b-glucosidase enzymes (Raman and Gnansounou, 2014). During saccharification, the cellulose is hydrolysed to glucose by the catalytic action of the enzymes. However, the lignin is not affected by the enzymes and they are removed by filtration after saccharification and are transferred to the combined heat and power (CHP) section to be burnt as a solid fuel. Later, the liquid fractions from saccharification containing glucose (C6 sugar) is mixed with C5 sugars from pretreatment and are subject to anaerobic fermentation at 32 °C for 48 h by C6 and C5 fermenting organism *Saccharomyces cerevisiae* and *Pichia stipitis* (Taniguchi et al., 1997) to produce crude ethanol followed by purification through distillation and molecular sieve.

*Biorefinery process of ethanol and furfural production:* At present there are no commercial vetiver biorefinery plants available; therefore a description of conceptual biorefinery concept is presented here to explain the various processes involved. The aim of the biorefinery concept is to utilise the components of the biomass to produce valuable products such as bioethanol, furfural and lignin through various processes. Vetiver grown in waste land is harvested for their leaves and is transported to the biorefinery facilities where the leaves are milled to desirable size and stored. Desired amount of milled vetiver biomass is transferred to the pretreatment reactor where the biomass is allowed to react with dilute sulphuric acid for a given residence time. During the pretreatment process, under acidic (2% v/v), temperature (160–170 °C) residence time (10–15 min) conditions (NREL, 2011; Raman and Gnansounou, 2014) the hemicellulose present in the biomass is hydrolysed to C5 sugar and dissolves in the liquid fraction of the process. Whereas, the cellulose and lignin content in the biomass remains as a solid fraction but with a weak bonding within each other. Later both the solid and liquid fractions from the pretreatment are separated by filtration. The liquid fraction rich in C5 sugar is further processed for furfural production by dehydration process, where the process temperature of liquid fraction containing C5 is raised to 190–210 °C with a residence time of (10–15 min) (Yoo et al., 2012). At these conditions the dehydration of C5 sugars takes place and the reaction of acid and C5 sugars results in furfural production along with acetic acid and other organic acid in