Energy Reports 2 (2016) 246–253

Contents lists available at ScienceDirect

Energy Reports

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

Techno-economic and environmental assessment of bioethanol production from high starch and root yield Sri Kanji 1 cassava in Malaysia

M. Hanif[a,*], T.M.I. Mahlia[a,b], H.B. Aditiya[a,c], W.T. Chong[c], Nasruddin[d]

[a] Department of Mechanical Engineering, Universiti Tenaga Nasional, 43000 Kajang, Selangor, Malaysia
[b] Faculty of Integrated Technologies, Universiti Brunei Darussalam, Jalan Tungku Link, Gadong BE1410, Brunei Darussalam
[c] Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia
[d] Department of Mechanical Engineering, Universitas Indonesia, 16424 Jawa Barat, Indonesia

ARTICLE INFO

Article history:
Received 16 November 2015
Received in revised form
1 March 2016
Accepted 29 March 2016

Keywords:
Bioethanol
Techno-economic analysis
Sri Kanji 1 cassava
Environmental assessment

ABSTRACT

Transportation played a significant role in energy consumption and pollution subsequently. Caused by the intense growth of greenhouse gas emission, efficient and sustainable improvement of the transportation sector has elevated the concern in many nations including Malaysia. Bioethanol is an alternative and renewable energy that has a great potential to substitute for fossil gasoline in internal combustion engine (ICE). Although bioethanol has been widely utilized in road transport worldwide, the production and application of bioethanol in Malaysia is yet to be considered. Presently there is comprehensive diversity of bioethanol research on distillation, performance and emission analysis available worldwide. Yet, the study on techno-economic and feasibility of bioethanol fuel in Malaysia condition is unavailable. Thus, this study is concentrated on bioethanol production and techno-economic analysis of cassava bioethanol as an alternative fuel in Malaysia. Furthermore, the current study attempts to determine the effect of bioethanol employment towards the energy scenario, environmental and economy. From the economic analysis, determined that the life cycle cost for 54 ktons cassava bioethanol production plant with a project life time of 20 years is $132 million USD, which is equivalent to $0.11 USD per litre of bioethanol. Furthermore, substituting 5 % of gasoline fuel with bioethanol fuel in road transport can reduce the CO_2 emissions up to 2,038 ktons in year 2036. In case to repay the carbon debt from converting natural forest to cassava cropland, cassava bioethanol required about 5.4 years. The cassava bioethanol is much cheaper than gasoline fuel even when 20 % taxation is subjected to bioethanol at current production cost. Thus, this study serves as a guideline for further investigation and research on bioethanol production, subsidy cost and other limitation factors before the extensive application of bioethanol can be implemented in Malaysia.

1. Introduction

In the past decades the Malaysia transportation energy consumption increased from 12.1 Mtoe in 2000 to 22.4 Mtoe in 2013 (ST, Comission; US Energy Information Administration, 2012). Concerns about fossil fuels dual issues of energy security and global warming have motivated interest in alternative and more sustainable energy resources (Lombardi, 2003; Ong et al., 2011). Transportation plays a major part in the greenhouse gas (GHG) production, in which motor vehicles responsible for 19% of global CO_2 production (Balat and Balat, 2009; Energy Information Administration, 2009). Therefore, decreasing emissions in this sector would extensively assist in realization of climate change targets (Jayed et al., 2011). Bio-ethanol, or ethanol produced from biomass, has been acknowledged as a potential alternative to gasoline in internal combustion engine (International Energy Agency, 2015; Siddegowda and Ventakesh, 2013; Shane et al., 2008; Cooney et al., 2009).

Currently the vast majority of bioethanol are produced from first generation feedstocks like corn, sugarcane, wheat and cassava (Renewable Fuels Association, 2010; Kovarik, 0000; Dai et al., 2006; Nguyen and Gheewala, 2008; Wongwatanapaiboon et al., 2012). In Malaysia, corn and sugarcane are cultivated for food and animal feed purposes, while cassava is cultivated for starch

* Corresponding author.
E-mail address: anepmarzuki@gmail.com (M. Hanif).

http://dx.doi.org/10.1016/j.egyr.2016.03.004

production. At this time, cassava has been recognized as a potential bioethanol feedstock in Asia as it can be cultivated on marginal land and content high ethanol yield of 3600 L/ha (The State of Food and Agriculture, 2008). Furthermore, Malaysia Agricultural Research and Development Institute (MARDI) has bring in a new cassava variety known as Sri Kanji 1 which has higher crop yield of 92.9 ton/ha and starch content of 30.5% (NurulNahar and Tan, 2012). Hence the theoretical ethanol yield of Sri Kanji 1 would be 19,000 L/ha. Therefore Sri Kanji 1 cassava is selected as raw material for bioethanol production due to high productivity and high bioethanol conversion. The comparison of ethanol yield for various feedstocks is simplified in Fig. 1.

Nomenclatures

Symbol	Descriptions	Unit
BC	Bioethanol needed	tons
BCC	Carbon stock for bioethanol cropland	ton/ha
BFP	Bioethanol fuel price	$/litre
BP	By product credit	$
CC	Capital cost	$
CDG	Carbon dioxide generated	tons
CDP	Carbon dioxide price	$/ton
CLR	Cropland required	hectare
CPP	Carbon payback period	year
CPW	Compound present worth factor	$
EC	Energy content of gasoline fuel	GJ/ton
EY	Ethanol yield	kg/ha
FBC	Final bioethanol unit cost	$/litre
FC	Feedstock cost	$
FP	Feedstock price	$
FU	Feedstock consumption	tons
GC	Gasoline consumption	tons
GR	Gasoline replacement	tons
HVB	Heating value of bioethanol fuel	MJ/kg
HVG	Heating value of gasoline fuel	MJ/kg
i	Project year	year
LCC	Life cycle cost	$
LSC	Carbon stock for natural forest	ton/ha
MC	Maintenance cost	$
MR	Maintenance rate	%
NAE	Net avoided emission	$tons_{CO_2}$/tons
n	Project life time	year
η	Fossil gasoline replacement rate	%
OC	Operating cost	$
OR	Operating rate	$/ton
PC	Annual bioethanol production capacity	tons/year
PP	Payback period	year
PV	Present value	–
PWF	Present worth factor	–
ρ	Density	kg/m^3
r	Discount rate	%
RC	Replacement cost	$
RM	Ringgit Malaysia (currency)	RM
SR	Substitution ratio of bioethanol to gasoline fuel	–
SV	Salvage value	$
TAX	Annual total tax	$/year
TBS	Annual total bioethanol sales	$/year
TCS	Total carbon saving	tons
TGS	Total gasoline saving	tons
TPC	Annual total production cost	$/year
TR	Tax ratio	%

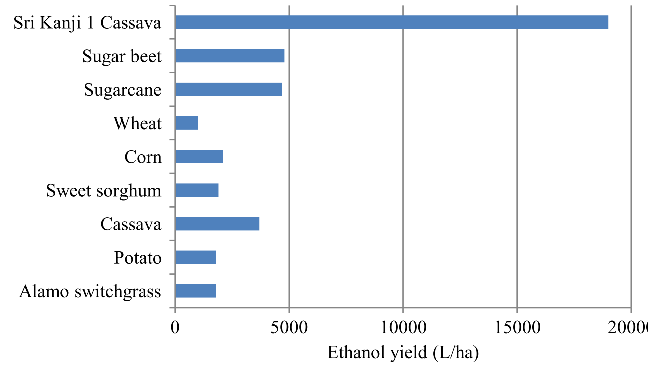

Fig. 1. Production ethanol yield for various source of bioethanol feedstock (The State of Food and Agriculture, 2008).

The major advantages of cassava over other crops are growth tolerance to poor environmental condition, all year long planting and harvesting, high root productivity, continuous development of high yield-improved varieties, less input in planting and harvesting, high quantity and quality carbohydrate source, starchy crop with highest energy content per acre and higher ethanol yield per acre (Kuakoon, 2011).

The main challenge to utilize Sri Kanji 1 cassava as raw material for bioethanol production is the raw material supply capabilities. With current cultivation area for cassava is only 3000 hectare and most of it is used for starch industry, it would be insufficient for bioethanol production (FAO, 0000). This can be solved by increasing the cassava cultivation area as cassava can be cultivated in a marginal land. A new policy on cassava plantation for bioethanol production needs to be considered to support the development of cassava bioethanol industry.

The aim of this study is to conduct techno-economic and environmental analysis of ethanol production from Sri Kanji 1 cassava as gasoline replacement in road transport. The analysis consists of the estimation of ethanol production cost in Malaysia, taxation and subsidiary scenario, energy and environmental impact and ecosystem carbon payback period.

2. Methodology

2.1. Prediction of energy consumption

The polynomial curve fitting equation is used to evaluate and project long-term time series and to determine a smooth curve that best fits the data but does not necessarily pass through all the data points. Mathematically, a polynomial of order k in x is an expression in the following form:

$$y = c_0 + c_1 x + c_2 x^2 + \cdots + c_k c^k. \qquad (1)$$

In this research, the forthcoming energy consumption is assumed comparable to the pattern of past years by utilizing polynomial curve fitting to evaluate long term time series for energy consumption pattern. Thus, Eq. (1) is used to estimate and forecast future energy consumption pattern.

2.2. Life cycle cost and payback period analysis

2.2.1. Life cycle cost

In this section, life cycle cost model for bioethanol production plant is established and clustered into six groupings as follows:

$$LCC = CC + OC + MC + FC - SV - BP. \qquad (2)$$