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Communication

Development status and life cycle inventory analysis of biofuels in Taiwan

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ABSTRACT

This research conducted the life cycle inventory analyses of biofuels in Taiwan. The biofuels considered include bioethanol production from sugarcane as well as biodiesel production from soybean and rapeseed. Energy inputs and pollutant emission (including carbon dioxide) are the input/output items analyzed. Results obtained from the inventory analyses can be summarized as follows. Bioethanol production from per hectare sugarcane cropland is 5160 L (liters), meanwhile, 476 and 1012 L biodiesel can be produced from 1 ha of soybean and rapeseed, respectively. The energy input to produce a liter ethanol, a liter biodiesel produced from soybean and rapeseed are 1256, 9602 and 5191 kcal, respectively. Those energy inputs are still less than the energy content of ethanol or biodiesel. It can be concluded that there is a positive energy benefit in producing biofuels based on a comparison with the previous work. In addition, through their life cycle, 1478.4 kg CO_2 emission is generated from one hectare of soybean land and 2954.1 kg is generated from rapeseed land. Life cycle carbon dioxide emissions released from burning ethanol is 0.08 kg/LOE in contrast to 2.6 kg/LOE released from burning fossil gasoline.

1. Introduction

With recent increase in crude oil prices and uncertainty concerning petroleum reserve, there is an emerging interest in the development of biofuels. The scarcity of fossil energy makes renewable energy resources further attractive. Nowadays, numerous countries are devoted to seeking clean and renewable energy. Biofuels are regarded as a new measure for solving energy and environmental problems effectively. They have advantages over conventional fossil fuels including reduced emissions, renewability and cleaning properties (Demirbas, 2006). In general, renewable energy includes biomass, hydropower, wind power, ocean energy, solar energy and geothermal energy. The so-called biomass energy or bioenergy includes solid biomass (i.e., forest product wastes, agricultural residues and wastes, and energy crops), biogas, liquid biofuels and the organic component of industrial waste and municipal solid waste.

Taiwan is a densely populated island with only limited natural resources. According to the statistics released by the Bureau of Energy, Ministry of Economic Affairs (BOE, 2008), Taiwan's total energy consumption has grown greatly over the past two decades, going from 40.68 million kiloliter of oil equivalent (MKLOE) in 1987 to 114.66 million kiloliter in 2007 (the average annual growth rate of 5.32%). In 2007, Taiwan's dependence on imported energy was 98.36% (BOE, 2008). As industry and commerce progress rapidly, increasingly more people are moving to cities for convenience. This leads to greater demand for vehicles, which negatively impact health and environmental quality because of emissions of air pollutants. One of the key solutions to reduce the impacts is the effective use of biofuels.

Taiwan's energy policy hopes to decrease the dependence on imported energy and mitigate greenhouse gas emissions by increasing the supply of renewable energy. In order to encourage the production and use of biofuels, the Ministry of Economic Affairs promulgated the "Measures for Subsidizing Energy Crop" to harvest soybean and rapeseed. This research, thus, conducts a life cycle inventory (LCI) analysis to identify and discuss the inputs and outputs from the bioenergy production and utilization process. This paper is divided into three major parts. The development status of biofuel is introduced first, followed by the LCI analysis of biofuel production in Taiwan. The last part summarizes an analysis from the related findings. The results can thus be used to assess the feasibility of bioenergy development.

2. Development status of biofuels in Taiwan

In order to encourage the use of biofuels, the Bureau of Energy (BOE hereafter) and the Environmental Protection Administration in Taiwan continually promote biofuels in 16 counties (Taiwan EPA, 2005). A variety of oil can be used to produce biodiesel, including virgin vegetable oil feedstock (rapeseed and soybean oil

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Table 1
Summary of the promoting strategies for biofuel in Taiwan[a]

Biodiesel				
Year	2006	2007	2008	2010
Capacity (kL)	650	6500	45,000	1,00,000
Promotion project	Green bus	Green county	Overall B1	Overall B2
Growth area (ha)	2000	8000	20,000	80,000
Bioethanol				
Year	2006	2007	2009	2011
Capacity (kL)	–	770	12,000	100,000
Promotion project	–	Green official car	E3 in metropolis	Overall E3
Growth area (ha)	30	30	3000	20,000

[a] Resource: Bureau of Energy under the Ministry of Economic Affairs, Taiwan.

are most commonly used), waste vegetable oil and waste edible oil. Waste edible oil was used as feedstock for the first biodiesel production plant in Southern Taiwan (Chiayi County) from 2004, which was designed at an annual capacity of 3000 metric tons of biodiesel. In early 2007, biodiesel has been used in 428 buses in Kaohsiung City. Additionally, the "Green Country" project was carried out by the BOE in July 2007 to establish a regional production and supply market system. Finally, there are plans to use B1 (blends of 1% biodiesel with 99% petroleum diesel) in 2008, and B2 in 2010 to reach the objective of 10 million liter for biodiesel development (Bureau of Energy (BOE), 2007).

In the meantime, the Council of Agriculture has planned to grow 30 ha of sweet potato to produce ethanol starting in 2007. Also, the BOE and CPC Corporation (the state-own petroleum company in Taiwan) has being providing E3 (blends 3% ethanol with 97% gasoline) for government vehicles in Taipei City since July 2007. This program is expected to expand to Kaohsiung City in 2009 and will be adopted nationwide in 2011.

In summary, the development of biofuels in Taiwan has been significantly considering all of the sources in recent years. Table 1 shows a summary of the promoting strategies for biofuels in Taiwan. The BOE has announced an anticipated biodiesel capacity of 4.5 million liter per year by 2008 and ethanol capacity of 10 million liter per year by 2011. The capacity of the four registered biodiesel plants in operation and under construction, however, amount to 2 million liter only. Nevertheless, there are no ethanol plants currently operating in Taiwan. It is necessary to establish more biofuel plants in order to meet the policy target. Moreover, the harvested area of crops that supply biofuel feedstock is still very limited. The development of biofuels in Taiwan appears to be an emerging issue.

3. LCI analysis

This research applied life cycle assessment (LCA) procedures outlined in ISO 14040:2006, where only the two LCA phases of: (1) goal and scope definition and (2) LCI analysis are incorporated. The life cycle impact assessment phase is not considered due to the lack of valuation and weighting data. In this paper, the LCI is conducted to construct the inventory of inputs of energy and materials as well as outputs of pollutant and carbon dioxide emissions while considering the environmental impacts of renewable energy (e.g., biodiesel and ethanol). The following section introduces the LCI analysis of biofuels in Taiwan including ethanol production from sugarcane as well as biodiesel production from soybean and rapeseed.

3.1. Ethanol production from sugarcane

While scoping the life cycle of ethanol production system, the following five stages are considered, namely, (1) sugarcane harvesting/production, (2) sugarcane transportation, (3) ethanol production, (4) ethanol transportation and (5) its use as the energy source (including bagasse-derived electricity and its use as the biofuel). The inventory analysis considers the resource inputs of labor, chemicals, fuel oil and electricity, but do not include built-in energy in equipment, trucks and civil engineering. Carbon dioxide emissions (excluding other greenhouse gases) as well as waste water effluents are considered as the outputs. Lastly, a functional unit is defined as the ethanol produced from 1 ha of sugarcane farmland in 1 year. A detailed description of the various stages of life cycle is described in the following (Chang, 2006):

- *Sugarcane cultivation*: in this stage, a number of inputs such as labor, fuel oil, fertilizer, pesticides and herbicides are considered. The process of sugarcane production is separated into five stages including soil preparation, planting, fertilization, irrigation, weeding and harvesting.
- *Sugarcane transportation*: the route from cropland to the ethanol refinery is considered as the transportation distance. The fuel consumed by transportation and the resulting exhaust emissions are assessed.
- *Ethanol production*: due to lack of steam and heat data used in boiler, the main input to convert sucrose into ethanol is the electricity consumed by the ethanol refinery, while the exhaust gas and waste water are considered as outputs.
- *Ethanol transportation*: similar to the process of sugarcane transportation, the fuel consumption and exhaust gas of transportation from the ethanol refinery to gas stations are estimated.
- *Energy use*: in this stage, the surplus electricity derived from bagasse combustion and ethanol used as a biofuel are considered. The air emissions caused by burning bagasse and ethanol are the only output estimated.

The data needed for the analysis were collected from various sources including institutional statistics (Taiwan Sugar Corporation, 1998; Council of Agriculture, 2005), and published studies (Intergovernmental Panel on Climate Change, 1996; Sheehan et al., 1998; Moreira, 2000; Beeharry, 2001; Stillwater Associates, 2003; Schmitz et al., 2003; Patzek, 2004; Pimentel and Patzek, 2005). The important assumptions that were made in the calculation of the LCI are as follows:

- One person (the sugarcane grower unit) is engaged in cultivating the sugarcane. It is assumed that one person works 2000 h per year and utilizes an average of 8000 L of oil equivalents (LOE) per year (Pimentel and Patzek, 2005).
- The sugarcane harvested from 1 ha of land in 1 year is 64.5 tonnes (a total of 80.6 tonnes can be grown over two harvest periods. Given the nature of sugarcane, the first harvest period will last 18 months and the second harvest period will last 12 months, the average yield over 12 months is 64.5 tonnes) estimated by Taiwan Sugar Corporation in its 1998 yearly report.
- The fossil fuel consumption within the sugarcane production stage is calculated to be 90 L (Beeharry, 2001; Pimentel and Patzek, 2005).
- Biomass crops and ethanol are assumed to be transported by diesel-powered trucks. The energy intensity of such trucks (light truck) is assumed to be 0.2255 LOE/tonne km (adopted from the estimates by the Industrial Technology Research Institute, http://auto.itri.org.tw), and the assumed value for the carbon emission factor of petroleum diesel is 20.2 tonnes-C/TJ (Intergovernmental Panel on Climate Change, 1996). If heavy trucks are used in sugarcane transportation, the energy intensity is less.