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Net Energy Ratio and Life cycle greenhouse gases (GHG) assessment of bio-dimethyl ether (DME) produced from various agricultural residues in Thailand

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ABSTRACT

Net Energy Ratio and Life cycle greenhouse gases (GHG) assessment of five agricultural residues to produce dimethyl ether (DME) including rice straw, palm empty fruit bunches, cassava rhizome, sugar cane tops and leaves, maize stem with DME derived from lignite coal and natural gas by simulation of two-stage DME production. Sugar cane tops and leaves indicated highest NER at 4.83 and lowest GHG emission at 0.89 kg CO_2e/kg DME due to their properties and low GHG burden in acquisition phase. Compared to fossil-DME and diesel, it was found that the bio-DMEs derived from rice straw, sugar cane tops and leaves and maize stem have potential for substitution with much lower life cycle GHG emissions as well as high NER. On the other hand, cassava rhizome and palm empty fruit bunches show low possibility of utilizing as DME feedstock due to high moisture content as well as low heating value. Reducing their moisture content by using flue gas and solar drying are improvement measures to make them promising as bio-DME feedstock.

1. Introduction

Fossil fuels play a very important role in society being used primarily for heat and power production, and also as liquid fuels for the transportation sector. The conventional use of fossil fuels for these purposes eventually causes emission of CO_2 to the atmosphere, which has been known to consequently contribute to climate change. Moreover, there are other important issues of the use of non-renewable fossil fuel feedstock particularly the security of supply and their limited availability. Since there are so many problems concerning the use of fossil fuels outlined above, several alternatives are investigated. One well-known feedstock is biomass which can be directly used for producing heat and power, and also for producing various organic chemicals including substitutes of fossil fuels. Presently ethanol and biodiesel are used as major for substitution of gasoline and diesel respectively. Both, however, are still made from the sugars and vegetable oils found in arable crops or so-called 1st generation of biofuel. However, there is the issue of competition between energy and food crops to consume natural resources which are limited i.e. cultivation land, irrigation water, fertilizers, etc. To address this issue, other liquid fuels need to be identified which are not derived from vegetable products (2nd generation) and used efficiently with existing vehicle engine technologies. Dimethyl ether (DME) is a reasonable option because it can be derived from any lignocellulosic biomass as feedstock and its properties make it a good substitute for diesel. As per the Alternative Energy Development Plan (AEDP 2012–2021) revised

Abbreviations: DME, dimethyl ether; Bio-DME, biomass-derived dimethyl ether; Coal-DME, coal-derived dimethyl ether; GHG, greenhouse gases; LC-GHG, life cycle greenhouse gas; LCI, life cycle inventory; GWP, global warming potential; LHV, low heating value; RPR, residue to product ratio; EFB, empty fruit bunch (of oil palm); FFB, fresh fruit bunch (of oil palm); NER, net energy ratio.

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in 2013, Thailand is expected to develop new fuel for substituting diesel and 1st generation biodiesel. The target amount of 25 ML/day includes various advanced biofuels e.g. Biodiesel from microalgae, Bio-Hydrogenated Diesel, Biomass to Liquid, etc. So bio-DME might also be an alternative fuel for consideration.

DME is conventionally derived from fossil resources which contained rich hydrocarbons i.e. natural gas, coal then is converted via gasification to synthesis gas (syngas). The DME has so far been primarily used as an aerosol propellant in spray cans to replace chlorofluorocarbons (CFCs) for an environmental friendly reason (Fleisch et al., 1997). However, in recent years, there has been an increasing interest in using DME as alternative fuel due to its attractive fuel properties e.g. cleaner and more efficient synthetic fuel for diesel engines, similar characteristics of liquefied petroleum gas (LPG); can be blended with or substitute LPG. DME is a very promising alternative fuel for compression-ignition engines with lower pollutants exhausted (Arcoumanis et al., 2008). A study by Larson and Yang (2004) showed that substituting LPG for cooking application with coal-DME could save primary coal needed (about 25%) due to the co-produced electricity. Therefore some studies have been conducted to assess the environmentally advantages of DME production from various biomass feedstock; for example, Silalertruksa et al. (2013) indicated the life cycle GHG emissions of bio-DME derived from rice straw are lower than fossil-derived diesel by 12–60 g CO_2e/MJ or 14–70%.

However, Thailand also has other abundant biomass feedstock derived from agriculture products e.g. sugar cane tops and leaves from sugar cane cultivation, empty fruit bunches from palm feed mill, etc. which could serve as feedstocks for DME production. This study aims to compare the NER and LC-GHG emissions of DME from various agricultural residues with that derived from lignite, natural gas and conventional diesel. The availability of biomass must be considered in order to account for sufficiency and identifying the promising feedstock for bio-DME production. The results of the study can provide direction for research on DME production and improving practices in feedstock acquisition stages to increase NER and also reduce GHG emissions from DME production in Thailand.

2. Agriculture residue feedstock selection

The major agriculture products of Thailand such as rice, maize, palm, and cassava are considered for evaluation of the availability of their residues. A review of the agricultural residues in Thailand indicated that some residue types are already being fully or partly utilized by other activities. e.g. saw dust from para rubber trunk used as agriculture material, fiber from palm fruit directly used for furniture industry or bagasse from sugar cane used as pulp for the paper industry and feedstock for heat and electricity generation for own-use in sugar mills.

The amount of residue can be calculated by the residue to product ratio (RPR) which is defined as the amount of residue per kilogram of product. By the utilization rate and RPR, the residue availability of each residue to be used for DME production can be assessed. Table 1 shows the utilized rate and RPR of each agricultural residue (Utistham et al., 2007). The data show the minimum and maximum utilization rate; this study assumes the average value as the base case for further calculation. The description of each major agricultural residue is as follows.

Table 1
Residue to product ratio (RPR) and utilization rate of each agricultural residue.

Agricultural product	Residue	RPR	Utilization rate %		
			Min	Max	Average
Sugar cane	Tops and leaves	0.20	10	30	20
	Bagasse	0.30	100	100	100
Rice in-season	Husk	0.23	70	80	75
	Straw	1.19	50	50	50
Rice off-season	Husk	0.23	70	80	75
	Straw	1.19	50	50	50
Cassava	Stem and leaves	0.12	60	80	70
	Rhizome	0.09	0	0	0
Maize	Stem and leaves	0.89	10	10	10
	Corncob	0.19	70	70	70
Palm	Fiber	0.15	100	100	100
	Empty fruit bunches	0.22	50	60	55
	Leaves	0.27	100	100	100
	Shell	0.13	70	80	75

2.1. Rice straw

Rice is a well-recognized agricultural product grown in every region of Thailand. In 2012, 37.9 Mt of produced rice (including 27.2 and 10.7 Mt of major rice and second rice, respectively) was harvested from 64.9 Mha. The major product is the rice grain and the remaining rice straw is often burnt or left in the field; hence it is one of the interesting feedstocks to consider for DME production. The harvesting machines are used for large paddy fields; these machines can separate the rice grains and bale the straw immediately. However, the rural small fields still use manpower for harvesting. When another residue, rice husk, taken place in the rice mill and all have already be utilized as soil conditioner, livestock bed material and also energy feedstock in small electricity producers.

2.2. Sugarcane top and leaves or sugar trash

In 2012, Thailand was the fourth largest sugarcane producer of the world with 96.5 Mt and the average yield of 0.74 Mt per ha. Following the policy target on bioethanol in recent years for producing 12 ML per day, the cultivation area of sugar cane has been rapidly increasing. Currently, the harvesting practice of sugarcane in Thailand mostly uses manpower with burning the trash before for comfortable collecting. Therefore, this trash is potential to use as biomass feedstock either by manual collecting separately or using advanced harvesting machines.

2.3. Empty fruit bunches of palm

The promotion of biodiesel policy was coupled with the increasing world oil prices. The production in 2012 was 11.32 Mt of fresh fruit bunches (FFB) with around one Mha of cultivation area. Palm is a perennial crop so the outputs are produced all year round. The usual harvesting practice utilizes manpower to collect the FFB which is then delivered to the palm mill factory very quickly; thus empty fruit bunches (EFB) will be generated at the factory which is the target of this study. The other residues of this FFB are either utilized as fuel in the palm mill e.g. fiber and shells, or used as material for other industries e.g. palm kernel. Meanwhile leaves and trunks need to be picked up from the oil palm plantation which is more difficult to collect and all are used as compost.

2.4. Cassava rhizome

This is another target bioethanol feedstock in order to reduce stress of sugar cane demand. Cassava is a good source of carbohydrate because of its edible starchy root. Thailand is the third largest cassava producer with 27.5 Mt in 2012. After the farmer collects the root of cassava, the main product, its rhizome are cut out. Although the weight of these residues is not much, they have high potential for using as energy feedstock because these residues are not utilized for other activities and so were burnt in field.