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Environmental and energy assessment of alternative fuels for diesel in Thailand

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ABSTRACT

Thailand has recently implemented the Alternative Energy Development Plan (2015–2036) aiming to reduce the dependency on conventional fuels, notably diesel from oil palm. To ensure sustainability of substituting diesel, this study aims to assess the environmental effects of three promising biofuels namely, conventional biodiesel or Fatty acid methyl ester (FAME), Bio-hydrogenated diesel (BHD) and the newest alternative fuel, Partially Hydrogenated Fatty Acid Methyl Ester (H-FAME) compared to diesel in transport sector. The system boundary is "Well-to-Wheels. This study does not show a significant difference in the energy performances and environmental effects of the studied biofuels. The partial substitution of diesel by FAME, H-FAME and BHD can decrease fossil use and greenhouse gas (GHG) emissions significantly. In terms of global warming potential GWP, more than 100 million tonnes CO_2eq would be reduced in the next 20 years according to the projection of 25% replaced conventional diesel consumption. To improve the performance in terms of resource use and GHG mitigation, the study results suggest encouraging the use of H-FAME and BHD as a good choice. Both these alternative fuels can be blended with conventional diesel more than 2 times compared with FAME. In the initial stage, substitution could start with implementing H-FAME and slightly reduce the use of FAME after which BHD could be implemented along with FAMEand H-FAME.

1. Introduction

Biofuels have been launched aiming to be less reliant on fossil resources, and also for reasons of energy security for future generations (Kudoh et al., 2015; Raman and Mohr, 2014). One of the most important fuels for conventional diesel substitution is biodiesel. The common meaning of biodiesel is the fuel made from biomass, whose properties should be similar to petroleum-based diesel fuel. In the past, the word biodiesel solely referred to a mixture of fatty acid alkyl esters and made from vegetable oils, animal fats, or recycled greases, the so-called first generation biodiesel (McGill et al, 2008). Nowadays, there are various types of conversion pathways from biomass to diesel-like fuels such as drop-in fuel, gasification and synthesis (bio-chemical route and thermo-chemical route) (IEA, 2010). There are many advantages of implementing biodiesel fuels such as being less reliant on conventional diesel, use agricultural commodities, and palm oil has potential in Thailand (Pleanjai and Gheewala, 2009; Silalertruksa et al., 2012; Permpool et al., 2016). In addition, the environmental impacts are expected to be a crucial indicator for biodiesel utilization.

However, the first generation biodiesel is now facing many problems such as the limitations and critical concentration of blending with diesel as its high concentration has been found to cause e.g. poisoning of catalysts and filters in the conventional diesel engine due to fuel impurities. It also made problems especially in diesel vehicles equipped with exhaust after-treatment devices. The current fuels quality Directive for Europe, 2009/30/EC, limits the concentration of esterified biodiesel FAME in diesel to 7% v/v (B7). Thailand has implemented B7 since January 2014 (DEDE, 2014a). The limits are set to ensure proper functioning of vehicles, low emissions and integrity of vehicles including their exhaust after-treatment devices (Nylund et al., 2011). In case of Thailand's alternative energy plan, the AEDP 2015–2036 has been launched as a target each alternative fuel. Diesel should be replaced by conventional biodiesel at 14 MLPD along with others such as BHD which has been launched

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since 2013 (DEDE, 2015). There are 7 types alternative fuels set for diesel substitution in Thailand including new energy crop development, referring to jatropha and microalgae, using ethanol for blending such as FAME (Fatty Acid Methyl Ester), ED95 (Ethanol blended with Additives) and diesohol. Two other ways of development of oil conversion technology are BHD (Bio-Hydrogenated Diesel) and Partially Hydrogenated Fatty Acid Methyl Ester (H-FAME) (DEDE, 2015). Among these new alternative fuels, BHD and H-FAME are interesting fuels as both can be directly used in conventional diesel engines and have biomass as feedstock. In case of co-process BHD, the hydrotreating process is fed by two raw materials namely, vegetable oil and heavy gas oil, which then lead to a BHD-ready diesel as an output (Kiatkittipong et al., 2014; Silapakhampeeraphab, 2013) has been distributed in the market since 2013 while the feasibility of stand-alone BHD was studied and might be applied in the future. H-FAME is Partially Hydrogenated FAME; this production process is so called upgrading biodiesel as it uses partial hydrogenation to increase the performance of the FAME in a conventional diesel engine. Currently, H-FAME can be blended with conventional diesel up to 15% without engine damage (Yoshimura and Bhandhubanyong, 2015). This fuel is not yet commercial in Thailand but its function and performance has attracted the policy makers to add it as an alternative fuel for substituting diesel in the national target. This study aims to assess the effects on greenhouse gas emissions and energy performance of alternative fuels for substituting diesel in Thailand based on the currently policy target, AEDP 2015–2036.

2. Methodology

Essential tools used in this study are net energy ratio (NER), renewability, and life cycle assessment (LCA) considering greenhouse gas (GHG) emissions and resource depletion. These tools are based on system boundary “well-to-wheels (WTW)”, starting from oil palm cultivation, transport (oil palm fresh fruit bunches or FFB), palm oil milling, transport (crude palm oil or CPO), fuel conversion, transport (fuel) and use of fuel. FAME, H-FAME and BHD are also produced from palm oil. Palm oil has high potential for producing alternative fuel for substituting diesel (Permpool et al., 2016; Triyanond, 2015; Yoshimura and Bhandhubanyong, 2015; OAE, 2014).

2.1. Net energy ratio (NER)

The NER is common indicator based on the first law of thermodynamics (Gheewala, 2013). This tool is the ratio of the total energy output to the total energy input through the “well-to-wheels” life cycle. The NER can indicate the preliminary potential of biofuel production; if it shows the values more than one means that there is a gain in energy from the investment of a unit of energy. This study uses this indicator for evaluating the potential of all each of the alternative fuels and also compare it with diesel. From the point of view of thermodynamics, NER can actually never be more than one; however, since the energy from the sun (for biomass production) is not counted, biofuels can possible have an NER greater than one.

2.2. Renewability

This indicator is the ratio of total energy output to the total fossil energy input (Silalertruksa and Gheewala, 2012b; Gheewala, 2013). The basic of assessing the renewability is separation between types of energy carriers; identifying the fossil energy input (non-renewable energy). Renewability more than one indicates that more than one unit of renewable energy was gained by the investment of one unit of fossil energy; which is desirable. A renewability value lower than one would not make sense to pursue. This study uses this indicator to point out the amount of renewable energy have gained or lost in the biofuel system.

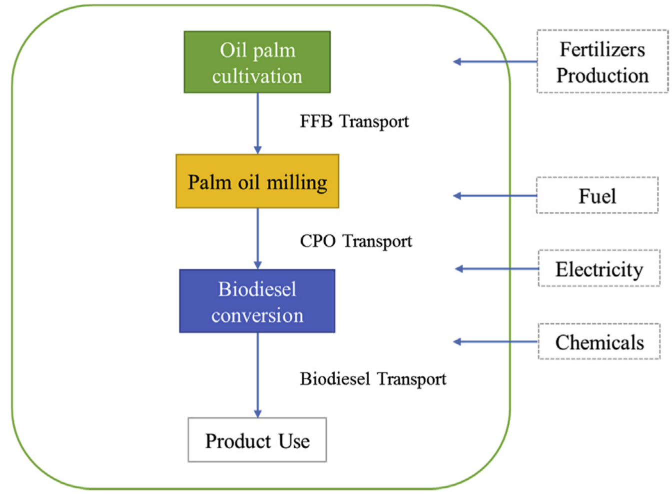

Fig. 1. Simplified schematic of FAME life cycle.

2.3. LCA of alternative biofuels

2.3.1. LCA of FAME

The life cycle of biodiesel production is divided into four stages (Fig. 1). The first stage is the oil palm cultivation stage, followed by crude palm oil (CPO) milling, FAME biodiesel production Transportation of fresh fruit bunches (FFB) from field to mills and transport of CPO from mill to biodiesel plant are also considered. The life cycle inventory data for FAME production are derived from Silalertruksa and Gheewala (2012a).

2.3.2. LCA of BHD

The life cycle of BHD consists of oil palm cultivation, palm oil milling, and BHD production (pretreatment and hydro-treating process). Inventory data of BHD from oil palm cultivation and palm oil milling are derived from the same data sources as for FAME production mentioned earlier, while BHD conversion data were referred from the NExBTL production (Trade name of Neste Oil's

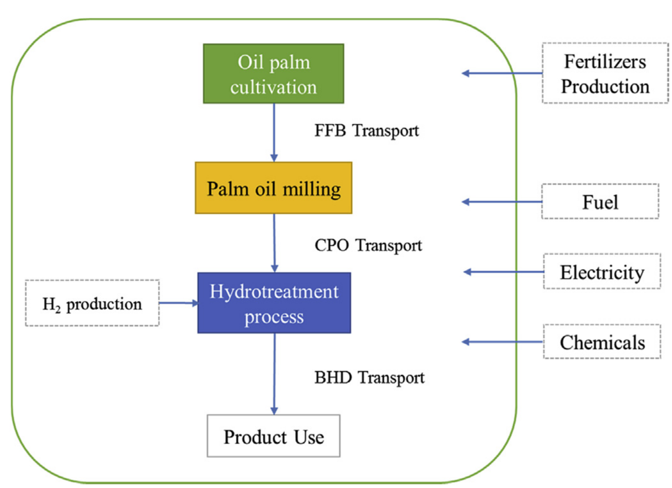

Fig. 2. Simplified schematic of the BHD.