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Economic feasibility of biodiesel production from waste cooking oil in the UAE

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ABSTRACT

The absence of proper collection methods for waste cooking oil (WCO) particularly in residential areas make the tendency to drain it and clog the sewage stream or dispose of it into the trash bin the only unfavorable choices. Therefore providing an integral residential collection mechanism, incentive or penalty system, inexpensive and robust conversion technology into utilizable fuel, and downstream community usage would change this in environmental malpractice stress and valorize this energy opportunity. The focus of this work is to study the economic feasibility of biodiesel production from waste cooking oil in the UAE, subjected to seven economic scenarios. To provide statistical information on the quantity and quality of generated WCO, a social survey was conducted. The local residential and commercial sector was targeted to gain information on the type of oil, method of drainage and quantity of waste cooking oil. A comparison can be made between conventional and sonication methods of production and results are assessed based on the selling price, net present value (NPV) and internal rate of return (IRR). As sonication assisted production is suited for high throughput, it demonstrated better profitability despite of its higher CAPEX and OPEX. Results also indicated that large scale production favored reduction in selling prices and subsidies. The auxiliary benefits like CO_2 emissions were calculated and it shows a reduction of 23.1% in emissions and reduces in maintenance cost associated with the current drain clogging. The conclusion that can be drawn is that large scale production with sonication and no oil incentive is the most economically feasible model for the UAE.

1. Introduction

It is a well-established fact that the world currently needs to shift towards adopting renewable and non-polluting energy resources, in order to reduce the harmful greenhouse gas emissions, to protect the environment and enhance sustainable development. Several countries have already defined set targets to offset a certain percentage of their existing energy production with renewable resources. According to the Renewable Energy Policy Network's global status report (Renewables, 2014), as of 2014, a total of 144 countries have policy targets towards renewable energy. An estimated global annual investment of US$ 214.4 billion was made in renewable power and fuels. Major countries in terms of investment are China, United States, Japan, United Kingdom and Germany. Renewables now occupy 19% of the total world's energy share (2012). The UAE is also among such countries with a renewable energy target. UAE is aiming to achieve 7% renewable energy based power by 2020 to reduce the dependency on oil. Alternative fuels are one part of the macro scenario of promoting renewable energy resources in the world. The transport sector needs a dependable, strong, and economic alternative fuel which can effectively replace petroleum based options. The UAE transport sector consumes 22% of the total energy consumption, which is the second highest to the industrial energy consumption (63%) (Renewable energy prospects, 2016). In 2010, the total energy consumption by the transport sector in the UAE was estimated at over 110,000 GWh and is predicted to be doubled by 2030 (Renewable energy prospects, 2016). Gasoline is consumed mostly due to the initial subsidies in the domestic sector, but also the industrial sector that employs heavy vehicles which use diesel as fuel. Road transport comprises 99% of the transportation share, as other modes of transport are not prominent. The number of vehicles is reported as approximately 600,000, which is projected to increase to 2 million by 2030 in Abu Dhabi alone (Renewable energy prospects, 2016). The Abu Dhabi Government, through the Waste Management Center (CWM), is seeking development of alternate fuels, which can be produced from organic waste materials. Research in this field has existed in many parts of the world for several decades and biofuels are quickly gaining recogni-

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tion for their capabilities in providing society with a clean-green fuel option (McKendry, 2002). Biodiesel is one such fuel option that is a strong competitor against petro-diesel due to their high similarities. It can be directly used in the existing engine without any major modifications (Cararetto, Macor, Mirandola, Stoppato, & Tonon, 2004) .The fact that the overall greenhouse gas emissions are much lower in comparison to petro-diesel makes it a highly favorable option.

However, in the UAE making biodiesel viable is much more difficult in comparison to other parts of the world, since the UAE itself is a major producer and exporter of petroleum based fuels. Among the OPEC countries, the UAE stands 6th highest in terms of proven crude oil reserves which are estimated to be at 97,800 million barrels (Petroleum, 2014). Abu Dhabi is estimated to have 60% of this capacity (United Arab Emirates, 1997). The annual revenue as of 2013 from petroleum exports stands at $ 126,307 million (Petroleum, 2014). The challenge lies in making biodiesel as economical as petro-diesel, maintaining the fact the petro-diesel is priced at one of the lowest prices in the world.

Biodiesel, chemically, is a fatty acid alkyl ester, which is a product of vegetable oil (Triglyceride) transesterification. Transesterification is the reaction of a lipid, which is the vegetable oil, with an alcohol to form fatty acid alkyl ester and glycerol in the presence of a catalyst which could either be heterogeneous, homogeneous, or an enzyme as given in the overall stoichiometric Eq. (1).

$$\text{Triglyceride} + 3\ \text{Alcohol} \leftrightarrow 3\ \text{FAME} + \text{Glycerol} \tag{1}$$

Heterogeneous catalysts are solid catalysts which do not easily dissolve in the alcohol, whereas homogeneous catalysts could either be a concentrated acid such as sulphuric (H_2SO_4) or hydrochloric (HCL), or a base such as sodium hydroxide (NaOH) or potassium hydroxide (KOH). Methanol is the most preferred alcohol due to its better reacting properties and low cost (Stavarache, Vinatoru, & Maeda, 2007). The major cost factors are the price of raw materials required for this reaction and the equipment used for production. Vegetable oils are generally expensive and using vegetable oil for large scale biodiesel production creates supply problems, and affects the vegetable oil market. The better alternative to vegetable oil is using waste or used cooking oil. Several works have been carried out which showed that good quality biodiesel can be produced from WCO. Apart from the feedstock, molar ratio of oil to methanol and catalyst percentage are also important as they govern the reaction and directly influence the process cost. In a work by Pulakale, Maddikeri, Gogate, Pandit and Pratap, (2015) WCO transesterification with methanol in the presence of a heterogeneous solid catalyst (K_3PO_4) achieved 70% biodiesel purity at 6:1 molar ratio of methanol to oil. Pal et al. (Pal & Kachhwaha, 2013) achieved as high as 89.8% purity biodiesel from WCO and methanol transesterification with unspecified amount of KOH (Potassium Hydroxide) catalyst and a similar molar ratio of 6:1.

Another crucial factor that directly governs the reaction, the quality of biodiesel and the cost, is the production technique. Transesterification is a slow reaction, which requires mechanical agitation for completion and to produce a quality product. It is conventionally provided by rotary stirrer, yet the reaction continues to experience a slow conduction and takes a few hours to complete. The current state of the art technique is sonication, which uses a low ultrasonic frequency irradiator to create cavitation bubbles in the reaction mixture, propelling the reaction faster by increasing the interaction between the reactants in a compacted scale (Mason, 1999). The produced cavitation bubble have very high internal temperatures and pressures, which help in accelerating the reaction (Gogate & Kabadi, 2008; Gogate, 2007). This technique drastically reduces the conversion time, thus favoring mass production of biodiesel. However, this is an expensive technique since the equipment cost of the ultrasound is much higher as compared to mechanical procedures. There is ongoing research at several places to further simplify and economize this method, a review of the works on sonication transesterification helps in knowing the optimum conditions that result in good quality biodiesel at low parameter consumption. Kelkar, Gogate and Pandit (2008) worked on transesterification of waste cooking oil assisted by a 20 KHz ultrasound technique. Using methanol and H_2SO_4 as the catalyst, they achieved 99% purity biodiesel. They also tested the applicability of ultrasound for different reaction parameters such as molar ratio and catalyst amount. Babajide, Petrik, Amigun and Ameer (2009) investigated transesterification of waste cooking oil with methanol and KOH, under 24 KHz sonication conditions and achieved 96.8% pure biodiesel. Darwin, Agustian and Praptijanto (2010) also worked on transesterification of waste cooking oil but under a continuous type ultrasonic assisted tubular reactor and achieved 95.69% pure biodiesel. However, they used high powered equipment with a frequency of 20 KHz. Extensive work is also being carried out on designing better sono-chemical reactors for higher throughput and lower reaction time (Gole & Gogate, 2011, 2012; Maddikeri, Pandit, & Gogate, 2012). In our previous projects we have worked on investigating sonicated transesterification in continuous reactors and found it to be much better than conventional process (Hussain, Samad, Daqaq, & Janajreh, 2016; Janajreh, Samad, & Hussain, 2016).

For the economic analysis, the procedure in prior works was to analyze biodiesel production from a domestically abundant crop or vegetable, while few works also considered waste cooking oil in their analysis. Lopes, Neto, Mendes and Pereira (2013) investigated the economic feasibility of biodiesel production from Macauba in Brazil. They considered eight different scenarios of different combinations of catalysts and alcohol, with their main focus on enzymic catalysis. They reported all the eight scenarios to be profitable, however the selling prices of biodiesel and other parameters varied in each case. The highest profit margin and least selling price was in the case of methanol as alcohol and alkali as catalyst. In another work by Lopes, Steidle Neto and Martins (2011) they carried out an economic simulation of biodiesel production from different sources using a newly developed software tool, SIMB-E. They judged the viability of the process by considering economic indices such as NPV, Benefit to Cost ratio (BCR), Capital Return Time (CRT), and IRR. Zhang, Dube, McLean and Kates (2003) analyzed the economics of biodiesel production from waste cooking oil and compared it with vegetable oil (canola), considering both alkali and acid catalyzed transesterification processes. On that basis they also conducted a sensitivity analysis to identify the factors that are most significant for the commercialization of biodiesel. They inferred that the process with WCO was more economically feasible because of the lowest manufacturing cost, high IRR and low breakeven price.

Although literature provides good case studies of biodiesel production in various parts of the world, this work would be among the very first economic studies of biodiesel production for the UAE. This work will help not only the UAE, but also neighboring GCC countries to analyze the potential and feasibility of biodiesel. GCC countries such as Qatar, Kuwait and Bahrain who have similar demographics and are also oil producing nations. This study will give such countries a close idea of the biodiesel production scenario. In a global scenario, this study will help different non-oil producing nations to compare their own pros and cons of biodiesel production with that of the oil rich countries. This study provides different scenarios which will help many countries to decide on the best techno-economic production configuration.