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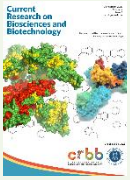

A review on community scale stationary and mobile production of biodiesel

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ABSTRACT

Biodiesel has been commercially produced on a large scale, but its application is still limited primarily due to its production cost, which is relatively more expensive than that of fossil fuel. Recently, there has been an ongoing parallel development whereby biodiesel production is carried out on a community scale, including a mobile production unit of biodiesel with local input and demand. The produced biodiesel is often intended for use by the concerned local community, which greatly reduces logistics and transportation cost. Unlike typical biodiesel production plants, a mobile biodiesel unit consists of a biodiesel production facility placed inside a standard cargo container and mounted on a truck, so that it can be transported to a region near the location of the raw materials. In this paper, we review existing concepts and units for the development of community-scale and mobile production of biodiesel. These include the main reactor technology for biodiesel production, as well as the pre-treatment prior to conveyance to the reaction unit and post-treatment. The pre-treatment includes oil extraction from oilseeds by an oil-expeller unit, as well as quality control of the oil before it enters the reaction unit. The post-treatment includes refining and purification of the biodiesel to meet the product specification set by the biodiesel industry. This paper also discusses the production cost of biodiesel on a community scale, particularly when using a mobile biodiesel unit. The production cost varies from $0.76-1.12/l. This range is still not yet competitive to the current average price of approximately $0.98/l of diesel around the world. The production cost may be reduced by applying a biorefinery concept that may translate into an economically alluring and environmentally attractive business model.

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1. Introduction

Biodiesel, a substitute for diesel fuel, can be produced from triglycerides available in vegetable oils and animal fats (Balat, 2007; Marchetti et al., 2007; Mishra and Goswani, 2018; Abduh et al., 2018). It has been reported that there is more than 350 feedstock that can be used to produce biodiesel, depending on various factors such as the oil content, yield per hectare, production cost and oil characteristics (Atabani et al., 2012). The production of biodiesel can be carried out on different scales. For large industrial scales (100–250 kiloton/yr), the processing technology has higher efficiencies at the expense of exorbitant capitalization and on-site construction. The raw material, typically vegetable oil used as a feedstock, is either imported or available from dedicated plantations. The transport of raw material from its source and the products to the end-user generally requires high transportation costs (Bernesson et al., 2004).

Biodiesel can also be produced on a small scale (< 15 kiloton/yr), which requires less complicated and expensive processing technologies and can be applied in rural areas. This may lower the capital cost and reduce the transportation cost of both the feedstock and product, as well as improve the overall efficiency of market delivery (Bernesson et al., 2004). Recently, there has been an ongoing parallel development whereby small-scale mobile biodiesel units are designed with local input and demand. Unlike the typical biodiesel production plants, the mobile biodiesel unit consists of a biodiesel production facility placed inside a standard cargo container and mounted on a truck, so that it can be transported to a region near the location of the raw materials materials (Bhachu et al., 2005; Teal and Sickels, 2005; Patten, 2005; Keady, 2008; Baum and Kelly, 2009; Oliveira et al., 2009; Brasil, 2011; Rummer, 2013). The biodiesel product is also intended for use by the concerned local community. In addition, the mobile biodiesel unit can reach small-scale oilseed producers scattered in remote locations, particularly in the less developed regions.

In this paper, we review existing concepts and units for the development of community-scale and mobile production of biodiesel. These include the main reactor technology for biodiesel production as well as the pre-treatment prior to conveyance to the reaction unit. The pre-treatment includes oil extraction from oilseeds by an oil-expeller unit, as well as quality control of the oil before it enters the reaction unit. This paper also discusses the post-treatment after the production of biodiesel. It includes the refining and purification of biodiesel to meet the product specification set by the biodiesel industry.

2. Conventional production of biodiesel

2.1. Raw materials

It has been reported that the cost of feedstock represents 75% of the overall production cost of biodiesel (Haas et al., 2006; Singh et al., 2007; Silitonga et al., 2011; Lin et al., 2011; Ragit et al., 2011; Atabani et al., 2012). Hence, the selection of suitable raw materials is very important in the production of biodiesel. The feedstock can generally be divided into four categories, viz.: (i) edible vegetable oil, (ii) non-edible vegetable oil, (iii) waste or recycled oil, and (iv) animal fats (Singh et al., 2007; Balat and Balat, 2010; Lin et al., 2011; Ragit et al., 2011; Balat, 2011). It has been reported that more than 95% of biodiesel are currently produced from edible oils such as rapeseed (84%), sunflower oil (13%), palm oil (1%), and soybean oil and others (2%). However, there are many issues about using edible oils for biodiesel production, such as the increase in vegetable oil price, deforestation, and the growing gap between demand and supply of such oils in many countries (Balat and Balat, 2010; Balat, 2011; Deng et al., 2011).

Non-edible oils such as rubber seed and Jatropha seed are considered as promising alternatives as raw materials for producing biodiesel as they can eliminate the competition for food. Waste cooking oil and animal fats can also be used as a feedstock to produce biodiesel. However, their amount may not be enough to satisfy the global energy demand (Atabani et al., 2012). In addition, the high amount of free fatty acid impedes the transesterification reaction and decreases the biodiesel yield (Atadashi et al., 2011; Oh et al., 2012; Abduh et al., 2016). Several alternatives of biodiesel feedstock are shown in Table 1. From the table, it can be observed that the oil productivity varies which depends on the oil content and yield of the oil isolation process. Microalgae have higher growth rates and productivity compared to other raw materials, but its commercialization is hindered by a high production cost.

Recent studies have shown that blending different oils can improve the property of the produced biodiesel (Sarin et al., 2007; Sarin et al., 2009; Jena et al., 2010). It has also been reported that genetically engineered plants such as poplar, switchgrass, miscanthus and big bluestem are a promising feedstock for biodiesel production (Janaun and Elis, 2010; Lin et al., 2011).

Table 1. Estimated oil content and productivity of different raw materials for producing biodiesel (Atabani et al., 2012)

Raw material	Oil content (%)	Oil productivity (L/ha/yr)
Rubber seed	40-50	80-120
Soybean	15-20	446
Sunflower seed	25-35	952
Rapeseed	38-46	1190
Castor bean	53	1413
Jatropha seed	50-60	1892
Karanja seed	27-39	225-2250
Peanut seed	45-55	2689
Palm	30-60	5950
Microalgae	30-70	58700-136900

2.2. Isolation of oil

Solvent extraction and mechanical pressing are most commonly used methods for the isolation of oil from oilseeds. Solvent extraction involves the use of organic solvents that have a high affinity with the oil contained within oilseeds. Typically, the seeds are pre-treated either by heating, cracking, or flaking that can facilitate cell wall rupture by distorting the cells (Becker, 1980). Hexane is one of the commonly used solvents for extraction of oil, but its applications are limited due to environmental concerns. Other alternatives are also used such as ethanol and supercritical carbon dioxide to isolate oil from the oilseeds (Johnson and Lusas, 1983).

Mechanical pressing such as screw and hydraulic presses are very prevalent to isolate oil from oilseeds with and oil recovery lies in the range of 50-80% (weight basis) which highly depends on the type of the oilseeds (Singh and Bargale, 2000). A screw press is carried out continuously in which the dehulled seeds are typically roasted, conveyed, and milled in-situ (Khan and Hanna, 1983). In contrast, a hydraulic press is operated in a batch mode of operation in which the dehulled seeds are typically crushed and heated at higher temperatures before being pressed at high pressure for a certain time until almost of the oil within the seeds have been recovered (Abduh, 2015; Abduh et al., 2016a).

A lot of studies have been carried out to optimize the process variables of mechanical pressing such as pressure, temperature, and the pressing time. The oil recovery can also be increased by several pre-treatment approaches such cracking, dehulling, conditioning, flaking, and drying to obtain smaller particle size and lower moisture content (Khan and Hanna, 1983). It has been reported that hydraulic pressing is considered an appropriate method to isolate oil from the oilseeds to be used as a raw material for community-scale stationary and mobile biodiesel plant particularly in developing countries. The initial cost of investment and operating cost are much lower than using the screw press and solvent extraction processes (Singh and Bargale, 2000).

2.3. Transesterification

A lot of studies have been conducted to obtain vegetable oil with properties that approximate the properties of diesel fuels. High viscosity and low volatility are the most important properties that must be addressed before vegetable oils can be used as an engine fuel (Ma and Hanna, 1999; Al-Zuhair, 2007). There are at least four methods to overcome or reduce the high viscosity of vegetable oils, viz.: (i) dilution, (ii) pyrolysis, (iii) micro-emulsion, and (iv) transesterification. Numerous studies have been carried out to investigate the potential application of dilution, pyrolysis, and micro-emulsion to develop clean and environmentally safe fuel (Schwab et al., 1987; Fukuda et al., 2001; Helwani et al., 2009). However, there are several issues that hinder further development. Dilution is a simple process, but a diluted oil often still has a high viscosity, poor volatility, and poor stability (Lin et al., 2011). Micro-emulsion and pyrolysis have been reported as costly methods which yield low-quality biodiesel as compared to transesterification (Forson et al., 2004).

Transesterification is considered as the established method and is widely used for biodiesel production due to its low cost and simplicity (Sharma and Singh, 2009; Jain and Sharma, 2010; Shahid and Jamal, 2011). During transesterification, triglycerides in oil or fats react with alcohol (normally methanol) in the presence of acid or base catalyst to produce fatty acid alkyl ester known as biodiesel and the by-product glycerol (Freedman et al., 1984; Vicente et al., 2004; Robles-Medina et al., 2009). Transesterification consists of three consecutive reversible reactions whereby triglycerides are converted stepwise into diglycerides, monoglycerides and glycerol.

Various studies have been conducted to gain insights into the process parameters that affect the transesterification reaction, viz.: (i) free fatty acid, moisture, and water content, (ii) type of alcohol and molar ratio employed, (iii) type and concentration of catalysts, (iv) reaction temperature and time, and (v) mode and speed of stirring (Bhachu et al., 2005; Teall and Sickels, 2005; Patten, 2005; Mullard, 2007; Keady, 2008; Baum and Kelly, 2009). Transesterification can be carried out by catalytic and non-catalytic methods. The non-catalytic method includes the use of supercritical methanol and higher alcohols such as ethanol, propanol, and butanol. Catalytic transesterification is normally employed to produce biodiesel because alcohol is barely soluble in oil or fats. The addition of a catalyst enhances the solubility of alcohol and increases the reaction rate. The catalyst can either be homogenous, such as alkaline and acid catalysts, or heterogeneous, such as enzymes and alkaline earth metals (Chouhan and Sarma, 2011; Atabani et al., 2012). The typical operating conditions for different transesterification methods are shown in Table 2.

From Table 2, it can be observed that a higher yield (98%) can be obtained in a short time (2–4 min) by the supercritical method as compared to the alkali- and acid-catalytic method. Since no catalyst is used, the purification of biodiesel and recovery of glycerol are much easier and environmental-friendly (Demirbas and Demirbas, 2007; Canakci and Sanli, 2008; Karmakar et al., 2010). However, this method requires large investment for the reactor and high operating cost due to high temperature and pressure as well as high methanol consumption.

The alkali- and acid-catalytic method requires only mild temperature and ambient pressure. Alkaline catalysts such as sodium and potassium hydroxide are the most widely used catalyst for biodiesel production. Various studies have reported that alkaline catalysts are the fastest and most economical catalysts. It has been reported that an alkaline catalyst speeds up reactions approximately 4000 times faster than the same amount of an acid catalyst (Atabani et al., 2012). Employing alkaline catalysts can lead to high purity and yield of biodiesel (96%) in a relatively short time (30–60 min). However, the use of alkaline catalysts requires the free fatty acid (FFA) level of the oil to be below the desired limit (between 0.5 and 3%). Formation of soap and reduction in yield is inevitable at FFA levels above 3% (Demirbaş, 2003; Meher et al., 2006; Canakci and Sanli, 2008; Sharma et al., 2008; Karmakar et al., 2010; Singh and Singh, 2010; Janaun and Ellis, 2010; Deng et al., 2011).

Acid catalysts such as sulfuric and hydrochloric acids are more tolerant than alkaline catalysts of vegetable oil with a high FFA and water content. Hence, acid catalysts are typically used to reduce the FFA level below 3% before transesterification with alkaline catalysts. It has been reported that a high yield (90%) can be obtained via acid-catalysed reaction after 3–48 h. One of the important issues concerning alkali- and acid-catalytic methods is the purification of biodiesel and glycerol recovery. A large amount of water is typically used for biodiesel produced using alkali- and acid-catalytic methods to remove the salt produced from the neutralization process and the residual acid or base catalyst (Demirbaş, 2003; Meher et al., 2006; Canakci and Sanli, 2008; Sharma et al., 2008; Karmakar et al., 2010; Singh and Singh, 2010; Janaun and Ellis, 2010; Deng et al., 2011).

2.4. Standard specification for biodiesel

There are two major international standards for biodiesel, viz.: (i) the American Standard Specifications for Biodiesel Fuel (B100) Blend Stock for Distillate Fuel (ASTM D6751) and (ii) the European Standard for Biodiesel (EN 14214). The summary for the EN 14214 specification is given in Table 3. The specifications given by the ASTM D6751 standard (not shown) are very similar to the EN 14214 standard. The major differences lie in their intended application and test methods. The former is for biodiesel to be used as automotive fuel for diesel engines, whereas the latter is for biodiesel (100%) to be used use as a blend component with diesel fuels (Cao et al., 2007; Atabani et al., 2012).

3. Small-scale stationary production of biodiesel

3.1. Case 1: Asperhofen Oko-Diesel-projekt, Austria

The Asperhofen Oko-Diesel-project is an example of a farmer co-operative biodiesel production from canola and sunflowers. The co-operative consists of 290 members that contract 430 ha of land for canola and sunflower plantations, with an average yield of 3 ton/ha, which is approximately 1300 ton of oilseeds (Bender, 1999). Located near Vienna, Austria, the annual production of the community facility in 1992 was 0.4 ton of biodiesel (Bender, 1999), but this increased to 1.5 kiloton in 2007(Martin, 2007). It has been reported that 1000 L of biodiesel can be produced from 3 ton of oilseeds. The biodiesel produced is of high quality and satisfies the minimum European standards for biodiesel. The produced biodiesel is used as fuel by the farmers, whereas the by-product glycerol, which contains potassium hydroxide (the catalyst), is spread as fertilizer on the plantation area with potassium-deficient soil (Bender, 1999).

Table 2. Comparison between catalytic and non-catalytic method for the transesterification of vegetable oil with methanol (Sharma and Singh, 2009; Atabani et al., 2012)

	Alkali catalytic method	Acid catalytic method	Supercritical method
Temperature (°C)	60	60	245-295
Pressure (MPa)	ambient	ambient	10-25
Catalyst conc. (wt%)	0.5-1	0.25-2	no catalyst
Time (min)	30-60	180-2900	2-4
Methanol: oil ratio	6:1	6:1	32:1
Yield (%)	96	90	98

3.2. Case 2: Biodiesel production from non-edible oils in India

Kalbande et al. (2008) developed a biodiesel processor to produce biodiesel from non-edible oil extracted from Jatropha and Karanja from the local area. The biodiesel processor mainly consists of: (i) a transesterification vessel, (ii) a sodium or potassium methoxide mixing pot, (iii) a stirring arrangement, (iv) a settling arrangement, and (v) a bubble wash arrangement. Jatropha fruits were decorticated by a groundnut decorticator, whereas the Karanja fruits were decorticated manually, and the seeds were separated. The oil was extracted from the seeds using a mechanical screw-type expeller and heated up to 100 °C to remove moisture. The oil was then cooled down to 60 °C before being reacted with methanol (20%) and NaOH/KOH (0.5-1%w) in the transesterification vessel. The mixture was mixed vigorously with a mechanical stirrer at 700 rpm for 1.5h, and a 90% yield was obtained. The reaction mixture was poured into a separating funnel and allowed to separate and settle overnight by gravity settling (for approximately 8 h). The glycerol was drained off, and the biodiesel was bubble-washed with water for 8–24 h to bring down the pH value of biodiesel to 7. The kinematic viscosity and specific gravity of the produced biodiesel were found to satisfy the Bureau of Indian Standard Specifications (Kalbande et al., 2008).

The produced biodiesel was blended with diesel and tested for power generation in a 7.5-kVa diesel engine generator set. The overall efficiency of the generator set when running on the Jatropha-biodiesel blended fuel was found to be less than when the generator was diesel-fueled. Nevertheless, the biodiesel processor can be used to produce quality biodiesel from edible and non-edible vegetable oils via alkali-catalyzed transesterification. The processor is deemed suitable for community-scale production of biodiesel and can produce about 0.02 ton of biodiesel annually. The processor can also be integrated with rural energy systems for domestic and small-scale production of biodiesel (Kalbande et al., 2008).

3.3. Case 3: Biodiesel production in a small community in Thailand

Phalakornkule et al. (2009) reported community-scale production of biodiesel from animal waste in a remote location in Thailand. The project was carried out with community participation and financial support from the government. The system consists of a mixing tank, a reactor and two washing tanks. The animal waste, particularly pork fat, was collected from local markets. The fat was initially filtered by cloth to remove bits of food residues. The filtered oil was mixed with 28 %v methanol and 0.4%w/v NaOH in a stirred tank reactor for transesterification. The mixture was stirred at 290 rpm at 65°C. After 1.5-h reaction time, a yield of 89% was obtained, with an estimated production capacity of 0.03 ton/yr (Phalakornkule et al., 2009).

Table 3. European standard for biodiesel (Atabani et al., 2012)

Property	Method	DIN EN 14214		
		Min.	Max.	Unit
Ester content	EN 14103	96.5	-	% (m/m)
Density (15°C)	EN ISO 12185	860	900	kg/m^3
Viscosity (40°C)	EN ISO 3104	3.5	5	mm^2/s
Flashpoint	EN ISO 3679	120	-	°C
Sulphur content	EN ISO 20884	-	10	mg/kg
Cetane number	EN ISO 5165	51	-	-
Sulfated ash content	ISO 3987	-	0.02	% (m/m)
Water content	EN ISO 12937	-	500	mg/kg
Total contamination	EN 12662	-	24	mg/kg
Copper band corrosion (3h, 50°C)	EN ISO 2160	Class 1	Class 1	rating
Oxidation stability (110°C)	EN 14112	6	-	h
Acid value	EN 14104	-	0.5	mg KOH/g
Iodine value	EN 14111	-	120	g I_2/100 g
Linolenic acid methyl ester	EN 14103	-	0.2	% (m/m)
Methanol content	EN 14110	-	0.2	% (m/m)
Monoglyceride content	EN 14105	-	0.8	% (m/m)
Diglyceride content	EN 14105	-	0.2	% (m/m)
Triglyceride content	EN 14105	-	0.2	% (m/m)
Free glycerol	EN 14105/6	-	0.02	% (m/m)
Total glycerol	EN 14105	-	0.25	% (m/m)
Phosphorus content	EN 14107	-	4	mg/kg
Metals I (Na+K)	EN 14108	-	5	mg/kg
Metals I (Ca+Mg)	EN 14538	-	5	mg/kg

The product was allowed to settle in the first washing tank for 2 h to produce two distinct liquid phases, with a crude ester phase at the top and a glycerol phase at the bottom. The glycerol phase was drained through the bottom valve, and the crude ester phase was washed three times with the same volume of water as the biodiesel product. After each washing step, the air was aerated from bottom to top for 10 min at 40 °C and water was allowed to settle and drain out. Finally, the product was heated to 100 °C for 10 min (Phalakornkule et al., 2009).

Relevant properties of the purified biodiesel such as flash point, ash level, free glycerol and several others were determined, all satisfying the Thai biodiesel standards for agricultural engines. This indicates that the extent of reaction of the purification steps was satisfactory, and the biodiesel could be used directly in agricultural engines without reported operational problems (Phalakornkule et al., 2009).

3.4. Case 4: Small-scale biodiesel production technology in Cameroon

Sarantopoulos et al. (2009) reported community-scale production of adequate and affordable biodiesel from locally sourced raw materials like palm oil in rural areas in Cameroon. The biodiesel would be used exclusively by the local population to cover their energy needs. The production system consists of a pre-treatment unit, a batch reactor, and a washing unit.

The crude palm oil used as feedstock was obtained from a local market. The FFA level was determined by titration, with an initial value of 8.13%w obtained, which was far above the 0.5% level limit for satisfactory transesterification using alkaline catalysts. Therefore, the FFAs were first converted to esters in a pre-treatment process, using an acid catalyst to reduce the FFA content to below 0.5%. This step was then followed by a base-catalysed transesterification step to produce biodiesel. It was determined that the optimum quantity of acid and alcohol for the pre-treatment stage was 0.5% H2SO4, catalyst-to-oil ratio, a 6:1 molar ratio of methanol to oil, and a reaction time of 45 min (Sarantopoulos et al., 2009).

The transesterification reaction was carried out in a batch reactor with a 6:1 molar ratio of methanol to oil and a 1%w/v NaOH as an alkaline catalyst. It involved the mixing of the pre-treated palm oil with methoxide and heating at 55°C while stirring for 1 h. The mixture was allowed to settle under gravity. The glycerol was separated, and the esters were washed with water for catalyst recovery. The biodiesel was dried by exposure to the atmosphere for 12 h (Sarantopoulos et al., 2009).

Sarantopoulos et al. (2009) stated that the community-based installation included a batch reactor with a capacity to produce 180 l of biodiesel per batch and a maximum of 4 batches daily. This implies that the production can be easily regulated to meet the needs of the community and adapted to any constraint due to feedstock availability. With this installation, 0.14 ton/yr of biodiesel could be produced locally.

4. Small-scale mobile production of biodiesel

4.1. Batch system

4.1.1. Case 1: Standard mobile biodiesel unit

Oliveira et al. (2009) and Brasil (2011) constructed a mobile biodiesel production unit (Fig. 1) comprising a stirred reactor, a decanter, and a distillation unit for biodiesel purification. The unit is typically mounted on a truck and conveyed from one oil-producing farm to another for the oil into biodiesel. The produced biodiesel is kept by the oil producers for their own use. The constructed unit is fully operational and has an estimated production capacity of a 0.19 ton/yr.

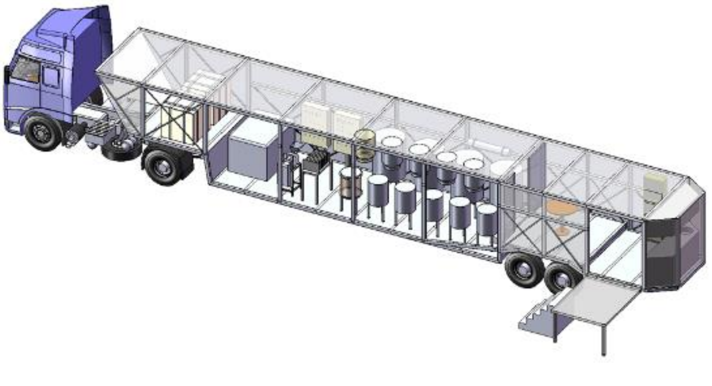

Fig. 1. Mobil biodiesel production unit designed by Oliveira et al. (2009)

The unit is equipped with a small lab facility in the rear end of the unit, where the quality of the biodiesel produced can be quickly evaluated by analytical techniques such as near-infrared spectroscopy. Oliveira et al. (2009) mentioned that the benefits of installing and operating small-scale biodiesel production units are: (i) low-capital investments, (ii) reduction in the use of fossil fuels since they are replaced with local renewable energy sources, (iii) electricity needs can be supplied by a generator that runs on biodiesel, and (iv) a unit can be operated by inexperienced users without relying on highly qualified technicians. The biodiesel produced by the mobile unit had an ester conversion of 90-97% and with a purity of 98-99%.

Baum and Kelly (2009) also invented a mobile biodiesel manufacturing plant using vegetable oil and methanol as input. The mobile plant is made up of: (i) an oil expeller for mulching raw feedstock to extract oil from the feedstock, (ii) a mixer/reaction vessel in which the raw oil is mixed with a catalyst material, and (iii) at least one separation unit to separate methyl ester from other products. These units are incorporated in a self-contained shipping container containing a power generation means. The mobile unit has an estimated production capacity of 0.35–0.47 ton/yr.

The mobile plant also includes a power generation means, i.e., a diesel generating set or a diesel power pack. Typically, the power generation means produces hydraulic power or electricity, which then powers the other process components. The power generation means is preferably fully enclosed within a separate compartment in the container. The invention claimed that it can take most oil-bearing crops and produces biodiesel that satisfies the international specification which can go straight into the tank of any diesel engine without any modification (Baum and Kelly, 2009).

Bhachu et al. (2005) designed a portable biodiesel plant capable of processing different grades of waste cooking oil (WCO) to produce biodiesel. The biodiesel plant is separated into five sections, viz.: (i) reactant preparation, (ii) pre-treatment, (iii) transesterification, (iv) purification, (v) solvent recovery and product storage. These sections are incorporated into a standard truck-trailer 8-ft wide by 40-ft long by 9.5-ft tall. The plant can be conveyed to the storage location of the feedstock, particularly small community areas, where it will process the feedstock into biodiesel. The biodiesel is then stored locally to facilitate redistribution in the community. The estimated capacity of the mobile unit is 0.14 ton/yr.

4.1.2. Case 2: Integrated rendering facility and biodiesel refinery

Mullard (2007) patented a mobile animal waste recycling and biodiesel production system. The system is made up of an integrated rendering facility and biodiesel refinery contained in a 70 m^3 refrigerated shipping container attached to a trailer. The unit is fully transportable, allowing it to travel to different locations to collect animal waste and process it into biodiesel. The rendering facility takes animal waste as input and separates the oils and fats, which are then used as an input for the biodiesel refinery. The produced biodiesel is used as fuel to power both the rendering facility and the biodiesel refinery and may also be used to fuel the semi-trailer vehicle.

Typically, the animal waste was crushed into pieces of around 5 mm, before being liquefied with suitable enzymes at 40–55 °C. The liquefied material was then mechanically separated by a centrifuge into the water, fats/oil, and fine solid phases. The oil was then filtered using a removable strainer and cloth with a suitable mesh size to remove any contaminants. The filtered oil was transferred to a cylindrical propane reactor. The housing was equipped with a zeolite ozone bio-filter to absorb noxious odours that might have persisted even after the recycling of the organic waste (Mullard, 2007).

The oil in the reactor was heated to approximately 80–90 °C. After the pressure in the reactor was reduced to 0.5 psi, a vacuum unit was used to remove water from the oil. The pressure was held constant until no more water collected in the liquid trap. The oil was allowed to cool to about 50 °C and then mixed with methoxide (molar ratio of methanol to oil was not given). The mixture was heated using an immersion heater and circulated for about an hour, and then allowed to settle. After approximately 12 h, glycerol was drained from the bottom of the reactor. The remaining oil in the reactor was reheated to about 50°C and mixed again with methoxide (molar ratio of methanol to oil was not given). The mixture was heated using an immersion heater and circulated for about an hour, and then allowed to settle. After approximately 12 h, the newly formed glycerol was drained from the bottom of the reactor. The biodiesel was conveyed to a washing tank for bubble washing for at least 12 h and then allowed to settle. After that, the remaining water left in the tank was drained. The biodiesel was passed through a filter to remove any impurities (Mullard, 2007).

4.2. Continuous system

4.2.1. Case 1: Continuous nozzle jet separation reactor

Teall and Sickels (2005) patented systems and methods for modular production of biodiesel from new or recycled oil. The systems consist of a mixing unit, a reactor unit, a separation unit, a distillation unit, and a filtering unit. These components are incorporated into a single platform, such as a skid amount, or housing, such as a standard shipping container that can easily be shipped to a remote city by a truck. The mobile unit has an estimated production capacity of 3.4–10.2 ton/yr (Teall and Sickels, 2005).

The modular production unit had additionally fixed and/or relocatable components to serve as a biodiesel processing plant. The unit was also equipped with a processing system for raw materials, which included a hot box for filtration and separation of waste and particulate matter from recycled triglyceride-starting materials. The hot box roller barrel was also used to introduce heat to the raw or recycled oil feedstock. The processing of the finished biodiesel product involved filtering and separation functionality to remove water impurities from the finished biodiesel product. This modular production can produce relatively large quantities of biodiesel with a production capacity of about 3.4–10.2 ton/yr (Teall and Sickels, 2005).

4.2.2. Case 2: Computer-controlled separator filtration and catalysing vessel

Patten (2005) patented a computer-controlled and automated mobile production of biodiesel from waste cooking oil (WCO). WCO was typically collected at dispersed locations and sent to large refineries at centralized locations for processing and conversion to biodiesel. However, such systems were inherently less efficient than mobile processing facilities. Patten invented a method and apparatus for reclaiming spent oil using a strainer/separator filtration process and catalyst media, contained in a mobile enclosure such as a truck.

The mobile refinery was used at various collection sites for WCO cleaning and conversion into biodiesel. Upon collection, the oil was passed through a strainer/separator filtration process to remove particulate contaminants and water. The oil was then heated and conveyed to a catalysing vessel, which was able to titrate a proper amount of catalyst; the vessel also monitored and removed the accumulated glycerol. The produced biodiesel was conveyed to a washing vessel to remove any remaining impurities while also monitoring and balancing the pH of the biodiesel. After refining, the biodiesel was transported to a delivery tank (Patten, 2005).

Upon delivery, the biodiesel was filtered again, and the amount and specifications of the biodiesel were logged by a computer. In the case of failure, the driver was immediately noticed by the computer. The mobile refinery was then directed to the nearest service centre. This system allows for continuous online monitoring and may be checked via the internet. The advantage of this centralized regeneration is that the waste produced by filtration can be concentrated in a single treatment and disposal facility (Patten, 2005).

4.2.3. Case 2: Computer-controlled separator filtration and catalysing vessel

Keady (2008) patented a mobile processing plant that includes devices and methods for the automation of mobile biodiesel production from a feedstock oil. Typically, the oil was pumped into the mobile processing plant. A sample was taken from the oil by an automatic titration system to determine the FFA content of the oil and the catalyst level for transesterification. The catalyst was then added to methanol and mixed with the oil in a porous mixing device to produce biodiesel. The oil passed through an interface containing sub-tubes which delivered the oil through the interface into the porous mixing block (Keady, 2008).

The pressure of the fluid saturating the porous block can be varied to minimize oil absorption by the porous block while ensuring that the fluid in the porous block lining the tube surface enters the oil stream. The unreacted oil and glycerol can be separated from the biodiesel using a centrifugal separator. It consists of a mixing region, a spin separating region and a flow separating region, with optional recycling loops that feedback into the system. The separated biodiesel can be washed with water in an additional cleansing unit comprising of several chambers connected by tubes (Keady, 2008).

4.2.4. Case 4: Homogenization and separator reactor

Rummer (2013) patented a compact biodiesel production system. It comprises of: (i) an oil expeller for crude oil extraction from the raw feedstock, (ii) a degumming process reactor for the removal of at least one of the gums, metal compounds and other impurities from the crude oil, (iii) a reactor and separator unit or vessel for transesterification of the crude oil to biodiesel and for glycerol removal from the methyl esters, (iv) a flash tank for methanol recovery, (v) a mixer and blending tank for the completion of the neutralization reaction, (vi) an ion-exchange purification vessel for the removal of residual glycerol, soaps, free fatty acids, unreacted oil, waxes, salts, water and methanol, (vii) a water separator, and (viii) a polishing filter to remove any remaining particulate impurities before the biodiesel exits the system into a collection tank. These units are incorporated in a standard 20-ft container for ease of relocatability (Rummer, 2013).

This system allows continuous transesterification of oil, with methanol and NaOH as a catalyst, to produce biodiesel using a homogenization and separator reactor. The reactor consists of several chambers. In the first chamber of the reactor, oil is mixed with a stoichiometric amount of methanol-to-oil ratio and in the presence of a 2–10%w NaOH catalyst. In the second chamber, a coalescer is added to enhance the separation of glycerol from the produced crude biodiesel. A drainage outlet is available at the bottom of the chamber for the removal of glycerol and other substances which are heavier than the crude biodiesel. In the third chamber, the crude biodiesel is reacted for a second time with about 8–15% of the amount of the biodiesel mixture containing a 2–10%w NaOH catalyst. In the fourth chamber, residual glycerol is separated from the enriched crude biodiesel. The temperature of the process should be maintained at about 60 °C, and the pressure set slightly above the ambient pressure (Rummer, 2013).

4.3. Comparison between community-scale and mobile production of biodiesel

An overview of existing community-scale and mobile biodiesel production concepts and units are shown in Table 4. From the table, it can be observed that most of the feedstock are vegetable oil, except in some cases where non-edible oil and animal fats are used as input. Methanol is used in almost all cases except for the mobile biodiesel refinery invented by Patten (2005) and the mobile biodiesel concept proposed by Abduh et al. (2013).

Pre-treatment of the feedstock includes pre-heating, filtration, degumming, enzymatic treatment, and esterification. For an input with a high FFA content, esterification is applied to reduce the FFA below 3% (Bhachu, 2005; Sarantopoulos et al., 2009). Automatic titration can also be applied to reduce the high FFA, as patented by Keady (2008). In the case of animal waste, enzymatic treatment is applied to liquefy the waste before transesterification. Filtration is typically applied to remove any contaminants that may be present in the oil (Patten, 2005; Baum and Kelly, 2009; Sarantopoulos et al. 2009; Brasil, 2011),

From Table 4, it can be seen that transesterification of triglycerides is performed either in batch or in a continuous setup. For batch transesterification, a stirred/mixing or cone-shaped tank is normally used. The temperature of the reactor is normally maintained at 50–65 °C, except for the mobile manufacturing plant invented by Baum and Kelly (2009) which operates at 90 °C. A homogenous catalyst (NaOH/KOH/CH_3ONa) is normally used, and the reaction is performed for at least 1–1.5 h.

Transesterification of oil or fat with alcohol produces a mixture of biodiesel and, glycerol as well as free fatty acid, di- and monoglycerides. In addition, unreacted alcohol, and catalyst also presence in the mixture that need to be removed. Refining of the biodiesel mixture is required to make that the biodiesel meets the international specifications (van Gerpen et al., 2004). Washing with water is commonly used for the refining process. Various studies have been carried out to increase the efficiency of the washing process including washing with distilled water (50-80 °C), dilution of the biodiesel mixture in petroleum ether followed by washing with water, neutralization with H_2SO_4 as well as two sequential steps of biodiesel washing using NaCl and $NaHCO_3$ in water (Karaosmanoglu et al., 1999; Haas et al., 2003).

In addition, refining of biodiesel by membrane separation and continuous centrifugal contactor separator has also been developed to reduce water usage (Abduh, 2015b; Wang et al., 2009; Gomes et al., 2013). Based on the existing studies, washing with water at 50 °C is considered the most suitable method community-scale stationary and mobile biodiesel plant (Karaosmanoglu et al., 1999). After washing, the biodiesel often has a relatively high-water content due to small amounts of dissolved water and the presence of fine residual water droplets indicated by a slight cloudy exterior of the washed biodiesel. The high-water content in the biodiesel must be reduced to avoid microbial growth that can promotes hydrolysis of esters to form free fatty acids (Monteiro et al., 2008). There are various techniques to reduce the water content of crude biodiesel such as drying with hot air using a bubble column, vacuum driers and falling film evaporators (van Gerpen et al., 2004). However, spraying biodiesel with hot air is the most used method to reduce the water content of washed biodiesel in community-scale stationary and mobile biodiesel plant.

For a continuous setup, different types of reactor configurations can be used, viz. continuous fixed bed (Monteiro et al., 2008), continuous centrifugal contactor separator (Tremblay et al., 2008; McNeff et al., 2008; Abduh et al., 2015; Abduh et al., 2016), automated catalysing vessel (Patten, 2005), homogenization and separator chamber (Rummer, 2013), continuous mixer (https://biocube.com), and cone-shaped tank with nozzle jet (Teall and Sickels, 2005). Alkali-catalytic transesterification is observed for all the continuous setup, except for the study carried out by McNeff et al. (2008), which used supercritical methanol at high temperature and pressure. The advantage of the so-called Mcgyan process (Fig. 2) is that the conversion rate is within seconds, and it can be used for a variety of feedstock. This process does not require a catalyst and does not produce glycerol as a major by-product. Hence, the post-treatment stage of purifying the biodiesel is relatively easy as compared to other systems that require the separation of the remnants of the catalyst and the by-product glycerol.

5. Future perspective for mobile production of biodiesel

5.1. Continuous centrifugal contactor separator

A continuous centrifugal contactor separator (CCCS) is a device that integrates mixing, reaction, and separation of liquid-liquid systems; thus, it demonstrates process intensification in an interesting way (Kraai et al., 2008; Kraai et al., 2009; Abduh et al., 2015; Abduh et al., 2016). The CCCS consists of a hollow, rotating centrifuge in a static housing. The immiscible liquids (pure plant oil and methanol) enter the device through the annular zone between the static housing and the rotating centrifuge, where they are intensely mixed. The mixture is then transferred into the hollow centrifuge through a hole in the bottom of the centrifuge. Here, the product phases (biodiesel and glycerol) are separated by centrifugal forces (up to 900 g), ensuring excellent separation of the fluids.

Abduh et al. (2015) has provided proof of the principle of the synthesis and subsequent refining of FAME in a cascade of two CCCS devices. This system has an estimated production capacity of 6.6 ton/yr. The relevant properties of the refined FAME obtained using this technology were determined and shown to meet the ASTM specifications. Hence, this technology has particularly great potential to be applied in small mobile biodiesel units due to the compact size, robustness, flexibility in operation and high volumetric productivity of the CCCS devices.

5.2. Continuous fixed bed with supercritical methanol

McNeff et al. (2008) developed a novel continuous fixed bed reactor to produce biodiesel using a metal oxide-based catalyst. It has been shown that porous metal oxides (e.g., zirconia, titania, and alumina) with different surface treatments (acids, base and unmodified) that are amenable to a fixed bed reactor are capable of continuous rapid esterification and transesterification simultaneously under high pressure (2500 psi) and elevated temperature (300–450 °C). The so-called Mcygan process can be used with inexpensive feedstock (animal fats, waste cooking oils, acidulated soap stock) that has a high FFA content and contains different alcohol (methanol, n-propanol, n-butanol).

The process was tested for 25 different lipid feedstocks with an acid number ranging from 0.04–88 mg KOH/g (molar ratio of methanol to oil was varied from 32.7 to 73.7). The system reached a steady-state after approximately 30 minutes, with an 86–95% conversion of FAME achieved for the 25 kinds of lipid feedstock for residence times of the reactants between 5.4 and 56.9 s. The process was scaled up to a pilot plant scale by increasing the reactor volumes by 49 times to achieve an annual production level of more than 40000 gallons/year with a contact time of 56.9 s. The catalyst used was 80-µm, 60-Å unmodified titania (UMT). The system was run for more than 115 h of continuous operation using refined soybean oil and methanol as the feedstock with a molar ratio of 32.7 and a reactor temperature of 360°C. The average percent conversion was 87.5%. The system has an estimated production capacity of 0.14 ton/yr.

5.3. Reactive distillation column

Reactive distillation (RD) is a hybrid process that combines chemical reaction and product separations in a single fractional distillation apparatus (da Silva et al., 2010). Simultaneous separation of reactant and product shifts the equilibrium towards the product side, hence increasing the conversion and selectivity (Estrada-Villagrana et al., 2006; Tuchlenski et al., 2011; Kiss et al., 2012). Various studies have been undertaken to explore the production of biodiesel using an RD system (Sotoft et al., 2010; Mueanmas et al., 2010). He et al. (2006) developed a novel reactive using RD column for biodiesel production from canola oil and methanol. The feed was passed through an in-line static mixer, which served as a pre-reactor, and entered the RD column near the top. The reactant mixture then flowed down across the plate. Methanol vapour obtained from the product mixture in the reboiler flowed upward to provide a uniform mixing in the column. The product mixture exited the reboiler to a glycerol-biodiesel separator. Here, the glycerol and biodiesel were continuously separated by gravitational force.

5.4. Membrane reactor

The study of two-phase membrane reactor technology for simultaneous transesterification and separation to produce high-quality biodiesel was studied by various researchers (Dubé et al., 2007; Cao et al., 2008a; Cao et al., 2008b; Badenes et al., 2011; Baroutian et al., 2011). This reactor allows reaction and separation to occur in one chamber and ensures that reversible transesterification favors the formation of biodiesel by removing the products simultaneously from the reactants, hence increasing the reaction rate and biodiesel yield (Armor et al., 1998; Sirkar et al., 1999). The application of a continuous membrane reactor using various lipid feedstock with different FFA contents, such as soybean oil, canola oil, hydrogenated palm oil/palm oil blend, yellow grease, and brown grease, to produce biodiesel was studied by Cao et al. (2008a). Successful transesterification was observed for all the investigated feedstock and the produced biodiesel satisfied the ASTM D6751 standard.

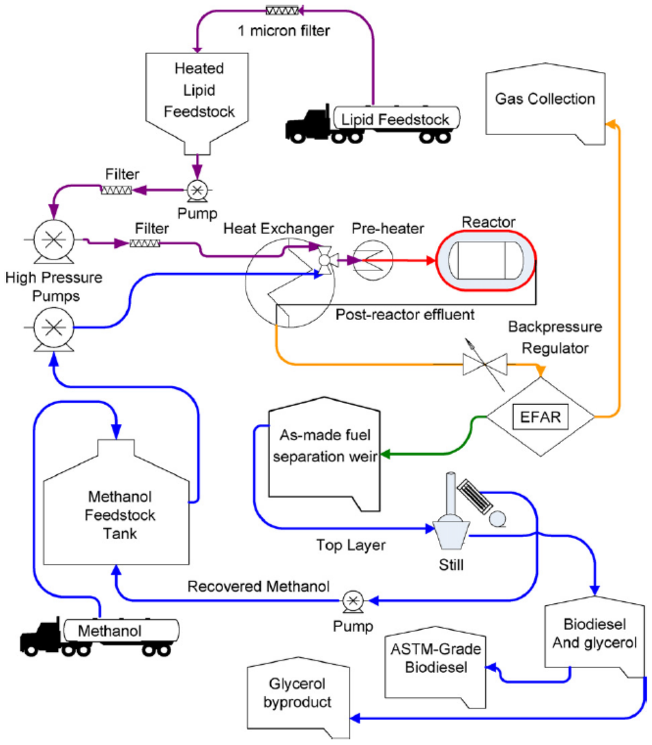

Fig 2. Process flow diagram of a biodiesel factory using the Mcgyan process proposed by McNeff et al. (2008)

Table 4. Existing community scale and mobile biodiesel production concepts and unit

Feedstock	Catalyst	Pre-treatment	Reactor	Post-treatment	Capacity (ton/yr)	Ref.
WCO (6:1 molar ratio methanol: oil)	0.5%w NaOH	Esterification (H_2SO_4), filter, heating (65 °C)	Stirred tank (65 °C)	Hydrocyclone, distillation, neutralization, extraction	0.14	Bhachu et al. (2005)
Jatropha/karanj (20 % methanol)	0.5-1%w NaOH/ KOH	Heating (100 °C)	Stirred tank (60 °C, 700 rpm, 90% yield after 1.5 h)	Settling (8 h), bubble washing (8-24 h)	0.02[a]	Kalbande et al. (2008)
Pork fat (28 %v methanol to fat)	0.4%w/v NaOH	Filtration	Stirred tank (65 °C, 290 rpm, 89 % yield after 1.5 h)	Settling (2 h), water washing, heating (100 °C, 10 min)	0.03	Phalakornkule et al. (2009)
Soybean/WCO (6:1 molar ratio ethanol: oil)	1%w CH_3ONa	Filtration	Stirred tank (55 °C, 90-97% yield after 1-1.5 h)	Settling (1 h), water washing, distillation	0.19	Oliveira et al. (2009)
Vegetable oil (methanol)	NaOH/KOH	Settling, Heating (45 °C)	Mixing tank (90 °C)	Settling, evaporation, Filtration	0.35-0.47	Baum and Kelly (2009)
Palm oil (6:1 molar ratio methanol: oil)	1 %w/v NaOH	Esterification (H_2SO_4)	Cone-shaped tank (55 °C, 1h)	Settling, water washing, drying (12 h)	0.14	Sarantopoulos et al. (2009)
Animal waste (methanol)	Methoxide	Grinding, enzymatic treatment, heating, centrifugation	Cylindrical tank (two-steps transesterification, 0.5 psi, 50 °C, 12 h)	Separation, bubble washing (12), filtration	n/a	Mullard (2007)
Soybean oil (32.7 molar ratio methanol: oil)	TiO_2 (80 µm, 60 Å)	Filtration Heating (360 °C)	Continuous fixed bed (360 C, 2500 psi, 87.5% yield after 56.9 s)	E-FAR system (alumina packed bed)	0.14	McNeff et al. (2008)
Sunflower (6:1 molar ratio methanol: oil)	1%w NaOMe	Pre-heat to 60 °C	Continuous centrifugal contactor separator	n/a	5.6	Kraai et al. (2009)
Jatropha (6:1 molar ratio ethanol: oil)	1%w NaOEt	Pre-heat to 60 °C	Continuous centrifugal contactor separator	n/a	10.1	Abduh et al. (2013)
Sunflower (6:1 molar ratio methanol: oil)	1%w NaOMe	Pre-heat to 60 °C	Continuous centrifugal contactor separator	Water washing, drying	6.6	Abduh et al. (2015)
New/recycled oil (ethanol)	NaOH	Hot box roller barrel	Cone-shaped tank with nozzle jet (65 °C)	Centrifugation, distillation	3.4-10.2	Teall and Sickels (2005)
Vegetable oil (methanol/ethanol)	NaOH/KOH	Vacuum filtration, heating	Automated catalysing Vessel	Separation, washing, filtration	n/a	Patten (2005)
Vegetable oil, (methanol)	NaOH	Automated titration	Porous mixing device	Spin separator	n/a	Keady (2008)
Vegetable oil, (methanol)	2-10%w NaOH	Degumming	Homogenisation and separator chamber (55 °C)	Settling, neutralization, evaporation, filtration	n/a	Rummer (2013)

a) estimated assuming 330 d/yr

5.5. Ultrasonic cavitation reactor

Recently, the application of ultrasound in biodiesel production has gained numerous attentions. The use of ultrasound provides the mechanical energy for mixing and the required energy of activation for initiating transesterification. In a typical process, when a reaction mixture is irradiated with ultrasound, radicals are produced during a transient implosive collapse of bubbles that accelerate the chemical reaction in the bulk medium. The radial motion of the bubbles generates micro-turbulence and brings about intense mixing of the immiscible reactant. Hence, the interfacial region between oil and alcohol increases intensively, which results in faster reaction kinetics, shorter reaction time and higher biodiesel yield (Stavarache et al., 2003; Colucci et al., 2005; Stavarache et al., 2006; Armenta et al., 2007; Deshmane et al., 2008; Kalva et al., 2009; Hanh et al., 2009).

Transesterification of vegetable oil using low-frequency ultrasound (28–40 kHz) was investigated by Stavarache et al. (2006), who reported an excellent yield of 98% for the 28-kHz ultrasound. At a frequency of 40 kHz, the reaction time reduced significantly (Stavarache et al., 2006). In another study, it was hypothesized that when low ultrasonic waves (20 kHz) are applied to a two-phase reaction system, the mass transfer and kinetic rate would be enhanced by an increase in the interfacial area and activity of the microscopic and macroscopic bubbles formed (Colucci et al., 2005).

5.6. Alcohol recovery

Conventional biodiesel production involves transesterification of plant oil with methanol in the presence of a suitable catalyst (Bender, 1999; Bernesson et al., 2004; Oliveira et al., 2009; Brasil, 2011). Typically, a 6:1 methanol-to-oil molar ratio is used for alkali- and acid-catalytic methods, whereas for the supercritical method, this ratio can be up to 32:1. Excess alcohol is commonly added to shift the equilibrium to the product site. In addition, the excess quantity of alcohol hastens the conversion of triglycerides into biodiesel (Schwab et al., 1987; Fukuda et al., 2001; Forson et al., 2004; Helwani et al., 2009; Al-Zuhair, 2007). The excess alcohol is often distributed in the mixture of biodiesel and glycerol phases. According to the biodiesel specifications (Table 3), the permissible level of methanol in biodiesel is 0.2 %w/w. The excess methanol in the by-product glycerol should be removed to improve the commercial value of the glycerol. Hence, the excess alcohol must be removed from both the biodiesel and glycerol phases. Typically, alcohol recovery involves using a distillation column. It is estimated that 60% of the excess methanol could be recovered, and the recycled alcohol can be reused, thereby reducing the amount of fresh methanol needed for subsequent transesterification reactions and consequently lowering the operational cost (Abduh et al., 2015).

Studies on alcohol recovery in biodiesel production have been previously carried out. Mythili et al. (2014) investigated methanol recovery using a methanol vaporization reactor during biodiesel production from Jatropha oil. They reported that 2.3% of methanol was recovered from the biodiesel phase, whereas 27.4% of methanol was recovered from the glycerol phase. Canacki et al. (2003) studied the recovery of methanol from biodiesel produced from soybean oil, yellow grease and brown grease using a distillation setup. Xie et al. (2011) reported that 85.8% of methanol in glycerin could be recovered by coagulation.

Several patents on mobile biodiesel unit briefly explain the alcohol recovery section used in each mobile unit. Rummer (2013) used an integral methanol extraction/recovery system to recover the excess methanol, whereas Brasil (2011) used an evaporation column to recover the excess alcohol. Teall and Sickels (2005) reported that a continuous flow distillation unit was used to recover the excess alcohol. Baum and Kelly (2009) used a methanol separation system which consists of a flash tank and a condensation column. All the patents claimed that their invention proved to be safe despite of transporting alcohol and able to reach diverse location with safety, durability while ensuring the quality of the produced biodiesel. Safety features of the mobile units include an emergency exit and fire extinguished at the back end of the unit (Oliveira et al., 2009).

Dhar and Kirtania (2009) performed a simulation study using Aspen Plus software to investigate the recovery of excess methanol in a biodiesel production process. A distillation column was introduced before the phase separation to recover alcohol from both the biodiesel and glycerol phases. The simulation results showed that at certain operating conditions, approximately 95–98% of excess methanol could be recovered. In another simulation study, Abduh et al. (2016) developed a refining model that includes a methanol and water recovery section, with the objective to minimize methanol and water consumption in the FAME process. It was reported that approximately 97% of excess methanol could be recovered and recycled to further synthesize biodiesel (Abduh et al., 2016).

6. Production cost of biodiesel

6.1. Conventional production of biodiesel

The production cost of biodiesel fuels varies depending on the feedstock, geographical location, variability in crop production from season to season and the price of crude petroleum (Kralova et al., 2010). In addition, pre-treatment costs, operating life of the plant, performance efficiencies, and future timing of the commercial availability of both the feedstock supply chain and conversion technologies also influence the total production cost (Sims et al., 2010; Abduh et al., 2019). The cost of transportation and distribution of biodiesel particularly to remote markets also add to the total production cost of biodiesel (Agarwal, 2007).

Abduh et al. (2017) reported that the production cost of rubber seed oil and rubber seed biodiesel in a small-scale (55 ton/yr) biodiesel production system in Palangkaraya, Indonesia were estimated at \$0.42/l and \$1.12/l, respectively. This value is comparable with the price of diesel in remote areas in close to the investigated area (up to \$1.41/l). The study reported that the production cost is highly influenced by the production capacity whereas the capital investment has a relatively minor impact on the production cost of and biodiesel.

Table 5 Investment and production cost for small scale production of biodiesel

Feedstock	Capacity (ton/yr)	Investment cost (k$)	Production cost ($/l)	Payback period (yr)	Ref.
Pork fat	0.03	4.1	0.84	1.66	Phalakornkule et al. (2009)
Soybean oil	0.14	-	0.76	-	McNeff et al. (2008)
Soybean oil/WCO	0.19	112	-	-	Oliveira et al. (2009)
WCO	0.14	300	0.92	14.4	Bhachu et al. (2005)
Rubber seed oil	55	133	1.12	-	Abduh et al. (2017b)

Agarwal (2007) reported that the production cost of biodiesel before tax is approximately 120-175% more expensive than the mineral diesel. The cost of biodiesel from vegetable oil is estimated in the range of $0.54-1.3/l (Agarwal, 2007; Sims et al., 2010) whereas the production cost of biodiesel using enzyme and microalgae is estimated to be in the range of be $0.87-1.78/l (Stavarache et al., 2003) and $2.4/l (Janaun and Ellis, 2010), respectively.

The cost of biodiesel can be reduced if non-edible oils are considered instead of edible oils. Non-edible oils such jatropha and rubber seeds are easily available at lower prices as compared to edible oils. Most of the non-edible oils are currently not used to their potential and currently regarded as waste. It is reported that the estimated costs for biodiesel from non-edible oil seed is in the range of $0.30-0.69/l. This includes meal and glycerol credits and assuming that the production facility added onto an existing grain or tallow facility to reduce the cost of capital investment (Agarwal, 2007).

In countries like Netherlands, Germany, Belgium, Austria, USA, Japan, and India, WCO would be a good alternative because most of the frying oils are currently discarded. This oil can be used for making biodiesel to reduce the production cost of biodiesel and reduce the cost of water treatment in the sewerage system and in the recycling of resources (Sims et al., 2010). The cost of biodiesel from WCO is reported in the range of $0.34–0.42/l (Agarwal, 2007).

According to Helwani et al. (2009), continuous production plants may achieve higher throughput of biodiesel. This may reduce the production cost and lower the overall cost of biodiesel. Hence, the price for biodiesel in the market can be reduced. However, batch plants are less expensive to build and can more easily be adapted to changing raw materials and reaction conditions. In this sense, small scale production of biodiesel particularly at remote areas may increase the economic feasibility of biodiesel in the market.

6.2. Small scale production of biodiesel

Table 5 shows the limited data currently available for the economic assessment of small-scale production of biodiesel. The investment cost for a community scale production of biodiesel from pork fat (0.03 ton/yr) in Thailand is approximately $ 4100. It is reported that the production cost for this batch operation is $0.84/l with a payback period of 1.66 year (Phalakornkule et al., 2009). A slightly lower production cost of $0.76/l is reported for a continuous setup producing biodiesel from soybean oil using supercritical methanol with an estimated production capacity of 0.14 ton/yr (McNeff et al., 2008).

The investment cost for a mobile biodiesel unit capable of producing 0.19 ton/yr biodiesel from soybean oil or WCO is estimated at $112000 (Oliveira et al., 2009; Brasil, 2011). This cost is lower than the investment cost of $300000 reported by Bhachu et al. (2005). With a production capacity of 0.14 ton/yr, the mobile production unit has a payback period of 14.4 years at production cost of $0.92/l. Abduh et al. (2017a) reported an investment cost of $133000 for a 55 ton/yr production of biodiesel from rubber seed oil. The estimated production cost is $1.12/l. From Table 5, it can be observed that the range of production is still not yet competitive to the current average price of approximately $0.98/l of diesel around the world.

The relatively high small scale production cost of biodiesel must be reduced to be economically feasible by considering local resources for local demand. The local resources must be carefully selected from biomass that are readily available in sufficient amount but are not yet utilized. The production capacity must be adjusted to fit the amount of available feedstock and local demand on order to minimize the logistic cost. Combination of carefully selected feedstock and simple technology that match the demand of the community may help to reduce the feasibility of small-scale production of biodiesel.

The application of a biorefinery concept in the small-scale production of biodiesel that emphasizes on optimizing valorization of biomass, minimizing waste, and maximizing profit to achieve sustainable development (Abduh et al., 2017a) may be considered as a wise strategy to reduce the relatively high production cost of biodiesel. For the first aspect in a biorefinery concept, valorization of biomass in the biorefinery concept may include the use biomass that has not yet been utilized but readily available in abundance such as rubber seeds for the case of Indonesia that has the second largest rubber tree plantations in the world. The case of rubber seeds may also be applied for the second and third aspects of a biorefinery concept.

For the second aspect, minimizing waste may refer to the valorization of the outer shell of the rubber seeds that are typically removed prior to the isolation of oil from the dehulled rubber seeds. Abduh et al. (2017b) has demonstrated that the shell may be used as one of the substrates for the cultivation of Hermetia illucens to produce protein and oil rich biomass. For the third aspect, maximizing profit may be attained by producing co-products apart from biodiesel and glycerol. The pressed cake obtained after the isolation of oil may be further valorized as cattle feed it still contains a relatively high amount of protein (Widyarani, 2014; Abduh et al., 2017b).

In another study, Kumar and Singh (2009) reported that process modifications and engineering advancement in microalgal biodiesel production, the biodiesel cost can be reduced from $4.92/kg to $0.50/kg. The application of a biorefinery concept through coupling phycoremediation of pollution loads in the waste streams to microalgal biomass production results in economic advantage and environmental benefits. Hence, the application of a biorefinery concept for small scale of production of biodiesel particularly in the rural areas may translate into an economically alluring and environmentally attractive business model that may reduce the production cost and increase the welfare of the community.

7. Conclusion

Recent developments in community-scale, mobile production units of biodiesel have been reviewed in this paper. Currently, most of the feedstock used in community-scale, mobile biodiesel units to produce biodiesel is from vegetable oil, although in some cases non-edible oil and animal fats are used as input. Methanol is used in all cases, except for a very few cases where ethanol is used, as an alcohol input for transesterification. Pre-treatment of the feedstock such as pre-heating, filtration, degumming, enzymatic treatment, and esterification, is typically applied before transesterification. Transesterification of triglycerides is performed either in batch or in a continuous setup. For batch transesterification, a stirred/mixing or cone-shaped tank is normally used. The temperature of the reactor is normally maintained at 50–65 °C. A homogenous catalyst is normally used, and the reaction lasts for at least 1–1.5 h. The easiest post-treatments for product separation and purification include settling, water-washing, and drying. The methanol can be recovered from the product mixture by evaporation or distillation.

For a continuous setup, different types of reactor configurations are used such as continuous fixed bed, continuous centrifugal contactor separator, homogenization and separator chamber, and several others. Alkali-catalytic transesterification is normally applied for continuous transesterification of triglycerides to produce biodiesel. Supercritical methanol at a high temperature and pressure is also applied; its conversion rate is within seconds, and it can be used for a variety of feedstock. This process does not consume many catalysts and does not produce glycerol as a major by-product. Hence, the post-treatment stage of purifying the biodiesel is relatively easy compared to post-treatment in other systems that require separation of the remaining catalyst and the by-product glycerol. The production cost of biodiesel at a community scale varies from $0.76-1.12/l. This range is still not yet competitive to the current average price of approximately $0.98/l of diesel around the world. The production cost may be reduced by applying a biorefinery concept that may translate into an economically alluring and environmentally attractive business model.

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Conflict of interest

No potential conflict of interest was reported by the authors.

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