



Review

Potential emissions reduction in road transport sector using biofuel in developing countries

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ABSTRACT

Use of biofuels as transport fuel has high prospect in developing countries as most of them are facing severe energy insecurity and have strong agricultural sector to support production of biofuels from energy crops. Rapid urbanization and economic growth of developing countries have spurred air pollution especially in road transport sector. The increasing demand of petroleum based fuels and their combustion in internal combustion (IC) engines have adverse effect on air quality, human health and global warming. Air pollution causes respiratory problems, adverse effects on pulmonary function, leading to increased sickness absenteeism and induces high health care service costs, premature birth and even mortality. Production of biofuels promises substantial improvement in air quality through reducing emission from biofuel operated automobiles. Some of the developing countries have started biofuel production and utilization as transport fuel in local market. This paper critically reviews the facts and prospects of biofuel production and utilization in developing countries to reduce environmental pollution and petro dependency. Expansion of biofuel industries in developing countries can create more jobs and increase productivity by non-crop marginal lands and wastelands for energy crops plantation.

Contribution of India and China in biofuel industry in production and utilization can dramatically change worldwide biofuel market and leap forward in carbon cut as their automotive market is rapidly increasing with a soaring proportional rise of GHG emissions.

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1. Introduction

Mainly, air quality problems are caused by vehicle emissions (Zhang and Batterman, 2010). In recent years, due to the rapid vehicle growths in the world, exhaust emissions in developing countries have been growing strongly which is adversely affecting many populations (Uherek et al., in press; Oanh et al., 2010; Oener and Altun, 2009). There are 700 million light duty vehicles, automobiles, light trucks, SUVs and minivans, on roadways in the world. These numbers are projected to increase 1.3 billion by 2030, and 2 billion vehicles by 2050, where most of the increase is coming from developing countries (Balat and Balat, 2009). The combustion of petroleum based fuels has adverse impacts on the environment as well as human health (Oener and Altun, 2009). It has been estimated that approximately 0.8 million annual deaths from ambient air pollution in cities of developing countries (Roy, 2009). According to estimation by the World Health Organization (WHO), urban air pollution causes approximately 360,000 premature deaths in

Asia each year (Stone et al., 2010). The Fourth Assessment Report (AR4) of United Nation Intergovernmental Panel on Climate Change (IPCC) concludes that the observed global warming over the last 50 years is likely due to increase of greenhouse gas emission such as carbon dioxide, nitrous oxide and methane. Scientific data alarmed that hundreds of millions of people could lose their lives if average global temperature increases by more than 2 °C (Shuit et al., 2009). Recently, much attention has been focused to the development of cleaner alternative fuels for reducing air pollution and for reducing the dependence on fossil fuels (Zhang et al., 2010). Therefore, it became a global issue to develop such clean fuel which is technically feasible, domestically available and environmentally acceptable (Bouaid et al., 2009; Han et al., 2009). In order to raise vital energy and to encourage sustainable environmental stewardship, there is a role for biofuels in the developing world (Hubbard, 2010).

The most feasible biofuels for vehicles being considered globally are biodiesel and bioethanol. Bioethanol can be produced from a number of crops including sugarcane, corn, sorghum, grains, potatoes, etc. Whereas, Biodiesel is the fuel that can be produced from straight vegetable oils, edible and non-edible, recycled waste vegetable oils, and animal fat (Jianxin et al., 2007; Agarwal, 2007). In general, biofuels are considered as offering many benefits including sustainability, reduction of greenhouse gas emissions,

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regional development through using local product, agricultural development, and security of oil supply (Demirbas and Demirbas, 2007).

This paper presents a critical review on biofuel production based on feedstock available in some developing countries, impact of petroleum fuels and biofuels on environment and human health in order to provide information to researchers, engineers, industrialists, agriculturalists, and policy-makers. A large number of selective literatures are reviewed including most recent publications. It is expected that local production capacity and prospect of biofuels in developing countries are found to be more beneficial for sustainability, reduction of greenhouse gas emissions, creating many local jobs, energy security and rural development by agriculture. Implementation of government policies in introducing biofuel as transport fuel in developing countries can significantly reduce emission in road transport sector and contribute to a healthier environment.

2. Environmental and health hazards of petro-fuel emissions

Since last century, road transport has been identified as a significant source of air pollution and is currently one of the largest emission sources in megacities with subsequent adverse effects on human health (D'Angiola et al., 2010). Due to the rapid growth of vehicle fleets, motor vehicles account for a significant portion of urban air pollution in much of the developing world (Oanh et al., 2010; Balat and Balat, 2009). It has been also considered besides other benefits that one of the issues of increase in motorization in developing countries is found to be due to the economic development which finally led to increase in petroleum based fuels in road transport sector and adverse health effects.

Based on the analysis of aggregate data, one study assembled panel data for 50 countries and 35 urban areas and found that vehicles per capita rose at the same rate as income per capita, with passenger cars increased faster than commercial vehicles. Similarly, in another study estimated income elasticities for national vehicle ownership rates. Study found higher income elasticity for lower income countries, and predicted a rapid increase in car use in countries such as China, India, and Pakistan, where the growth rate of cars per capita was twice than that of income per capita (Kutzbach, 2009).

In urban areas, ground-level traffic vehicles are typically natural gas-fuelled, gasoline fuelled or diesel-fuelled. The physical characteristics and chemical compositions of natural gas, gasoline and diesel are not the same in different parts of the world. This complexity is further complicated by different meteorological conditions, different percentage of heavy polluters (more motorcycles in the developing world), design of motor ways (graded or non-graded roads), driving habits and different maintenance as well as quality and control measures for vehicles (Han and Naeher, 2006). Despite their importance, motor vehicle emissions are inadequately understood and quantified, especially in developing countries. It has been considered worldwide that motor vehicles are one of the largest sources of air pollutants (Guo et al., 2007).

The most hazardous urban air pollutants are lead, fine particulate matter and ozone from the basis of human body damage. Fine particulate matter is the pollutant of most concern in developing countries today on the basis of exposure, toxicity, and ambient concentrations. Ambient concentrations of fine particulate matter are often several times higher in developing country cities than those in industrial countries. Two major contributors in transport to fine particulate air pollution are diesel vehicles and two-stroke engine gasoline vehicles. Air pollution causes respiratory problems, adverse effects on pulmonary function, leading to increased sickness absenteeism, increased use of health care services, premature

birth and even mortality (WHO, 2004). Similarly in another study, it has been reported that among the most harmful substances from the emissions of motor vehicles into the air are carbon monoxide (CO), hydrocarbon (HC) and formaldehyde (HCHO), oxides of nitrogen (NO_x), particulate matter (PM) and organic gases other than methane (Non-Methane Organic Gases, i.e. NMOG). All these substances are considered to be toxic of different degrees or foster the development of cancer (Doll and Wietschel, 2008). Table 1 presents some health effects of exhaust emissions from motor vehicles.

Air pollution statuses of some developing countries are discussed below.

China: China faces severer motor vehicle pollutions due to annual vehicle growth of above 20% (Guo et al., 2007). The rapid private motorization trend has aggravated the challenge to urban

Table 1

Health effects of exhaust emissions from motor vehicles.

Exhaust emissions	Health Effects
Carbon Monoxide (Faiz et al., 1990)	Impairs perception and thinking, slows reflexes, causes drowsiness, brings on angina, and can cause unconsciousness and death; it affects fetal growth in pregnant women and tissue development of young children. It has a synergistic action with other pollutants to promote morbidity in people with respiratory or circulatory problems
Nitrogen Oxides (Faiz et al., 1990)	Can increase susceptibility to viral infections such as influenza; irritate the lungs and cause oedema, bronchitis and pneumonia; and result in increased sensitivity to dust and pollen in asthmatics. Most serious health effects are in combination with other air pollutants.
Hydrocarbons and other Volatile Organic Compounds (Faiz et al., 1990)	Low-molecular weight compounds: Eye irritation, coughing and sneezing, drowsiness and symptoms akin to drunkenness. Heavy molecular weight compounds: may have carcinogenic or mutagenic effects. Some hydrocarbons have a close affinity for diesel particulates and may contribute to lung disease
Ozone (Precursors: HC & NO _x) (Faiz et al., 1990)	Causing coughing, choking, and impaired lung function; causes headaches and physical discomfort; reduces resistance to colds and pneumonia; can aggravate chronic heart disease, asthma, bronchitis, and emphysema.
Lead (Faiz et al., 1990)	Affects circulatory, productivity nervous, and kidney systems suspected of causing hyperactivity and lowered learning ability in children; hazards even after exposure ends. Lead is ingested through the lungs and the gastrointestinal tract.
PM (Zhang and Zhu, 2010)	Respiratory problems, lung cancer and cardiopulmonary deaths
Toxic Substances (Faiz et al., 1990)	Causing cancer, reproductive problems, and birth defects. Benzene and asbestos are known carcinogens; aldehydes and ketones irritate the eyes, cause short-term respiratory and skin irritation and may be carcinogenic.
Polycyclic aromatic hydrocarbons (PAHs) (Okona-Mensah et al., 2005)	Lung cancer
Formaldehyde (Onursal and Gautam, 1997)	Eye and nose irritation, coughing, nausea and shortness of breath. Occupational exposure is associated with risk of cancer.
Dioxin (WHO, 2007)	Long-term exposure: Impairment of the immune system, the developing nervous system, the endocrine system and reproductive functions.

air quality improvement in some large cities (Zhou et al., 2010). Two thirds of China's urban residents breathe seriously polluted air resulting from one and a half decade of strong economic growth without taking care of its adverse effects (Doll and Wietschel, 2008).

India: Due to the strong motorization, India has become one of the biggest emitters of atmospheric pollutants from the road transportation sector globally and was among the top ten countries with highest exhaust pollutants from the road transportation sector. In India, road fuel consumption is approximately doubled in every ten years since 1980 (Baidya and Borken-Kleefeld, 2009).

Pakistan: In Pakistan, vehicular emissions are responsible for 90% of all the pollutants. According to the joint study carried by Pakistan Environment Protection Agency (PEPA) and Japan International Cooperation Agency (JICA), the average suspended particulate matters were 6.4 times higher than WHO guidelines and 3.8 times higher than Japanese standards (Memon et al., 2007). The average increase of SO₂ in air has increased to 23-folds over the past 20 years. Pollutants like CO, CO₂, Ozone, NO_x, and many volatile organic matters are deteriorating air quality at alarming levels in major cities of Pakistan. In terms of health and care, the losses caused due to air pollution are approximately about 500 million dollars per year while the diseases due to air pollution are increasing (Khan and El Dessouky, 2009).

Thailand: In Bangkok, the capital city of Thailand, road traffic contributes the majority (50%–90%) of the NO_x, CO, PM, and non-methane hydrocarbon (HC) emissions. The vehicle fleet grew at a rate of 5% per annum over the period from 1994 to 2006. In 2007 alone, more than 680,000 new vehicles were registered in the city, i.e. a growth of 62% in the last five years (Oanh et al., 2010).

Bangladesh: Air pollution is a major problem in Dhaka and other cities of Bangladesh. In a survey conducted by Society for Urban Environmental Protection (SUEP) surprisingly showed that emissions from several new vehicles are 3–4 times higher than the emission standards that in place. It is estimated that the transport sector is responsible for 70% of the national CO₂ emissions of which 20%–30% come from Dhaka (Roy, 2009). According to the World Bank study, nearly 2×10^5 tons air pollutants are emitted from motor vehicles alone. Another World Bank study says as many as 15000 deaths, a million cases of major illness and 8.5 million cases of minor illness are caused by air pollution in Dhaka and three other cities of Bangladesh. Ambient air quality condition had reached such a crisis proportion that the challenge of sustaining economic growth and ensuring reasonable quality of life has become tougher (Nasiruddin, 2006).

3. Impact of biofuel exhaust emissions on environment and human health

It is fact that the world fleet of motorized vehicles emits millions of tons of pollutants, subsequently leading to poor air quality conditions, mainly in large urbanized areas, causing, among other effects, human health deterioration and climate change (De Abrantes et al., 2009; Lumbreras et al., 2008). The environmental concern of the global warming and climate change has generated much interest in the environmental friendly alternative fuels. As defined by the Energy Policy Act of 1992 (EPACT, US), alternative fuels include ethanol, natural gas, hydrogen, biodiesel, electricity, methanol and so on. These fuels are being used to reduce petroleum consumption, harmful pollutants and exhaust emissions in the transportation sectors (Jia et al., 2005). Mostly, biodiesel and ethanol have been considered the major alternative of petroleum based transportation fuels (Jianxin et al., 2007; Demirbas, 2009a). The use of biofuels as internal combustion (IC) engine fuels can play a vital role to help the developing countries in terms of reducing the

environmental impact and the adverse human health effect of fossil fuels. Therefore, this section will review on both biodiesel and ethanol in terms of their advantages on environmental pollution and human health when these fuels are blended with petroleum fuels respectively.

3.1. Biodiesel exhaust emissions

Biodiesel as a low-emitting fuel can be used to meet future regulations to provide safeguard to environment and human health. Since vegetable oils based biodiesels does not contain any sulfur, metals or crude oil residues that significantly contributes on reduction of acid rain by not emitting sulfates and sulfuric acid in our atmosphere (Wedel, 1999; Çaynak et al., 2009). An independent research programs conducted in Europe and the U.S. have reported that biodiesel in a 20 percent blend with petroleum diesel created a significant reduction in visible smoke and odor. Biodiesel has higher oxygen content than petroleum diesel and its use in diesel engines have shown great reductions in emission of PM, CO, sulfur, PAH, smoke and noise (Zullaikeh et al., 2005; Wedel, 1999). The influence of different biodiesel fuels on the mutagenic activity of diesel-engine emissions (DEE) was demonstrated in previous studies. Generally, lower mutagenic activity was observed compared to petro diesel fuels (Bünger et al., 1998; Turrio-Baldassarri et al., 2004). Several different measurements were also performed that went beyond basic regulated pollutants. The limited data showed exhaust emissions were lower in total vapor phase hydrocarbons, total carbonyl compounds (CCs) and total poly-aromatic hydrocarbons (PAH) when biodiesel fuels were used (Peng et al., 2008). Some PAHs are potentially mutagenic and carcinogenic to humans (Yang et al., 2007). Lin et al. (2006) found that PAHs emissions decreased with increasing palm-biodiesel blends due to small PAHs content in biodiesel. Study conducted by Machado Corrêa and Arbilla (2008), using biodiesel (blends) obtained from castor oil using ethyl alcohol, showed that the average reduction for PAHs was found 2.7% (B2), 6.3% (B5), and 17.2% (B20) when compared with petro diesel. Almost similar results were obtained by Turrio-Baldassarri et al. (2004) and Durbin et al. (2000). Experimental study conducted by Ferreira et al. (2008) has shown an average concentration reduction of about 19.5% of benzene under three conditions of engine torque. This reduction is sufficiently significant since benzene is a carcinogenic compound. Among unregulated air pollutants, CCs have a relevant importance of its health effects and the potential for ozone formation (Peng et al., 2008; Machado Corrêa and Arbilla, 2008). Lin et al. (2009) showed a significant reduction in CC concentrations using paraffinic–palm-biodiesel blends at one low load steady-state condition. Therefore, the wide usage of paraffinic–palm-biodiesel blends as alternative fuels could protect the environment. Similarly, formaldehyde is considered carcinogenic to humans (Guarierio et al., 2008). Therefore, its reduction in diesel-engine emission is desirable. Several studies showed that Ethanol–biodiesel–diesel and waste cooking oil biodiesel (20% vol.) could be used to decrease formaldehyde emission by about 20–25% and 23%, respectively, but they increase acetaldehyde emission by 20–30% and 17%, respectively (Shi et al., 2006; Pang et al., 2006, 2008).

Although nitrogen oxides (NO_x) are considered a major contributor to ozone formation, in the literature two diverse interpretations for NO_x emissions are available. Firstly, higher temperatures of combustion using biodiesel cause higher NO_x emissions (Gomez et al., 2000; Saravanan et al., 2010). Higher exhaust temperatures from biodiesel fuelled engines may indicate higher NO_x (Agarwal and Das, 2001; Utlu and Koçak, 2008; Panwar et al., 2010). However, some researchers reported lower NO_x emissions in biodiesel fuelled engines (Sureshkumar et al., 2008; Qi

Table 2

Summary report on exhaust emissions of biodiesel as compared to diesel.

References	Biodiesel type	Operating Condition	Exhaust emission
Godiganur et al., 2010	Fish oil methyl ester	At constant speed of 1500 rpm under variable load conditions.	Lower CO and HC emissions Higher NO _x emissions
Gumus and Kasifoglu, 2010	Apricot seed kernel oil methyl ester	At different engine loads and constant engine speed, 2200 rpm obtained maximum torque.	Lower CO and HC emissions and smoke density Higher NO _x emissions
Aydin and Bayindir, 2010	cottonseed oil methyl ester	At full load and variable engine speed (1250–2500, with intervals of 250 rpm)	Lower CO, NO _x and SO ₂ emissions
Çelikten et al., 2010	Rapeseed and soybean oil methyl esters	At full load with different speeds at different fuel injection pressures (250, 300 and 350 bar).	Lower CO and smoke level and higher NO _x
Saravanan et al., 2010	Mahua oil methyl ester (MOME)	Variable load conditions	Lower HC, CO, NO _x and smoke emissions
Panwar et al., 2010	Castor methyl ester	At a rated speed of 1500 rpm at different loads	Lower NO _x emission (B10)
Ghobadian et al., 2009	Waste cooking biodiesel	At full load and variable engine speed (1200–3600, with intervals of 400 rpm)	Lower CO and HC emissions
Nabi et al., 2009a	Karanja methyl ester	At constant speed of 1200 rpm under variable load	Lower CO, smoke, engine noise & higher NO _x
Nabi et al., 2009b	Cottonseed oil methyl ester	At constant speed of 850 rpm under variable load	Lower CO, PM, smoke emissions and higher NO _x
Oener and Altun, 2009	Tallow methyl esters	At 100% throttle width and various engine speeds (1000–3000 with 500 rpm period)	Lower CO, NO _x , SO ₂ and smoke opacity

et al., 2010; Kalam et al., 2003; Kalam and Masjuki, 2002; Dorado et al., 2003). Secondly, increasing oxygen content in the blend shortens the ignition delay and reduces the amount of premixed fuel and peak burning temperature, which means a reduction in NO_x emissions (Lin and Huang, 2003). Table 2 presents the comparative summary report on exhaust emissions of using biodiesel and its blends with diesel fuel.

3.2. Bioethanol–gasoline exhausts emission

Henry Ford designed his first automobile (Model T) to run on both gasoline and pure ethanol. However, in the past, ethanol was not given expectancy due to its insufficient production and high price (Eyidogan et al., 2010). Ethanol (CH₃CH₂OH) has some advantages over gasoline, such as the reduction of CO, volatile organic compounds (VOC) and unburned hydrocarbon (UHC) emissions and better anti-knock characteristics. Since ethanol is a liquid fuel, the storage and dispensing of ethanol is similar to that of gasoline (Topgül et al., 2006). The formation of hydrogen bridges in ethanol molecule results in higher boiling temperature in comparison to gasoline, which increases storage stability. Ethanol is less toxic than methanol – another alcohol used as fuel. The high octane number of ethanol allows for higher compression ratios in comparison to gasoline fuelled engines (Costa and Sodré, 2010). Among alternative fuels, ethanol is one of fuels employed most widely due to the following main reasons. First, it can be produced from “cellulosic biomass”, such as trees and grasses and is called bioethanol. Secondly, ethanol is made up of a group of chemical compounds whose molecules contain a hydroxyl group (–OH) bonded to a carbon atom; so, the oxygen content of this fuel favors

the further combustion of gasoline. It can be concluded that ethanol–gasoline blended fuels will reduce the air pollution (Jia et al., 2005).

There are several studies for ethanol–gasoline, regarding the regulated and some unregulated emissions (Pouloupoulos et al., 2001; Song et al., 2006). Wu et al. (2004) investigated the engine performance and exhaust emission using ethanol–gasoline blended fuels (E0, E5, E10, E20 and E30) under various air–fuel equivalence ratios. Results showed that torque output increased slightly at small throttle opening when ethanol–gasoline blended fuel was used. It was also found that CO, CO₂ and HC emissions were reduced with the increase of ethanol content in the blended fuel. The Australian and EPA studies for ethanol–gasoline blends indicated that formaldehyde emissions were not significantly changed by E20 when compared to E0. However, emissions of acetaldehydes were found to be increased, mainly during cold-start operations. EPA considers both of these emissions are carcinogens (Wisner, 2009). Note that acetaldehyde is a hazardous compound and probable carcinogen. It is also a precursor to peroxyacetate nitrate (PAN), a respiratory irritant with acute toxicity (Niven, 2005). According to the Australian study, emissions of benzene, hexane, and toluene decreased, although slight increases appeared to occur in 1,3-butadiene and xylene. EPA found similar results when testing five 1983–1990 model vehicles with E10 (Wisner, 2009). Table 3 represents the summary report on exhaust emissions of ethanol–gasoline compared to gasoline fuel. In many developing countries, the pollutant emissions from motorcycle engines are becoming an increasing concern. Motorcycle emissions account for 16% of CO, 43% of THC, and 18% of NO_x emissions among all gasoline vehicles in Taiwan. In Bangkok, Thailand, motorcycles contributed

Table 3

Summary report on exhaust emissions of bioethanol as compared to gasoline fuel.

References	Test parameters	Exhaust emission
Kiani et al., 2010	Under varying engine speed and at constant engine loads of 25, 50, 70% and full load	Lower CO & HC emissions Higher CO ₂ and NO _x emissions (Only performance and combustion based)
Eyidogan et al., 2010	At two different vehicle speeds (80 km h ^{−1} and 100 km h ^{−1}), and four different wheel powers (5, 10, 15, and 20 kW)	
Wen et al., 2010	At constant engine load (3 N m) and different engine speeds (idle speed & 3500 to 8000 rpm with 1500 rpm period)	Lower CO & HC emissions Higher CO ₂ and NO _x
Koç et al., 2009	At two compression ratios (10:1 and 11:1) Engine speed from 1500 to 5000 rpm at wide open throttle (WOT)	Lower CO, HC and NO _x emissions
Najafi et al., 2009	At full throttle setting & under varying engine speed conditions (1000–5000 rpm)	Lower CO & HC emissions Higher CO ₂ and NO _x emissions
Celik, 2008	At a full throttle opening & constant speed (2000 rpm) C.R from 6/1 to 10/1	Lower CO, CO ₂ , HC and NO _x emissions

up to 30% of CO and 70% of THC in the air. The effect of ethanol–gasoline blends on criteria air pollutant emissions was investigated in a four-stroke motorcycle. According to the findings, the ethanol added into gasoline decreases CO and NO_x emissions (Yao et al., 2009).

4. Potential biofuels production in developing countries

Ethanol is the most commonly used biofuel to substitute gasoline and biodiesel is fungible to diesel. There are standard specifications for biodiesel in Europe (UNE EN-14214, 2003) and in America (ASTM D 6751-03). These standards specifications define the biodiesel (B100) used as the blend component with diesel fuel. Similarly ASTM also developed E85 (85% ethanol, 15% gasoline) fuel specifications for automotive Spark-Ignition (SI) engines prescribed by Renewable Fuels Association (2005). Both ethanol and biodiesel contain oxygen and lower exhaust emissions of a number of harmful pollutants. Mostly, non-OPEC countries are net oil importers. Of the 204 non-OPEC countries and non-independent territories, 173 (85%) were net oil importers in 2004. Similarly, 38 poorest countries out of 47 are net oil importers with most of them import all of their oil despite having substantial agricultural bases to grow energy crops and are capable of meeting most of their liquid/transport fuel needs through biofuel production (Pohit et al., 2009). In this section, the potentiality of biodiesel and ethanol production in the developing countries is reviewed.

4.1. Biodiesel production

Indonesia: Indonesia is the world's largest producer of palm oil and the second largest exporter. It accounts for 44.5% of the world's production and 45.3% of global export of palm oil. According to Indonesia's Ministry of Energy and Mineral Resources, in 2007, 520,000 tons of biodiesel were produced equivalent to 590,000 kL. There are currently eight biodiesel plants. By 2011 there will be another 15–17 more, adding 2 million kL of biodiesel production (Zhou and Thomson, 2009).

Malaysia: Malaysia's biodiesel production is mainly palm oil based though it has taken some initiative to introduce *Jatropha* production in mass level (Jayed et al., 2009). Since 1980s, Malaysian Palm Oil Board (MPOB) in collaboration with the local oil giant "PETRONAS" has begun transesterification of crude palm oil into palm biodiesel (also known as palm diesel) (Kalam and Masjuki, 2008). It is currently the world's second largest producer, accounting for 42.3% of worldwide production and 48.3% of the world's total exports of palm oil. The Malaysian Government has been researching the use of a B5 (5% processed palm oil and 95% diesel) blend for vehicles and industrial sectors (Zhou and Thomson, 2009). According to Malaysian Biodiesel Association (MBA), there are 10 active biodiesel plants in the country with a total annual biodiesel installed capacity of 1.2 million tons. An additional four biodiesel plants with combined annual capacity of 190,000 tons are on the way to be completed soon (Lim and Teong, 2010).

Brazil: Brazil has 56 government authorized biodiesel plants, with new projects awaiting approval. Eighty percent of the feedstock used for biodiesel is soybean oil and 15 percent is animal fats. Production in 2007 was estimated at 106.2 million gallons (354,051 metric tons) while 2008 production is estimated at 290.6 million gallons (968,797 metric tons) (Swisher, 2009). In order to reduce the importations of 6 billion m³ of diesel, the Brazilian government has enacted the Law 11,097 to authorize the use of 2% of biodiesel (B2) from 2005 to 2008 (Machado Corrêa and Arbilla, 2008). In July 2008 the mandatory blend was increased to three

percent (Swisher, 2009) and the use of 5% of biodiesel will be implanted finally in 2013 (Machado Corrêa and Arbilla, 2008).

Philippines: As the world's largest producer of coconut oil (CNO) and the second largest coconut producer, the Philippines is well positioned to produce coconut methyl ester (CME). There are about 60 CNO mills with an aggregate production capacity of about 4.5 million tons per annum. There were nine CME producers accredited with the Philippines' Department of Energy as of 23 January 2008, producing about 257 million l per year. According to the "Biofuels Act of 2006", 1% biodiesel into all diesel fuel was made. Within 2 years, a recommendation of minimum 2% CME was set (Zhou and Thomson, 2009).

Argentina: In Argentina, production capacity of biodiesel was about 0.7 billion liters in 2007, shipped almost 400 million liters abroad (Wane, 2009). It was expected that by the end of 2008, more than 15 medium to large biodiesel plants would be online with an estimated capacity of 528.3 million gallons (1.8 million metric tons) and projected production of 264.2 million gallons (880,724 metric tons). With the abundance of soybean oil in Argentina, the biodiesel industry is projected to continue its growth in the near future and is expected to have a production capacity of 1.1 billion gallons (3.5 million metric tons) by 2010 (Swisher, 2009).

Thailand: In Thailand, diesel accounts for more than 50% of transport fuel. The roadmap is to develop raw materials and replace 5% of the total diesel consumption in the transport sector with biodiesel by 2011 and increase it up to 10% by 2012. The biodiesel consumption of about 3100 million liters in 2012 will result in savings of foreign exchange of about US\$675 million per year (Siriwardhana et al., 2009). The Ministry of Energy has forced a mandatory measure on "B2" biodiesel (2% of B100) effective from 1 February 2008. This measure encourages the use of about 1.2 million liters of biodiesel a day. In Thailand, palm oil is a biomass resource which has high potential as a renewable energy source for biodiesel production. In 2008, the oil palm harvesting area in Thailand was 0.46 million ha and the FFB output was 8.68 million ton or 1.475 million ton of CPO (Crude Palm Oil) (18% oil yield). Currently, excluding CPO used as cooking oil and for export, only 0.25–0.30 million ton per year is available for biodiesel production, which is not enough to meet the demand. In order to solve this problem, the Thai government is planning to expand the oil palm cultivation area to 0.8 million ha by 2009 and to 1.0 million ha by 2012 (Papong et al., 2010).

India: Following global trend, India declared its biofuel policy in which biodiesel, primarily from *Jatropha* (non-edible oil), would meet 20% of the diesel demand beginning with 2011–2012 (Kumar Biswas et al., 2010) as India is the largest edible vegetable oil importer (Zhou and Thomson, 2009). In April 2003, the National Mission on Biodiesel was launched, identifying *Jatropha* as the most suitable oil seed plant. The aim is to reach 20% (B20) by 2012. In order to achieve this, the Government targeted 11.2 million ha to be planted with *Jatropha* by 2012 to produce sufficient oil seeds to support the biodiesel requirements (Zhou and Thomson, 2009).

Pakistan: Biodiesel project is feasible and has very booming future in Pakistan. There is about 28 million hectare area of land in Pakistan is unproductive due to water shortage, severe heat, and saline soil. Neighboring country, India is very much successful in producing biodiesel from *Jatropha* plant seeds, whereas *Jatropha* plants can be cultivated in Pakistan especially in saline soil with less quantity of water and it can also withstand high temperature. For biodiesel production, generally methanol or ethanol is required for reaction with vegetable oil. Methanol is produced from coal and reserves of coal in Pakistan are 180 billion tons, 5th largest in world. If in ideal condition Pakistan utilizes all uncultivated land for biodiesel production, then it can produce 56 million tons of biodiesel per year (Khan and El Dessouky, 2009).

Paraguay: Paraguay is 100 percent reliant on imported oil, and 75 percent of its fuel consumption is diesel. The first biofuel legislation was passed in 2005 that, among other things, established minimum blend requirements of one percent biodiesel in diesel fuel by 2007, three percent by 2008, and five percent by 2009. The maximum blending rate at fuel stations was established at 20 percent. Currently there are seven biodiesel plants operating in Paraguay. Approximately 67 percent of biodiesel is produced from animal fats, and two *Jatropha* plantations are being developed for future feedstock.

China: In 2003, China began to focus on biodiesel research and industrial development. Government announced a voluntary biodiesel standard (for 100 percent biodiesel) in July 2007 but there is currently no mandatory national biodiesel standard. A target for biodiesel use has been included in the government's Medium and Long-Term Development Plan for Renewable Energy, 200,000 tons (225 million liters) by 2010 and 2 million tons (2.25 billion liters) by 2020. The National Development and Reform Commission (NDRC) plans to develop domestically-grown biodiesel feedstock that do not compete with food crops for land or water resources. *Jatropha curcas*, an oil-nut bearing tree, is considered the most likely and trials of *Jatropha* cultivation have been underway in South-west China. The NDRC has designated South-west China as the official target area for *Jatropha* cultivation and envisions around 600,000 ha of *Jatropha* plantations in each of China's South-western provinces. According to the NDRC, total Chinese biodiesel output in 2006 was 190,000 tons. The U.S. Department of Agriculture estimates that production was around 300,000 tons in 2007 (GSI, 2008).

Lastly, it can be recommended that the use of edible oil to produce biodiesel in some developing countries is not feasible in view of a big gap in the demand and supply of such oils for dietary consumption. Therefore, it should be focused on the inedible oils such as *Jatropha curcas*, *M. indica*, *Ficus elastica*, *Azadirachta indica*, *Calophyllum inophyllum*, neem, *Pongamia pinnata*, rubber seed, mahua, silk cotton tree and tall oil microalgae whose potential availability can easily be found in developing countries and these are very economical comparable to edible oils (Demirbas, 2009b).

4.2. Bioethanol production

Ethanol, for instance, can be made from sugars (like sugar beets and sugarcane), grains (like maize and wheat), cellulose (grass or wood), and waste products (like crop waste or municipal waste). Sugarcane production for ethanol has become one of the attractive options for developing countries (Braun and Pachauri, 2006). There are almost 100 countries producing sugarcane covering an area of 200 000 km² (approximately 0.5% of the total world area used for agriculture) and it is easy to convert plants producing sugar to ethanol distilleries (Goldemberg and Guardabassi, 2009). It has reported that about 80 developing countries grow and process sugarcane, a high-yielding crop in terms of photosynthesis efficiency that can also be used to produce ethanol.

Brazil: Since Brazilian colonial times, sugarcane has played an important role in the economy. Favorable climate conditions, abundant and productive land allow Brazil to produce over 30 million tons of sugar and 20 billion liters of ethanol annually (Cerqueira Leite et al., 2009). Brazil continued its ethanol expansion plans, begun in 2005, to more than doubling production by adding of new sugar plantations and ethanol production capacity by 2012. About 15% of Brazil's ethanol production was exported in 2008. Most of the sugarcane plantation and ethanol plant expansion being carried out with national public financing and a growing share from foreign investors (Wane, 2009).

Philippines: Due to the availability of sugarcane as feedstock, the Philippines is able to produce ethanol. In Philippines ethanol production began in 2008. Several bioethanol plants are currently under construction. The use of biofuel was mandated within 2 years of the "Biofuel Act of 2006". Five percent ethanol (E5) accounts for all the gasoline fuel sold in the Philippines, and within 4 years of this Act (2010) all gasoline fuel will be 10% ethanol (E10) (Zhou and Thomson, 2009).

Thailand: As agriculture based country, the government of Thailand has encouraged production and use of bioethanol in order to reduce dependency on oil import, mitigate global warming impact and activate the grass root economy by stabilizing the income of farmers and generating employment in the local community. Thailand is the largest cassava exporter and the second largest sugarcane exporter in the world. Currently, cane molasses and cassava are the two major raw materials for bioethanol production. The Thai renewable energy policy promotes the use of gasohol, a 10% blend of bioethanol with 90% gasoline, for substitution of conventional gasoline with a target to increase the use of ethanol up to 3 million liters per day by 2011. In 2007, there were 7 ethanol plants with a total installed capacity of 955,000 L day⁻¹, comprising 130,000 L day⁻¹ cassava ethanol and 825,000 L day⁻¹ molasses ethanol. Several other plants were also in the phase of completion. The amount of gasohol consumption in the country has increased from 3.5 million liters (ML) a day in 2006–7.4 ML per day in March 2008 and was still increasing continuously because of the government's promotion policies (Silalertruksa and Gheewala, 2009).

China: Currently, (the) People's Republic of China imports close to half of its oil consumption. By 2030, oil consumption is projected to double driven largely by the exponential rise in private car ownership. Government proposed the establishment of a biofuel industry in the Tenth Five-Year Planning (2000–2005). As a result, (the) PRC's fuel ethanol industry was created in 2000. In 2001, a 200,000 ton capacity pilot ethanol production plant was established in Henan province. By 2008, there were five licensed fuel–ethanol plants in operation. By 2008, the fuel–ethanol production capacity reached 1.94 million tons (650 million gallons) (Li and Chan-Halbrendt, 2009). Currently, E10 (gasoline mixed with 10% ethanol) is being used in the transport sector in the five provinces (Heilongjiang, Jilin, Liaoning, Anhui, and Henan) and 27 cities (Qiu et al., 2010). In (the) PRC, alcohol fuels have been made from wheat, maize, sugarcane, cassava, sweet sorghum, etc. Many projects recently conducted are focused on sorghum bioethanol to replace the use of oil (Liu and Lin, 2009). China has also increased subsidies, tax and VAT exemptions in both biodiesel and ethanol to promote this industry.

India: In India, the demand for motor gasoline has been growing at an average annual rate of ~7% during the last decadent it shows an increasing trend. The current consumption of petrol for transportation needs (motor gasoline) is estimated at 15.23 billion liters annually (Sukumaran et al., 2010). India currently has targets to blend 5% of bioethanol in transport fuel in designated states even though the national government withdrew its over ambitious target to blend 20% biodiesel and bioethanol by 2017 (Prabhakar and Elder, 2009). Effective January 2003, India mandated the blending of at least 5 percent ethanol in the gasoline sold in nine states and four Union Territories to reduce the country's dependence on imported oil, help the sugar industry, and benefit the environment. India's sugar surplus and growing supplies of molasses were important drivers behind the ethanol program (Kojima and Johnson, 2005).

African Developing Countries: Africa represents the largest leaded fuel user in the world. Among 44 countries in Sub-Saharan Africa, 17 countries use leaded fuel only, 13 dual systems and 14

unleaded. Therefore, use of fuel–ethanol would have significant health benefits in replacing lead as an octane enhancer in most African countries. Ethanol programmes that produce a blend of ethanol and gasoline (gasohol) for use in existing fleets of motor vehicles have been pursued in a number of African countries including Malawi, Zimbabwe, Kenya and South Africa (Amigun and Von Blottnitz, 2009). Malawi is among the few countries that started producing bioethanol from sugarcane molasses since 1982. This ethanol is blended with petrol at the ratio of 1:9. Malawi produces 30 million liters of ethanol which is used to complement the imported fuel estimated at between 80 and 90 million liters per year. Kenya, Zimbabwe, Sudan and Uganda started similar programs. However, Sudan and Kenya stopped producing ethanol, but Kenya has since revived its ethanol production. Zimbabwe continued producing ethanol, but most of the ethanol produced is exported to other countries as alcohol (Jumbe et al., 2009).

Pakistan: Sugarcane is one of the major crops of the country. Pakistan stands fifth among the countries having a large tract of area under sugarcane crop. About 53.5 million tons of sugarcane is produced every year in the country. There is a vast potential for ethanol production from molasses of sugarcane. The potential of ethanol production from molasses has been estimated at about 500 million liters or 0.42 million tons per annum, which is about 36% of the present gasoline consumption in the transport sector in Pakistan (Harijan et al., 2009).

Nepal: Energy security for transport is a quite severe problem in Nepal. According to NOC (Nepal Oil Corporation), in 2006/2007, 752,446 m³ of petroleum products (diesel: 39.8% and gasoline: 13.1%) were imported from India mainly to meet transport needs. The government of Nepal has decided to blend 10% ethanol in the petrol to reduce dependence on imported fuels. Nine sugar mills are working in Nepal with total installed capacity of 17,050 tons of cane processing per day. Sugar mills are well established and contributing to the national economy, and they have an enormous potential to produce ethanol from their by-product, molasses (Khatiwada and Silveira, 2009).

Indonesia: In Indonesia, ethanol production is small as the number of sugarcane and cassava plantations is low. Ethanol producers face several challenges, one of which is that alcohol is strictly prohibited in Indonesia for religious reasons. As of April 2007, the annual production of ethanol was 82,500 kL. This, however, is expected to increase to 2 million kL annually by 2010 with about 12 additional plants coming on stream (Zhou and Thomson, 2009).

5. Conclusions

From this critical review, biofuels are found to produce less emission in automobiles. So, the air pollution problem and energy security issue could be seriously addressed by not only producing but also utilizing in road transport sector such as buses, cars, trucks and motorcycles etc. Many developing countries are producing and exporting biofuels but not utilizing as they are less conscious on health hazard and environmental pollutants. Energy giants like India and China are vegetable oil importers, so they are focusing on non-edible sources of biofuel feedstock. Expansion of biofuel industries in developing countries can create more jobs and increase productivity by non-crop marginal lands and wastelands for energy crops plantation. Brazil is most advanced in biofuel industry who has improved their economic and environmental position a lot in last few decades through biofuel industry. Indonesia, Malaysia, Philippines, Thailand have expertise in biofuel production but far behind in utilization as they focused on export. India and China have started research on biofuel production from non-edible oil sources as food grade oils as biofuel from edible oils can threaten their food security. Contribution of India and China in

biofuel industry can dramatically change worldwide biofuel market and leap forward in carbon cut as their automotive market is rapidly increasing with a soaring proportional rise of GHG emissions. Bangladesh, Pakistan, Paraguay and African states are far from establishing in biofuel market. Apart from government initiative to introduce biofuel in local road transport sector as fuel and production, concerns should be given on global environmental issue and health hazard to create a drive for this green fuel.

Future work: The authors of this paper will do investigation on regulated exhaust emissions such as CO₂, HC and NO_x, and unregulated emissions such as PAH, formaldehyde and dioxin emissions, etc from Jatropa, coconut and waste palm oil based biofuels.

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