Diversifying bio-petro fuel sources for future energy sustainability and its challenges

M R Othman1, Z Helwani1,2 and I Idris1
1School of Chemical Engineering, Universiti Sains Malaysia, 14300 Nibong Tebal, Pulau Pinang, Malaysia
2Department of Chemical Engineering, Riau University, Pekanbaru, 28293, Indonesia.

E-mail: chroslee@usm.my

Abstract. Petroleum has been important in the energy industry since 19th century when the refining of paraffin from crude oil began. The industry recently appears to be in a downtown and fragile moment despite the price of oil is slowly rising. Renewable alternatives such as bio-fuels have gained increasing traction while petroleum fuel seemingly concedes to bio-fuels due to the rising public concern on the environment and stricter emission regulations. To be a strategic fuel in the energy security matrix, both fossil and bio-fuels options should be considered. However, the use of bio-fuels to achieve a degree of carbon neutrality is not without challenges. Among the challenges are land development and socio-political issue, carbon neutrality due to ILUC, high 2G bio-fuel feedstock and production cost, competing technology from electric vehicles and the impending fourth industrial revolution, NOx emissions and variation in biodiesel quality. This paper briefly reviews the potential of fuels source diversification and the challenges and how they can raise up to the challenges in order to be sustainable and attractive. In order to achieve this objective, first carbon credit through carbon trading needs to continue to stabilize the energy price. Second, 1G bio-fuel needs to forgo the use of natural, peat forest, rubber estate since these are an effective carbon sink and oxygen source. Third, advanced bio-fuels with high yield, process economics and sustainability need to be innovated. Fourth, the quality and standard bio-fuel that reduces NOx emission need to be improved. Finally and most importantly, carbon capture technology needs to be deployed immediately in fossil fuel power plants.

1. Introduction
Global bio-fuel production has increased steadily since 2005 with annual growth rate of 14.1% [1]. Biodiesel production rose by 6.5% in 2016 with Indonesia providing more than 1149 thousand tons of crude oil equivalent [1] in the world bio-diesel market. This is despite the result from a previous study reporting that the first generation (1G) biodiesel made from edible vegetable oils emit higher greenhouse gas emission and require higher cost of production than its fossil fuel counterpart [2]. The increase in bio-fuel demand is expected to continue in the future. However, with the recent European Parliament’s vote to phase out the use of vegetable oil in bio-fuels by 2020 [3] and France government’s plan to end the sale of petrol and diesel cars by 2040 [4] and coal by 2022 [5] in order to meet the Paris climate accord’s target and carbon neutral (CN) by 2050, this trend may be short-lived. The entry of artificial intelligent (AI) to herald the fourth industrial revolution (IR–4) portends another challenge for bio-petro fuels and combustion technology. To the combustion engine, petroleum and
bio-fuel manufacturers, the recent episodes may not bode well to them, and to certain extend, pose an existential threat.

For developing countries with dominant fossil fuel economy, a drastic program to phase out fossil fuels completely could lead to a catastrophe, considering the benefits of these fuels to the social, economic and political wellbeing. Beside diversifying bio-petroleum fuel sources for energy sustainability during the slow but steady transit into a completely renewable energy economy, the developing countries may be able to benefit from carbon trading through installation of carbon capture technology in their existing and future fossil fuel power plants and infrastructure [6].

This paper briefly reviews the challenges and immediate and midterm potential solutions in order for the industries to remain resilient and resourceful to ensure the sustainability of the fuels and the economic well-being generated by using the fuels.

2. Bio-fuel challenges

The first generation (1G) biodiesel made from edible feedstock reportedly exacerbated the scarcity of food [7]. Attempting to move towards inedible 2G bio-fuels such as Jatropha oil [8-9], algae (3G) bio-fuel feedstock [10-11] and genetically modified algae (4G) bio-fuels is also met with significant challenges. In this paper, few of these challenges and the potential solutions to overcome the challenges are proposed.

2.1. Illegal forest clearance

Bio-fuel is perceived as carbon neutral because the CO₂ released to the atmosphere on combustion is consumed back by the bio-fuel crops during photosynthesis. As long as bio-fuel supply can meet the population growth and demand, the fuel can provide the needed energy security without affecting the environment. But, bio-fuel use was promoted more than necessary, causing the global bio-fuel demand and production to increase. Illegal planters emerge to fill the demand and natural forest was encroached to make way for illegal oil palm cultivation. This has become a great challenge for the government and legal oil palm industry to overcome. Laws that protect natural forests need to be enforced aggressively, some land for food crops cultivation need be reserved in order to ensure food security and, finally the 1-2G biodiesel industrial estate outside of natural forest, within the existing oil palm estate, coconut and fallow area needs to be developed. Reasons for such proposals shall be discussed shortly.

2.2. Indirect land use change

Figure 1 shows the equivalent carbon dioxide (CO₂) emission from indirect land use change (ILUC) for bio-diesel and bio-ethanol production [2]. The carbon emission from ILUC for all the four food crops to produce biodiesel is the same. The difference by the direct emission is possibly due to the different source of electricity. Biodiesel produced higher CO₂ emission than fossil fuel, indicating that it is not effective in achieving carbon neutrality (CN). Bio-ethanol made from maize and sugar on the other hand, achieved 50% carbon neutrality or more, which is on the right track toward 100 percent carbon neutral. The challenge would be for the bio-diesel manufacturers to reduce the emission further so that it can be an attractive fuel of the future.
Figure 1. Comparison of CO₂ emission by bio-fuels [2].

Figure 2 shows the equivalent CO₂ emission by palm oil due to indirect land use change (ILUC) [12]. Bars on the right represent positive carbon emission (unfavorable), whereas bars on the left represent negative carbon emission (favorable). This study signals a clear message that natural forest, peat forest and a land designated for natural rubber should never be allowed for oil palm cultivation. In order to reduce the CO₂ emission, the most suitable places to cultivate oil palm would be the land designated for oil palm plantation or existing oil palm land, coconut estate and tropical fallow. These places are an effective carbon-sink according to the study.

Figure 2. CO₂ emission by palm oil due to indirect land use change (ILUC) [12].
2.3. High biodiesel production cost
Production of bio-diesel from inedible (2-4G) feedstock incurs high expenses associated with acquiring the feedstock and transportation. Some inedible feedstock such as waste cooking oil that requires pretreatment and processing are significantly more costly than processing the edible oil. Companies that ventured into the biodiesel business could not get the return on investment (ROI) or cope with the expenses. Some companies had to file a bankruptcy notice [13].

Company may raise up to the challenge by becoming more resourceful in acquiring the needed feedstock alternatives and logistics. The feedstock that resembles the properties of hydrocarbon may use the existing crude refinery to produce bio-fuels. This would eliminate the huge capital upfront and make the bio-fuel production more feasible.

2.4. Competing technology
Norway, French and UK revealed their decision to ban petrol and diesel vehicles to herald a new era of electric vehicles [14]. Figure 3 shows the comparison of CO₂ emission from fossil fueled vehicles and electric vehicles [15]. Electric vehicles produce CO₂ emission but the amount is largely dependent on the power plants that generate the electricity. The higher electricity demand created by the electric vehicles is met by higher fuel consumption in the power plants. Higher fuel consumption subsequently emits more CO₂ emission. Coal power plant generates the highest CO₂ and hydro-electric plant generates the lowest CO₂. The figure suggests that a complete switch to electric vehicles will continue to produce CO₂ emission indirectly regardless of the fuel source types.

![Figure 3. CO₂ emission by petrol-diesel and electric vehicles [15]](image)

However, closed examination of the graph indicates that there is possibility for fossil-fueled vehicles to become environmentally more attractive than electric vehicles if there is significant reduction in the emission. The CO₂ emission from petrol-diesel vehicles can be reduced further by using better quality fuels and additives, blending the gasoline with bio-ethanol for gasoline engines or installing more effective catalytic converters that transform NOₓ into harmless gases from diesel engines.

NOₓ reduction technology is readily available [16] and so is the carbon capture to reduce CO₂ emission from large stationary sources such as power plants [17-22] that generate the electricity. These technologies can be deployed immediately to assist the industries in confronting the emerging challenges and to become more resilient.
2.5. \( \text{NO}_x \) emission

There is a report on public health impacts of excess \( \text{NO}_x \) emissions from diesel passenger vehicles in Germany [23]. The study indicates that higher public exposure to \( \text{NO}_x \) would lead to higher mortality rate. Germany reportedly has the highest mortality rate among the European countries due to the excess \( \text{NO}_x \) emission allegedly coming from the diesel emission scandal [24].

Figure 4 shows that higher biodiesel content in the blended fuel reportedly causes higher \( \text{NO}_x \) emission [24]. However, increasing biodiesel concentration in blended fuel reduces particulate matter (PM), carbon monoxide (CO) and unburned hydrocarbon (HC) emissions due to the better combustion by the former than its petroleum diesel counterpart. Although emission from PM, CO and HC are reduced markedly, \( \text{NO}_x \) emission is a major concern as it affects public health. \( \text{NO}_x \) reportedly increases premature mortality rate. A bio-diesel blend or 100% use of bio-diesel, despite has the potential to achieve the carbon neutrality (provided that there is no emission from ILUC and direct emission), it could pose a serious threat to the public health due to the \( \text{NO}_x \) exposure. This is one of the most challenging issues that bio-diesel manufacturers should overcome to render bio-diesel attractive and promising fuel for both mobile and stationary sources.

![Figure 4. NOx emission by biodiesel engines [24].](image)

There are 7 approaches that can be exploited by the bio-diesel industry to reduce \( \text{NO}_x \) emission from diesel engines [16]. The first approach called humid air method feeds water vapour into the combustion chamber. The second method recycles the exhaust gas to the combustion chamber. The third method uses water injection and water emulsion. The fourth method uses high scavange pressure and compression ratio in the engine. The fifth method uses selective catalytic reduction. The sixth method uses two-stage turbocharger and finally the seventh method requires engine component modification.

Alternatively, di-tertiary butyl peroxide and ethylhexylnitrate may be blended with bio-diesel since they are known to reduce \( \text{NO}_x \) without PM trade-off. Additionally, tertiary butylhydroquinone, an antioxidant, is an effective \( \text{NO}_x \) reducing agent, may also be used but at the expense of slight PM increase.
3. Conclusion
Bio-fuel is important in fossil fuel based economy in order to achieve a degree of carbon neutrality and energy security. Although bio-petro fuels exhibit the highest environmental impact and produce the most CO₂ on burning, they have the potential to perform favourably if their carbon emission is reduced significantly through carbon capture technology. This would be a logical choice for countries with dominant fossil fuel economy such as the United States of America and other developing countries to consider in order to power their countries sustainably. One of the contributing factors for the United State withdrawal from Paris climate accord [25] but continue to take part in the international climate talks [26] possibly as a result of this contemplation.

While bio-ethanol shows high potential towards carbon neutrality, bio-diesel on the other hand lags far behind from that objective. Bio-diesel quality that reduces emission significantly needs to be re-engineered. Carbon credit is important for bio-fuels to stabilize the energy price. Carbon capture technology to capture the carbon dioxide emission from large stationary sources such as power plants needs to be annexed to the existing and new plants. An immediate action plan would be to deploy carbon capture technology in fossil fuel power plants. Lands for food security and security of natural forest need to be reserved. There should also be aggressive law enforcement on illegal forest clearance & open burning. Since natural, peat forest, natural rubber estates are an excellent carbon sink and oxygen source, 1G bio-fuel needs to forgo the use of these lands. Advanced bio-fuel with high yield, process economics and sustainability is needed in order to cater for the expected increase in energy demand. The designated lands for high yield 1-2G biodiesel resource cultivation/development need to be properly planned, executed and controlled. A new market for bio-petro fuels needs to be created in the future when electric vehicles have established their presence. A good example would be a liquid fuel cell technology that converts bio-petro liquid fuel directly into electricity. Finally, any dispute arising from energy issues needs to be resolved diplomatically between governments of the countries.

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