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RESEARCH ARTICLE

Palm Oil-based Fatty Acid Methyl Ester (FAME) Biodiesel to Meet High Blending Rates in Malaysia

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ABSTRACT

Palm oil methyl ester (PME) is a form of fatty acid methyl ester (FAME) which in principle is biodiesel. Malaysia could greatly leverage the abundance of PME sources given its status as a palm oil-producing country. In this paper, palm oil is evaluated for its potential as a biofuel feedstock and its derivatives' vast use in the domestic market but limited use in other regions. In order to create a growth market of PME, Malaysia has introduced an increase of PME blend component in its nation's biodiesel use for transport and industrial sectors. A phased increase from 5% to the latest of 20% PME blend in biodiesel certainly has the potential to reduce greenhouse gas emissions, while creating a boost to the local market. However, the government must be careful in managing subsidies of conventional petroleum-based diesel fuel, as this would have an eventual effect on the supply chain of biodiesel in Malaysia. There are limited studies on diesel fuel physicochemical characteristics that are used as base-stock for the biodiesel blend and whether it could be manipulated to maximise yield while maintaining conformance to mandated fuel standards. Multiple relevant research papers were studied of its relevance to PME use as biodiesel FAME to meet high blending rates in Malaysia.

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Introduction

Biodiesel is a form of diesel fuel that is produced from vegetable oil or animal fat instead of petroleum crude oil (Demirbas, 2009). Biodiesel is an expression that is frequently used for FAME (Fatty Acid Methyl Ester) irrespective of their source (rapeseed, coconut, palm oil, soy, used cooking oil, etc.). FAME is formed through a chemical process referred to as 'transesterification' which is the transformation of vegetable oils' fatty acids into their respective esters. Biodiesel and FAME are typically used as transposable terms (Hasan & Kalam, 2013), however in some countries, 'biodiesel' is used to refer to a blended product of biocomponent and conventional fossil diesel only, but not the pure bioproduct.

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The objective of this paper is to understand palm oil-based FAME's use as a biodiesel blend component and to establish the need to increase the blend ratio in Malaysia. The possibility of manipulating diesel fuel base-stock's physicochemical characteristics is also explored to check if more cost-effective fuel sources could be identified.

Types of Biofuels; The "Generations"

Today´s biofuels are made from food crops (e.g. vegetable oils, starch or sugar). These are often referred to as first-generation biofuels and they compete with food production for feedstock. Using new feedstocks like wastes from plant harvests or crops which cannot be eaten (inedible) along with innovative alteration processes do provide the potential of further reducing carbon dioxide (CO_2). Such feedstocks are known as advanced or "next-generation" biofuels (Simmons, Loque& Blanch, 2008). These novel biofuels' sources reduce the probability of competition with feedstock for food production. In fact, using such advanced biofuels' sources allow higher biofuel blends which in return would lessen CO_2 emissions from conventional fuels.

FAME in Malaysia; PME

There are many types of FAME, of which Palm Oil Methyl Ester (PME) is available in Malaysia due to the abundance of palm oil. PME is suitable for use as biodiesel in Malaysia due to its warm tropical climate. Palm oil and palm oil-based derivatives including PME biodiesel are not seemingly suitable in colder climate countries given their possibility of precipitation resulting in the formation of wax and presenting a hazy appearance. As such, PME became a need by itself to boost local use of palm oil and its derivatives, especially in palm oil-producing countries like Malaysia, Indonesia and Thailand. This led to the increased blend ratio on PME content in Malaysia's biodiesel. A step increase roll-out plan was initiated by the government and as a result, local domestic use of PME has increased over the past 10 years. This is expected to boost local agriculture by creating an internal market use for palm oil.

As per Malaysian biofuels blending regulations from the Malaysian Biofuels Industry Act 2007, there has been a blend ratio increase upon time. The PME blending ratio into petroleum-based diesel fuel started with 5% back in November 2011 and has increased to 20% by mid-2021 (Malaysian Biofuel Industry Act 2007, effective 2011 & 2019, Official MPIC Directive 2020). This blending ratio is only applicable to targeted sectors in Malaysia such as transportation and other subsidized sectors. Diesel with 5% bio content is known as B5 biodiesel while 10% bio content is termed as B10 biodiesel and so on.

The recent Covid-19 global pandemic coupled with the change of Malaysian government in March 2020, certainly did influence the timeline of higher PME blend biodiesel roll-out in Malaysia. The B20 biodiesel implementation's planned date was shifted to about 6-8 months later in 2020 and into 2021. The timeline shift has certainly affected the domestic crude palm oil price and as such the cost of biodiesel production subsequently. This further necessitates the higher blending rates outlined by the Malaysian government to create a structured 'outflow' or 'use' of palm oil, locally.

Biodiesel Brief

The original innovator of the current diesel-fueled engine, Rudolf Diesel, had designed his compression-based ignition engine to use numerous types of fuels such as water mixed coal-dust, vegetable oil and mineral oil. Only much later his engine was run on conventional petroleum diesel. A couple of years prior to his demise, Rudolf Diesel did mention that his diesel engine invention would help greatly in countries dependent on agriculture (Net website Pacific Biodiesel, 2019).

Throughout the 1940s World War II, vegetable oils were the alternatives for diesel fuel. At present, many countries prefer to switch to biofuels as there is a great expectation in pollution reduction, and primarily due to it being a renewable energy source (Owolabi, Adejumo & Aderibigbe, 2012). Biodiesel specifically provides an alternative to using fossil fuel-based diesel in the current diesel-powered engines. A direct and immediate conversion of fuel type can be done, whereby one could simply switch from using petroleum-based diesel to biodiesel blends.

The first or original generation biofuels are categorized as competition with feedstock for food production. As such, with more research and technological advancements, advanced "second" generation biofuels have been developed. This "next" generation type of biofuels drastically reduces the potential of contending with plantations (Figure 2.1).

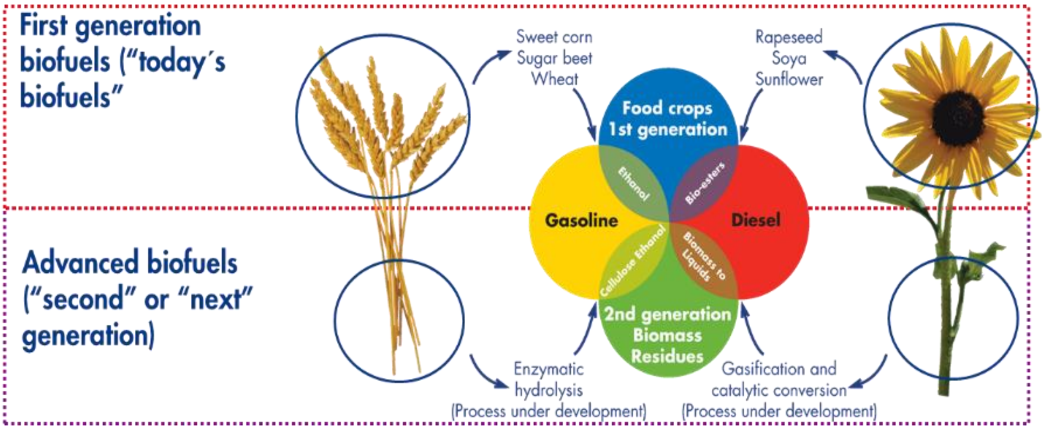

Figure 2.1. First and advanced generation biofuels sources

As for the synthesis of biodiesel, a chemical reaction referred to as 'transesterification' is needed. This is where triglycerides are reacted with alcohol (methanol, CH_3OH). The outcome of this process is glycerin as a byproduct and mainly FAME which is biodiesel (Figure 2.2).

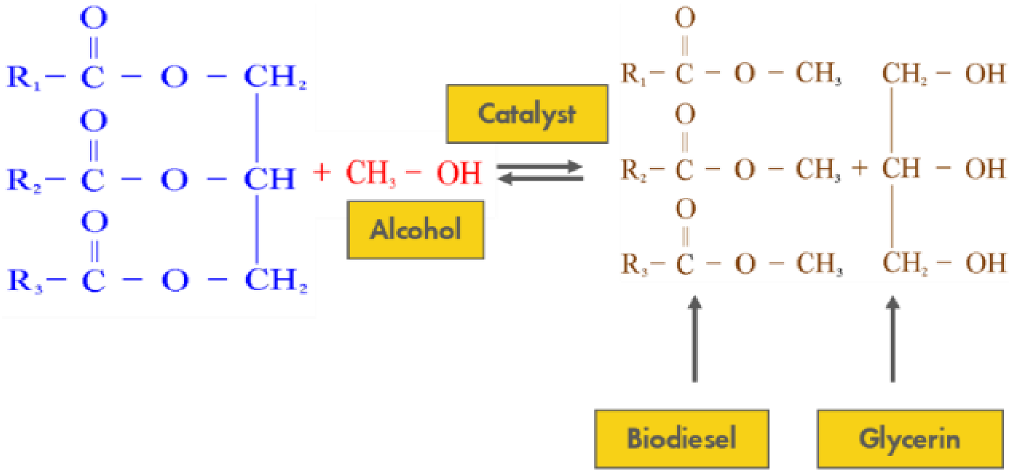

Figure 2.2. Biodiesel chemistry depicting organic molecule chains

FAMEs are classified according to the oil or fat from which they are derived. The sources vary from one country to another, depending on the availability of suitable plants which are grown, as it is dependent on the climate greatly. Palm oil methyl ester (PME) is only available in South East Asia, primarily in Malaysia, Indonesia and Thailand. Exports of palm oil and palm derivatives to Europe from this region are often influenced by international nature activists. Claims and accusations of intentionally set forest fire creating the haze phenomenon, use of child labour and threat to the wildlife including '*orang-utans*', have somewhat impacted the use of palm oil derivatives in the Europe/American markets.

Some of the common FAMEs are as in Table 2.1.

Table 2.1. Types of FAME

Type of methyl ester	Usage and production
RME (Rapeseed)	Predominantly in Europe (France, Austria, Germany). Now also being developed in China, Korea, and Taiwan
SME (Soyabean)	Predominantly in the USA, South America
PME (Palm)	Planted mostly in the South East Asia (Malaysia, Indonesia, Thailand), and also exported to Europe.
TME (Tallow)	Produced mostly in UK, Australia and New Zealand using tallow from the meat industry
JME (Jatropha)	One of the newest discoveries for biodiesel in the Asia Pacific region. Countries like China, India, Philippines, Indonesia, Thailand, Madagascar, South Africa and even Saudi Arabia are in the process of developing jatropha plantations.
CME (Coconut)	Produced in small quantities mostly in the Philippines, for local use with some export.
SunME	Sunflower Methyl Esters
UROME	Used Recyled Oil Methyl Esters are another source of biodiesels and are sometimes also given the terms below:
UVOME	Used Vegetable Oils Methyl Esters
UCOME	Used Cooking Oil Methyl Esters
UAOME	Used Animal Oil Methyl Esters

Direct Usage and Bio-blending

Vegetable oil, including palm oil-based, can be used as a fuel. This has been a revelation since 1980 (Ma & Hanna, 1999). While these types of biodiesel are usable, a blend does demonstrate better combustion and energy transfer. Among the benefits of using biodiesel of vegetable oils' sources, are its liquid movability, acceptable energy content which is a significant percentage of its diesel base-fuel volume, availability and renewability (Mishra & Goswami, 2017). In contrast, increased kinematic viscosity and lower volatility are the physical characteristics of any vegetable oil.

Vegetable oils as well as their bio-blends are not the easiest to manage neither does it operate smoothly for diesel engines. High kinematic viscosity and its acid composition, along with combustion and gum development when in storage, are key issues. In addition, other issues with vegetable oils would be the build-up of carbon and thickening of lubricating oil during usage of it.

PME Blending Rate in Malaysia

Malaysia National Biofuel Policy 2006 heavily promotes biofuels usage. The policy is aimed at the accomplishment of renewable resources as a supplement to the depleting supply of fossil fuels. Its objectives are to gather local resources for biofuels, to use currently available technology in generating energy for transportation and industrial sectors, to create biofuels exports opportunity and to benefit from the spin-off effect of more stable prices for palm oil (Malaysia National Biofuel Policy website, 2006).

In Malaysia, due to its richness of palm oil, the FAME used for biodiesel blend is palm oil methyl ester or PME. The government had initially planned on 1 January 2010 for a 5% blend of PME into conventional diesel, to be sold as B5 biodiesel at all retail fuel stations nationwide. However, the roll-out was deferred to June 2011 and restricted to certain states in Peninsular Malaysia including Selangor, Kuala Lumpur, Putrajaya, Negeri Sembilan, Melaka and areas of Northern Johor, Southern Perak and Western Pahang. A phased increase in blending rate was later planned and implemented in stages throughout Malaysia as can be seen from Table 2.2.1.

Table 2.2.1. Biodiesel blend timeline in Malaysia

Biodiesel Blend	Implementation Period (year)	Timeline
B5	2011 - 2014	Started off in the central region of Peninsular Malaysia (2011), then the northern region (2013), followed by the eastern region and East Malaysia (2014)
B7	2014 - 2015	Initially only in Peninsular Malaysia (Dec 2014) followed by nationwide (Jan 2015)
B10	2016	Nationwide only for Euro-IIM standard diesel
B20	2020 - 2021	Sarawak (Sep 2020), Sabah (Jan 2021) and Peninsular Malaysia (Jun 2021)

Physicochemical Properties of Biodiesel

According to El-Araby et al. in 2018, a trial confirmation of parameters such as density, viscosity and flash point for palm oil, biodiesel of palm oil origin and its blends was studied. It is understood clearly that there is a function or correlation of certain parameters in a biodiesel blend and its regular diesel base-stock. Biodiesel of increased bio-blends and its characteristics are summarized in Table 2.3.1.

Table 2.3.1. Different blends of biodiesel

Fuel	Density @15 °C g/ml	Kinematic viscosity @40 °C, mm^2/s	Flash point, °C
Diesel	0.827	2.28	64
B5	0.83	2.34	66
B10	0.833	2.49	69
B15	0.834	2.67	70.5
B20	0.835	2.82	71.5
B30	0.841	2.85	82.0
B100	0.877	4.56	196

Through some experimental results, it was concluded that as the bio-blend percentage (%) was made higher, the density increases. Palm oil-biodiesel mixture has kinematic viscosity which is high while its basic version of pure diesel is easier to flow as it has the lowest viscosity. As for the bio-blends, the viscosity range is wide. Flash points of diesel fuel are much lower than palm oil and its methyl ester, whereby there is no variation up to 20% in the case of biodiesel and 30% in the case of palm oil (El-Araby et al., 2018).

There has not been any previous study or research paper to determine if it is possible to manipulate diesel fuel physicochemical characteristics which are used as the base-stock for biodiesel blends. Thus, a further study on this is recommended, taking into consideration that the FAME used is of Malaysian palm oil origin with its own set of oil properties prior to being trans-esterified to palm oil methyl esters.

Literature Review

Several research papers were reviewed and the characteristics of palm oil biodiesel blends were analyzed. It was identified that there are no significant variations in bio-blends up to 30% FAME and in temperatures of 15 - 75 degree Celsius. Energy content is naturally reduced due to the reduction of fossil fuel-related carbon combustion. This is evident in the higher oxygen (O wt.%) content with slightly reduced carbon (C wt.%) content in biodiesel blends. A significant decrease in sulphur-related (SO_x) emissions is a direct correlation due to increased use of plant-based FAME and reduction in the petroleum-diesel component.

A summary of relevant findings based on selected research papers of biodiesel higher blends characteristic impacts is presented in Table 3.1. Authors and years, Research Paper titles and paper Conclusions are briefly mentioned.

Table 3.1. Summary of relevant research papers

Authors / Year	***Research Paper***	**Conclusion**
R. El-Araby, Ashraf Amin a, A. K. El Morsi, N. N. El-Ibiari, G. I. El-Diwani / 2017	*'Study on the characteristics of palm oil-biodiesel-diesel fuel blend'*	No noteworthy variance in fuel characteristics of bio-blends up to 30% volume of palm oil / palm oil-based biodiesel
C. Tsanaktsidis, K. Spinthiropoulos, G. Tzilantonis& C. Katsaros / 2016	*'Variation of density of diesel and biodiesel mixtures in three different temperature ranges'*	Density variation in bio-blends mix-volume part (fraction) have a direct (linear) relation
M. Valizadeh, S. Syafiie, I. S. Ahamad / 2014	*'Optimal planning of biodiesel supply chain using a linear programming model'*	Formulation of a linear model is developed to lessen total working costs (operational) of biofuel source and its supply chain
L. Razzaq, M. Farooq, M. A. Mujtaba, F. Sher, M. Farhan, M. T. Hassan, M. E. M. Soudagar,A. E. Atabani, M. A. Kalam and M. Imran / 2020	*'Modeling viscosity and density of ethanol-diesel-biodiesel ternary blends for sustainable environment'*	Density also the viscosity of binary bio-blends of diesel decrease with bioethanol addition. Two density and four viscosity models could determine the density and viscosity of ternary blends more accurately for temperatures ranging from 15 deg C to 75 deg C
S. K. Hoekmana, A. Brocha, C. Robbinsa, E. Cenicerosa, M. Natarajan / 2012	*'Review of biodiesel composition, properties, and specifications'*	Chemical composition directs the chemical and physical characteristics of a biofuel. As biodiesel has a considerable amount of oxygen content (usually 11%), that would mean it has lower carbon-hydrogen composition as compared to petroleum diesel. The direct impact of this is a 10% energy content reduction in mass which correlates to a volumetric energy reduction between 5-7%
R. M. Balabina, R.Z. Safievab / 2011	*'Biodiesel classification by base stock type (vegetable oil) using near infrared spectroscopy data'*	In recent years, bioethanol or biodiesel use as biofuels has significantly increased. When compared with infra-red, the near-infrared spectroscopy (>4000cm−1) is considered as cost-effective and immediate alternative for biodiesel quality control
Zulqarnain, M. H. M. Yusoff, M. Ayoub, N. Jusoh, A. Z. Abdullah / 2020	*'The challenges of a biodiesel implementation program in Malaysia'*	The manufacturing of biodiesel in Malaysia is still deemed as below capacity, with most production plants under-operating at < 25%. This is insufficient to satisfy the biodiesel energy demand of the country

A paper by Zulqarnain et al. in 2020 discusses how biodiesel has an advantage over regular petroleum-based diesel as it has better ignition-related features and heightened engine performance. This is despite the fact that energy content per molecule burnt is indeed lower. The summary of their work on characteristics of numerous bio-blends with conventional diesel is presented in Table 3.2 (Balabin & Safieva, 2018).

Table 3.2. Combustion properties of diesel bio-blends

	B0 (Pure Diesel)	B100 (Pure Biodiesel)	B20 (20% Biodiesel)	B50 (50% Biodiesel)
Density (kg/m^3)	837.90	860.00	842.32	848.95
Viscosity (cSt)	2.64	4.82	3.08	3.73
Higher heating value (MJ/kg)	44.79	39.9	43.81	42.35
Lower heating value (MJ/kg)	41.77	37.20	40.86	39.49
Cetane number	53.30	58.60	54.36	55.95
Air-to-fuel ratio	14.66	12.49	14.22	13.56
C (wt.%)	86.35	76.31	84.30	81.26
H (wt.%)	13.65	12.15	13.35	12.89
O (wt.%)	0.00	11.54	2.36	5.84

With the mentioned above works of literature reviewed, it becomes more assuring that some parameters such as density, cetane number, viscosity could be reviewed and "relaxed" in the country's diesel fuel specification. This would then provide an option to oil suppliers to produce base diesel intended for blending, which could still meet finished fuels blend specifications but at a slightly lower production or import cost.

Biofuels Legal Framework in Malaysia

According to Malaysia National Biofuel Policy 2006, a series of subsidiary actions to promote sectoral growth was developed. Nevertheless, since its implementation, the price of palm oil has climbed and at the same time, the price for fossil fuel has weakened, making it no longer economically viable for manufacturing palm oil-based biodiesel (Chin, 2011).

Malaysia National Biofuel Policy (MNBP)

The National Biofuel Policy was developed in the year 2005 after multiple stakeholder engagements and was built on previous research discoveries by the Malaysian Palm Oil Board (MPOB). Malaysia's Ministry of Plantation Industries and Commodities (MPIC) is the body that is accountable for the growth and operationalization of the biofuel policy. Back in 2005, during the set-up of the policy's framework, the Malaysian government was driven particularly by the necessity to alleviate palm oil prices as well as to identify potential new market entries. In March 2006, MNBP was eventually launched. It is supported by "five strategic thrusts", with operation stages of long-, medium- and immediate short-terms. Key benefits anticipated by the MNBP execution is to lessen dependence on fossil fuels, stimulate the increase of local manpower resources, use domestic technology in biofuel manufacturing, establish a new market for palm oil, control palm oil price and moderate the ever-challenging climate change by managing emissions (Figure 4.1) (Chin, 2011).

Palm oil has a vital part in providing the energy demand for the country by integration into Malaysia's national diesel supply through its derivative, biodiesel. Its usage as biofuel will generate a new mandate in the export business, thus serving to fortify Malaysia's position as a foremost manufacturer and exporter of palm oil. This then would benefit all investors in the local palm oil industry enduring to thrive and allow Malaysia to exercise higher assurance over palm oil cost.

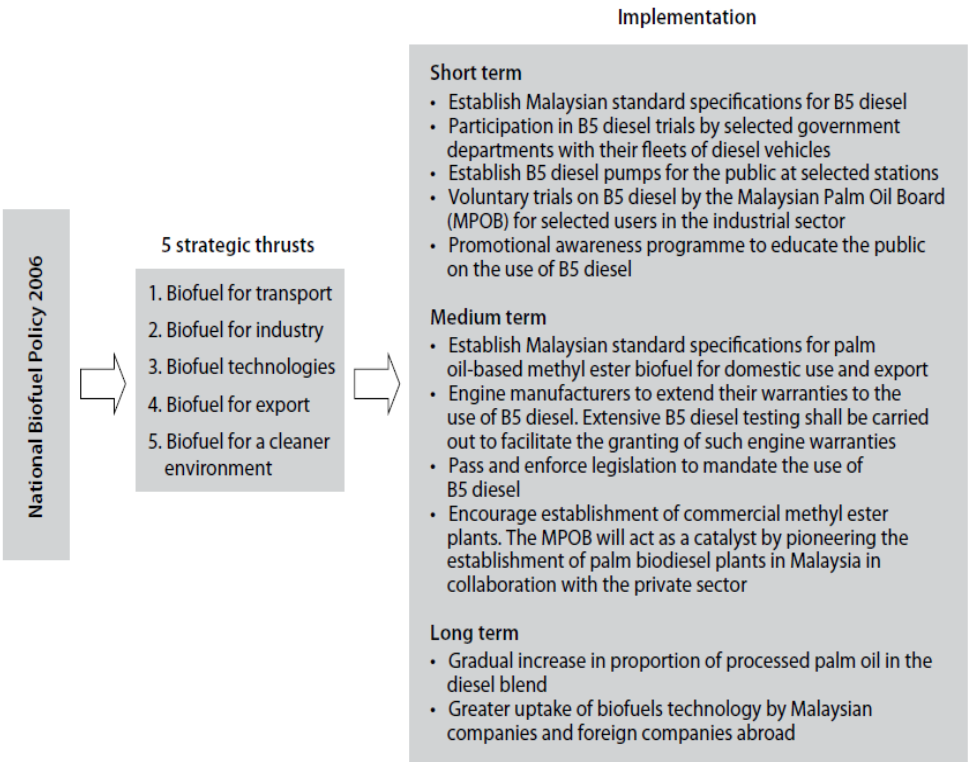

Figure 4.1. Malaysia National Biofuel Policy

Malaysian Biofuel Industry Act 2007

Pursuant to progress the Malaysia National Biofuel Policy (MNBP), a new legal act – Biofuel Industry Act 2007 was announced to continuously control and enable growth of the biofuels sector. This industrial act was legally enforced on 1 November 2008 and mandates the requirement to "add"/blend biofuel into petroleum diesel. Additionally, it is enacting the license issuance for downstream businesses, like manufacturing, bio-blending, logistics, export and inventory storage. The act only controls certain derivatives of palm oil, such as PME and palm olein, but not other categories of biofuels (Faizah, 2008).

Biofuels manufacturing licenses are issued by the Malaysian Ministry of Plantation Industries and Commodities (MPIC), a deliberate effort of re-designation of duties by the Malaysian Ministry of International Trade and Industry (MITI). Before this set-up took place, any desirable potential parties who intended to produce biofuels would have to officially apply for two authorizations; a production business license from the Malaysian Industrial Development Authority (MIDA) and another license from the Malaysian Palm Oil Board (MPOB) to use raw materials (palm oil) at the manufacturing plant. Hence, with this re-designation, a consolidated single license issued by MPIC would suffice.

Biodiesel and its Role in Environmental Quality

Currently, regular B0 diesel fuel specification (as per MS123:2014) is used to blend with B100 biodiesel (as per MS2008:2008). This is to fulfil the biodiesel blend regulation as per the Ministry of Plantation Industries and Commodities (MPIC) directive complying with the Malaysia Biofuel Act 2007. MS123 is developed to meet Environmental Quality (Clean Air) Regulations 2014 which has been enacted in accordance with Environmental Quality Act 1974 (Act 127). The latest 20% bio-blend rate requirement as of 1 January 2021 is for East Malaysia and 15 June 2021 onwards for Peninsular Malaysia. This B20 biodiesel is to comply with the latest MS123 and its FAME (Palm Oil Methyl Ester, PME) meeting MS2008.

Malaysia Government's Position

Malaysia is a country that focuses on palm oil plantation as its primary agricultural activity. Usage of palm oil in tropical countries is well established whereas palm oil and its derivatives used in four-season climates are not too encouraging due to the physicochemical properties of the product.

As such, with the rising interest in going 'green' globally and focus on sustainable resources, with limited ability to market palm oil to other regions, the Malaysian government must boost the local domestic use as well as manage its use overseas. With neighbouring countries also being palm oil producers, there is heavy competition within this region as well. Continuous consumption of palm oil and its biofuels version in European Union (EU) countries and well as United States of America (US) could boost international economic earnings. For this, the Malaysian government would need to actively engage with relevant EU and US agencies to ascertain confidently that palm oil is deemed as a desirable feedstock.

Malaysian government too must be careful in declaring reduction of emissions as a result of using palm oil-biodiesel and its production. Suitable policies to safeguard (or at least demonstrate safeguarding) agricultural land use are to be put-in-place (Faizah, 2008).

Simple commercial logic does indicate that biodiesel, especially with higher blends, would be more expensive than conventional diesel, given the rising palm oil prices and lowering of crude oil prices (Faizah, 2008). This means biodiesel is to be used mainly in local domestic logistics/transport or industrial sectors. The government should make a clear decision of subsidising it or not, and to relook into petroleum-based fuel subsidies for the local biodiesel market to be worthwhile.

Conclusion

The Malaysian government has developed a robust plan for the domestic rollout of palm oil methyl ester, PME-biodiesel. An attempt to strike a balance between boosting local agriculture-based revenue and managing greenhouse gas emissions has been addressed by multiple government agencies. Further to guide the industry, updated fuel specifications have been developed to ensure that higher biodiesel blends are suitable and acceptable. Department of Standards Malaysia also known as "Standards Malaysia", has established and rolled-out the specification of Euro II (2) M fuels through 'MS123-4:2020' high palm oil methyl ester, PME-blended diesel fuel. Specification of Euro V (5) via 'MS123-5:2020' high PME-blended diesel fuel in support of the national B20 biodiesel programme, has also been crafted and published. These new standards will give an advantage to vehicle makers, fuel manufacturers, wholesalers, and retailers by providing supervision, guidance and checks on the requirements for high PME diesel fuel. Both standards are referring to the final biodiesel blend of a-MS123 compliant base-diesel stock and a-MS2008 PME (FAME) compliant blend component.

As evidently mentioned in multiple relevant previous research and literature, several of the physicochemical properties of bio-blends are linear, thus presenting an opportunity to consider manipulating the base-stock diesel. This is to seek more base fuel diesel source options whereby it would directly impact the production and supply chain costs. Indirectly, this would also result in reduced production efforts in the oil refineries thus impacting overall carbon management and eventual sustainability of fuels.

Hence, as per the objective of this paper, the intent of the Malaysian government is strong, which is to progress palm oil-based FAME's use as a biodiesel blend component at a high blend ratio. It is also clear that there is a possibility of manipulating diesel fuel base-stock's physicochemical characteristics, which would enable oil suppliers to have more production and sourcing options.

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