ERIA Research Project Report FY2024, No. 13

Developing Biofuel-Based Road Transport Industry

Market Penetration Assessment of Biodiesel (B100) and Bioethanol (E100) as Road Transport Fuels in Indonesia

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ERIA
Economic Research Institute
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Developing Biofuel-Based Road Transport Industry:

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Preface

Indonesia aims to achieve four main objectives by the deployment of biofuels in road transport sector. First to contribute to meeting 23% renewable share target in 2025 total energy mix, to support the government's intention to reduce 29% of GHG emissions by 2030 compared to the business-as-usual scenario, to decrease the national trade balance deficit and improve energy security and self-sufficiency by reducing fossil fuel consumption and imports, and to develop the palm oil industry by stabilising CPO prices and adding values by down-streaming the palm oil industry.

The 2014 biodiesel blend mandate has been implemented with an increasing blending rate of 10% in 2014, known as 'B10', to 20% (B20) in 2016 and 30 % (B30) in December 2019. At the same time, Ministry of Energy and Mineral Resources (MEMR) data shows that diesel fuel imports decreased from 35% of total diesel fuel consumption in 2014 to 22% in 2018. Indonesia's blending rate should reach 40% (B40) by the middle of 2022.

Apart from using the biodiesel (B100) blend which is conventionally produced by transesterification of crude palm oil (CPO) fats with methanol known as 'FAME' or fatty acid methyl esters, Pertamina also plans to commercialise a new renewable fuel product called 'green diesel' (D100) or Refined, Bleached and Deodorized Palm Oil (RBDPO) categorised also as hydrotreated vegetable oil (HVO). Green diesel qualifies as a drop-in fuel, meaning that it can be blended with conventional diesel fuel, and it can use the same fuel supply infrastructure. In contrast to biodiesel, green diesel does not require adaptation of the vehicle powertrain or engines, making it more widely adoptable.

The Ministry of Industry of the Republic of Indonesia requested the Economic Research Institute for ASEAN and East Asia (ERIA) to conduct this study on "Developing Biofuel-Based Road Transport Industry: Market Penetration Assessment of Biofuels as Road Transport Fuels in Indonesia", which estimated the possible level of advancement of the different levels of biofuel blend in Indonesia based on the different economic and energy market situations, and developed a framework for policy recommendations to optimise the penetration level of biofuels towards 2040.

The study analysed first, the existing biofuel production technologies and paths in the world and the existing paths and technologies in Indonesia, second, the strategies and regulations to promote biofuel use, third, the automotive technology and the preparedness of the automotive sector to accommodate biofuel policies, and forth, the possible market penetration of the different biofuels and its impacts through modelling.

The report shows that several findings, among others: the importance of considering economic and energy market development, the need to synchronise the objective of promoting biofuels and of protecting health by reducing emissions from vehicles especially by the implementation of EURO IV vehicle and fuel standards, the importance of financing strategies, and the development of the coordinated policy measures across the different sectors – energy, industry, and agriculture – to be included in the biofuel roadmap.

On behalf of the Economic Research Institute for ASEAN and East Asia (ERIA), I would like to thank to the Ministry of Industry of the Republic of Indonesia for the opportunity given to ERIA to make contribution for the Republic of Indonesia through this study on Developing Biofuel-Based Road Transport Industry.

ERIA is ready to support continuously the Ministry of Industry of the Republic of Indonesia to build the analysis to support industry policies and planning in Indonesia.

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This study was conducted during the year 2020 following a series of workshops organised late 2019 – mid 2020 by the Maritime, Transport and Military Devices Directorate (IMATAP) of the Director General of Metal, Machinery, Transportation Device and Electronic Industry (ILMATE), of the Ministry of Industry. I was during that period the Director of IMATAP.

I would also like to thank Mr. Taufik Bawazier, the Director General of Metal, Machinery, Transportation Device and Electronic Industry (ILMATE), Mr. Sony Sulaksono, former Director and Mr Andy Kowara, former Expert Staff of the Maritime, Transport and Military Devices Directorate (IMATAP) and all the workshops' speakers and participants for their valuable contributions.

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List of Abbreviations and Acronyms

AEDP	Alternative Energy Development Plan
APROBI	Indonesian Biofuel Producers Association
ASENDO	Indonesian Spirits and Ethanol Association
ASTM	American Society for Testing Materials
CO	carbon monoxide
CO_2	carbon dioxide
CON	conservative situation or scenario
CPO	crude palm oil
GHG	greenhouse gas
ERIA	Economic Research Institute for ASEAN and East Asia
EU	European Union
FAME	fatty acid methyl ester
FFV	flex-fuel vehicle
H/C	hydrogen to carbon
HDO	hydrodeoxygenation
HEFA	hydro-processed esters and fatty acids
HVO	hydrogenated or hydrotreated vegetable oil
IEA	International Energy Agency
IMATAP	Directorate of Maritime, Transportation, and Military Industry
ITB	Institut Teknologi Bandung
MEMR	Ministry of Energy and Mineral Resources
MOD	moderate scenario
NOx	nitrogen oxide
OPT	optimistic scenario
PPO	pure plantation oil
R&D	research and development
RED	Renewable Energy Directive

RFS	Renewable Fuel Standard
RUEN	*Rancangan Umum Energy Nasional* (General Planning of National Energy)
US	United States
VEIA	Vehicle Technology Impact Assessment

Executive Summary

Indonesia would like to shift to a more balanced energy mix structure, i.e. to reach 23% of renewable share by 2025 and 31% by 2050. Promoting biofuel use in the road transport sector is one strategy to meet those targets.

The 20% mandatory biofuel blend in diesel fuel for road transport, called the B20 diesel fuel, has just been replaced by the B30 mandatory programme. The government is seriously targeting to increase the mandatory blending rate of biofuels and assess the possibility of introducing high-blended biofuels and the suitable vehicle technologies in the future.

The objectives of the study are twofold: (i) to estimate the possible level of advancement of the different levels of biofuel blend in Indonesia based on the different economic and energy market situations, and (ii) to develop a framework for policy recommendations to optimise the penetration level of biofuels towards 2040. Four sub-themes are, therefore, covered: (i) the existing biofuel production technologies and paths in the world and the existing paths and technologies in Indonesia, (ii) the strategies and regulations to promote biofuel use, (iii) the automotive technology and the preparedness of the automotive sector to accommodate biofuel policies, and (iv) market simulation through modelling.

The study reviewed the state-of-the-art of biofuel development in three countries where biofuel programmes are considered successful, i.e. Brazil and Thailand with their bioethanol and the United States (US) with their bioethanol and biodiesel programmes. Indonesia has so far proven its potential in building a biodiesel-based road transport sector that depends on palm agroindustry. Currently, it has demonstrated limited potential to produce bioethanol from sugarcane. The study also assessed the possibility and Pertamina's current capacity of producing drop-in green fuels from crude palm oil (CPO) as promising future biofuels.

Building a biofuel-based road transport industry would depend very much on external factors. In particular, the country's socio-economic development and the world energy market situation shall determine the competitiveness of biofuels relative to fossil fuels. Economic contraction due to the COVID-19 pandemic that intertwined with the drop in world oil price would reduce transport demand and transport fuel consumption, including biofuels. Economic experts are still discussing the impacts of both incidents in every economic aspect and how Indonesia would rebound in the future.

The use of the Vehicle Technology Impact Assessment (VEIA-ID) Model of the Economic Research for ASEAN and East Asia (ERIA) allowed estimating the impacts of three different scenarios where conservative (CON), moderate (MOD), and optimistic (OPT) situations or scenarios of biofuel development were simulated towards 2040. The three scenarios differ mainly in two assumptions. First, in terms of future economic and energy market development, including the estimated pandemic-related economic downfall and rebounding capacity of Indonesia. And second, in terms of biofuel policy measures where the most aggressive set of measures is implemented in the OPT scenario and the least aggressive set is implemented in the CON scenario.

Based on the simulation results, we recommend 10 principles in developing a biofuel roadmap for the transport sector:

- **The consideration of economic and energy sector as a key.** Economic growth determines economic activities that induce the movement of people and goods and demand for transport fuels. In the meantime, fossil fuel prices would develop following fluctuations in world oil market prices, which determine the competitiveness of domestically produced biofuels.
- **Cost-effectiveness to consider.** Biofuel policy measures would always reduce the country's dependency on fossil fuels and reduce direct carbon dioxide (CO_2) emissions. Nevertheless, policymakers should consider cost-effectiveness in reaching the determined targets. The simulation results show that the more optimistic the economic and energy market situation is, the more aggressive biofuel policies can be taken at lower costs.
- **Uncertainty is a major difficulty in planning a long-term biofuel roadmap.** We can only assume policies consistent with objectives, such as reaching Euro IV standards in fuels and reducing subsidies, especially in fossil fuels. If we stick to these objectives, we observe a significant increase in diesel prices resulting from cetane 48 diesel fuel elimination by 2025, which should increase the average diesel price higher than biodiesel. There should be no need to subsidise biodiesel starting in 2025. However, the increase in diesel and gasoline fuel prices to comply with the Euro IV standard, i.e. transport fuels with a sulphur limit below 50 ppm, is an issue that needs analysis and solutions, which are beyond the scope of this study.
- **Synchronising both biofuel and Euro IV objectives means Indonesia needs a policy roadmap** based most probably on the blend mandate of CPO–based biodiesel during the transition to Euro IV diesel fuel and the blend mandate of green diesel in the Euro IV diesel fuel period and beyond. The roadmap should be based on three principles.
  - ➢ First, gradually shifting to Euro IV diesel fuel without any diesel fuel price subsidy. Phasing out the currently dominant 2,500 ppm diesel fuel (not yet a complete shift to Euro IV standards) would trigger more than a 28% increase in the average diesel fuel price. Should the government refrain from subsidising diesel fuel, the price of CPO-based biodiesel would be lower than diesel fuel. Looking at historical price data from the Ministry of Energy and Mineral Resources (MEMR), the future price of CPO-based biodiesel will unlikely increase faster than that of diesel fuel.

    In this case, biodiesel subsidies would no longer be needed. The collected revenues from Indonesia's CPO export levy can then be fully used to build the oil palm agroindustry as mandated by Presidential Decree No. 61/2015. The main challenge with this policy is helping consumers to afford the more expensive Euro IV diesel fuel. To avoid economic shock, the government must prepare an effective subsidy scheme to prevent a sharp increase in production costs and, therefore, in the inflation rate. In all cases, Indonesia should not create any new diesel fuel subsidies.

    - Second, the biodiesel blending mandate policy should be maintained during the transition to Euro IV. The existing CPO-based biodiesel blend with high sulphur diesel fuel is good for direct emissions, as mentioned previously, and decreasing diesel fuel imports. Once Euro IV diesel fuel is available, high-blended CPO-based biodiesels – possibly as high as a 50% blend rate and beyond – can be sold as alternative (non-mandatory) fuels at gas stations. Simultaneously, flex-fuel vehicles, i.e. vehicles powered with low and very high blended biodiesel, will be available in the market.
    - Lastly, former MEMR Minister Ignatius Jonan once explained that green diesel should enter the market at Rp14,000 per litre. Therefore, economies of scale for green diesel should be created as soon as possible to decrease its price by introducing a very low percentage blend mandate. At the same time, a high percentage or pure 100% green diesel can be sold as an alternative (non-mandatory) fuel at gas stations. A study from the International Energy Agency (IEA) Bioenergy in 2020 suggested that feedstock costs can comprise 65%–80% of the production costs. Should CPO prices be controllable following the oil palm agroindustry's development, green diesel prices could also be reduced. A higher blend mandate can be reached once Euro IV diesel fuel is fully available.

- **The importance of financing strategies.** To reach determined targets would need some financing. In the current mandatory biofuel policies, the Indonesian government collects a CPO export fee to pay the price difference between pure diesel and biodiesel. This strategy would face difficulty when the demand for export CPO is low whilst the gap between high biodiesel price and low diesel price gets large, a possibility that can happen. Thus, the roadmap should be supported by a set of financing strategies. For example, feebate, i.e. a drop in biofuel prices at stations to compensate for the reduced fuel economy of high biofuel–blended fuels can be adopted. The decrease is obtained through a government subsidy from the fund collected by taxing conventional fuels. This scheme has been implemented in Thailand,[1] whose government gives a subsidy to reduce bioethanol high-blended (E85) fuel prices by taxing gasoline fuel prices.

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[1] https://www.fuelsandlubes.com/knowledge-base/fuel-consumption-in-thailand-in-uptrend/

- **Coordinated policy measures across the different sectors – energy, industry, and agriculture – need to be developed and included in the biofuel roadmap.** Whilst the economic situation and energy market condition can be considered exogenous, biofuel prices are key elements in the roadmap that can be affected by policy measures. The CPO-based biodiesel industry is well developed, but the bioethanol industry capacity is currently too low to meet demand from a national mandatory bioethanol blend programme. Innovative policy measures are needed to de-block the capacity bottleneck in bioethanol production to make its price competitive without jeopardising farmers' and producers' welfare. The development of such policy measures requires inter-ministerial cooperation.
- **In the road transport sector, gasoline consumption is still higher than diesel** with a ratio of around 55:45, whilst the gasoline–diesel fuel import ratio is around 70:30. Focus must clearly be given to biofuels that can substitute for gasoline. Apart from the problematic bioethanol, CPO-based green gasoline can play a more critical role in replacing pure gasoline. CPO is domestically produced; if it makes the most of green gasoline (and green diesel) cost component, those green fuels' prices would be more controllable.
- **In all situations, in 20 years, Indonesia should be able to replace at least 60% of diesel fuel consumption with diesel-based biofuels**, most likely with a combination of fatty acid methyl ester (FAME)–based biodiesel and green diesel mandates.
- The non-mandatory flex fuel and high-blend biofuel should enter in the later stage. Whilst gasoline–bioethanol flex-fuelled vehicles (FFVs) are available globally, Indonesia would need to deal with bioethanol production. High-blend biodiesel fuel with biodiesel FFVs may be an option later as the automotive industry would need around 5 to 10 years to produce this type of FFVs. Nevertheless, only luxury tax (PPnbM) reduction would not be enough to stimulate the strong sales of FFVs as these vehicles' fuel economy is on average less than conventional vehicles. Fiscal policy measures, such as feebate that give more advantage to biofuels, should boost FFV penetration in the automotive market.
- **Setting policy measures is arbitrary but impacts should always be assessed.** Policy measures incorporated in a roadmap are results of consultation and discussion involving stakeholders. This study proposes sets of policy measures adapted to the various economic and energy situations where biofuel and automotive industries' readiness has been considered. The proposed policy measures and their corresponding timeline are debatable. The discussion should include an assessment of policy measure impacts which should be used as an input to the discussion that creates an iterative process.

This study is limited in at least three aspects. First, the study cannot give the most reliable roadmap for a biofuel-based transport sector in Indonesia. The main reasons are the current high uncertainty in the country and the world's economic and energy price situation, and the lack of long-term biofuel policy measure package that can be used as a benchmark. Second, biofuel prices are assumed to grow at constant rates. The price should develop dynamically in theory, resulting from the interaction between the industry's supply and demand. Third, the study cannot assess the impact of biofuel policies in fossil fuel imports.

As a way forward, there are three main directions to follow. First, for economic experts to agree on how the economic situation and energy market would likely develop by 2040 and have (a) set(s) of long-term biofuel policy package to be assessed that should include financing strategies and policy measures in the biofuel industries. One emphasis should be on the short-term plan to comply with the EURO IV fuel standard, i.e. how to provide fuel at economical but affordable prices without increasing fossil fuel subsidy. Second, to develop a model of simplified biofuel sectors that allows estimating biofuel prices by 2040. Third, to develop a simplified model of refinery products' export and imports that allows assessing the impacts of biofuel policy measures on the import of those products.

Chapter 1

Introduction

Indonesia would like to shift to a more balanced mixed energy structure, i.e. to reach 23% of renewable share by 2025 and 31% by 2050. Promoting biofuel use in the road transport sector is one of the strategies to meet those targets.

The 20% mandatory biofuel blend in diesel fuel for road transport, called the B20 diesel fuel, was replaced by the B30 mandatory programme on 16 December 2019. The government is seriously targeting to increase the mandatory blending rate of biofuels and assess the possibility of introducing high-blended biofuels and suitable vehicle technologies in the future.

In 2006, several laws in the country regulated using specific blending percentages of bioethanol in gasoline fuel. However, implementing these regulations encountered several issues so that there is practically no bioethanol blend in gasoline transport fuel in Indonesia nowadays.

The first regulation to prepare the introduction of high-blended biofuels was issued in 2017, i.e. Presidential Regulation 22 of 2017 (RUEN 2017). Appendix 1 of RUEN lays the first direction on the introduction of flex-fuel engine vehicles. Flex-fuel engine vehicles are those whose internal combustion engine can be flexibly fuelled by conventional fossil fuels or 100% biofuels (B100 or E100). Furthermore, Government Regulation 73/2019 on luxury goods sale taxation explicitly relaxes taxes on the purchase of flex-fuel engine vehicles.

1.1. Why Indonesia Needs Biofuels

Crude palm oil (CPO)–based biodiesel is used by the Ministry of Energy and Mineral Resources (MEMR)[2] as a strategy to significantly reduce greenhouse gas emissions (GHG) if the upstream emission is not considered, assuming that industrial energy plantation absorbs GHGs. According to the MEMR (2020), the complete set of biofuel deployment objectives in Indonesia are as follows:

- to contribute to meeting 23% renewable share target in 2025 total energy mix,
- to support the government's intention to reduce 29% of GHG emissions by 2030 compared to the business-as-usual scenario,

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[2] As stated by Bp Sugeng Mujianto (MEMR) in the Workshop, 9 December 2020.

- to decrease the national trade balance deficit and improve energy security and self-sufficiency by reducing fossil fuel consumption and imports,
- to develop the palm oil industry by stabilising CPO prices and adding values by downstreaming the palm oil industry.

With the estimated increasing volume of biodiesel use, the Directorate General of New, Renewable Energy and Energy Conservation of the MEMR (2019) quantitatively summarised the effects of the biofuel mandatory programme in Indonesia in four areas: (i) increasing foreign exchange savings, (ii) increasing added value from processing CPO to biodiesel, (iii) increasing the number of labourers in oil palm plantations, and (iv) reducing GHG emissions.

Table 1.1. Quantified Benefits of Mandatory Biodiesel Programmes

	B20 Mandate (2018)	B20 Mandate (2019)	B30 Mandate (2020)
Used volume (million kilolitres)	3.75	6.62	6.59
Foreign exchange reserves (billion US$)	1.89	3.54	5.13
Added value from CPO processing to biodiesel (billion US$)	0.41	0.69	0.98
Number of labourers in oil palm agriculture	On-farm: 478.325 Off-farm: 3,609	On-farm: 828,488 Off-farm: 6,252	On-farm: 1.2 million labourers Off-farm: 9,055
Greenhouse gas reduction (million tonnes of CO_2)	5.61 ≈ 20,317 small buses	9.91 ≈ 35,908 small buses	14.25 ≈ 52,010 small buses

CPO = crude palm oil.
Source: MEMR (2019).

1.2. A Brief History of Indonesia’s Biofuel Policy

The first government regulations on biofuel were issued in 2006: (i) Presidential Decree No. 5 Year 2006 on national policies for optimising energy use and (ii) Presidential Instruction No. 1 Year 2006 on the use of biofuels. To support the implementation, the sixth president of the Republic of Indonesia, Susilo Bambang Yudhoyono, formed a

National Biofuel Development Team based on President Decision (*Keppres*) 20 Year 2006 to supervise the biofuel programme implementation and build a roadmap for biofuel development.

According to the national team's roadmap at that time, biofuel development in Indonesia aimed to reduce poverty and unemployment, generate more economic activities through the provision of biofuels, and reduce fossil fuel consumption. The first roadmap developed by the team aimed to reach 10% biodiesel blending percentage by 2010, 15% by 2015, and 20% by 2025. The roadmap also included targets on bioethanol blending percentages: 5% by 2010, 10% by 2015, and 15% by 2025.

Table 1.2. The First Biofuel Roadmap in Indonesia Developed by the National Biofuel Development Team

Year	2005–2010	2011–2015	2016–2025
Biodiesel	Biodiesel utilisation 10% of diesel fuel consumption 2.42 million kilolitres (kl)	Biodiesel utilisation 15% of diesel fuel consumption 4.52 million kl	Biodiesel utilisation 20% of diesel fuel consumption 10.22 million kl
Bioethanol	Bioethanol utilisation 5% gasoline consumption 1.48 million kl	Bioethanol utilisation 10% gasoline consumption 2.78 million kl	Bioethanol utilisation 15% gasoline consumption 6.28 million kl
Bio-oil • **Biokerosene** • **Pure plantation oil (PPO) for power plant**	• Biokerosene utilisation 1 million kl • PPO utilisation 0.4 million kl	• Biokerosene utilisation 1.8 million kl • PPO utilisation 0.74 million kl	• Biokerosene utilisation 4.07 million kl • PPO utilisation 1.69 million kl
BIOFUEL	BIOFUEL utilisation 2% of energy mix 5.29 million kl	BIOFUEL utilisation 3% of energy mix 9.84 million kl	BIOFUEL utilisation 5% of energy mix 22.26 million kl

Source: MEMR, as cited in Silviati (2008).

In 2008, the Indonesian government issued MEMR Regulation No. 32 on biofuel blending mandate that targeted the blending level at 10% by 2015 for industrial, transport, and power plant use. This regulation was amended twice – No. 25 in 2013 and No. 20 in 2014 – that finally set the starting date of B10 implementation in January 2014. In March 2015, the MEMR issued Regulation No. 12 Year 2015 to increase the blending percentage to 15% for industry and transport use starting on 1 April 2015, and 20% beginning on 1 January 2016. The ministry regulation set a blend rate of 25% for power generation beginning on 1 April 2015 and 30% starting 1 January 2016. The regulation set a blend rate of 30% of biodiesel for all uses starting 1 January 2020. MEMR Regulation No. 227 K/10/MEM/2019 set the blending percentage to 30%, which began on 16 December 2019.

Policy implementation on blending bioethanol with gasoline is not as successful as in the case of biodiesels. MEMR Regulation No. 12 Year 2015 has targeted a mandatory bioethanol blending level of 5% (E5) by 2020 and a further 20% (E20) by 2025. In practice, according to the Indonesian Spirits and Ethanol Association (ASENDO), between 2012 and 2017, around 500 kilolitres (kl) of bioethanol were blended with gasoline fuels. However, since 2018 there has been practically no more bioethanol to be mixed with gasoline fuel. Concrete measures on closing the price gap between producing fuel-grade bioethanol and gasoline price are still needed. As Wiratmini (2020) reported, the mandatory blending policies of bioethanol are under revision. The sources of incentive funding are being searched, and the government would start with a pilot project of blending 2% bioethanol in gasoline fuel in East Java in 2020.

1.3. Current National Policies

Current policies on biofuel use are based on the National Energy Policy or KEN[3] and the General Planning of National Energy or RUEN.[4] Presidential Regulation PP No. 79 Year 2014 regulates the National Energy Policy that targets the minimal renewable energy share in Indonesia's primary energy supply of 23% by 2025 and 31% by 2050.

As regulated by Presidential Regulation PP No. 22 Year 2017, RUEN set a biofuel target to increase by more than a factor of 6.5 by 2050. This means an average annual growth rate of 18.5%.

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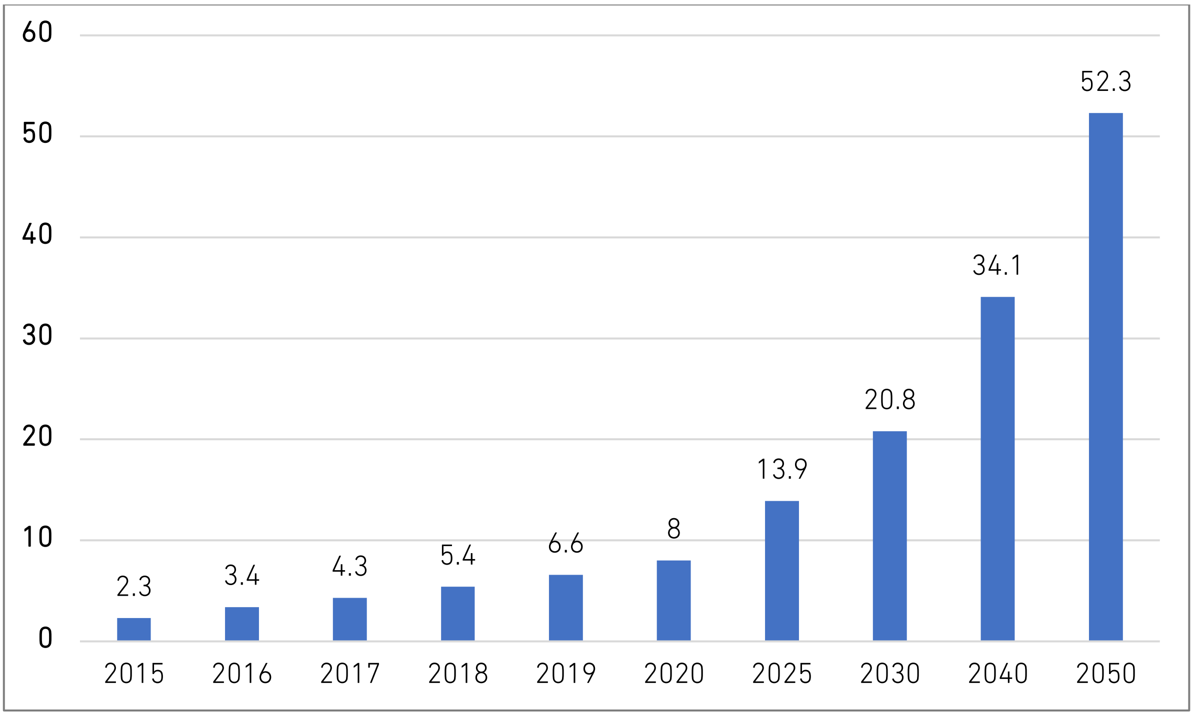
[3] *Kebijakan Energy Nasional* in Indonesian language

[4] *Rancangan Umum Energy Nasional* in Indonesian language

Figure 1.1. RUEN (2017) Biofuel Use Target (million kl)



Source: Authors based on RUEN (2017).

RUEN also targeted biofuel production as follows: 15.6 million kl by 2025 composed of 30% (11.6 million kl) biodiesel, 20% (3.4 million kl) bioethanol, and 5% (0.1 million kl) bio-jet fuel (bio-avtur), and 54.2 million kl by 2050.

To reach those targets, RUEN specified the following measures amongst others: (i) the gradual provision of 4 million hectares of land to meet biofuel feedstock demand between 2016 and 2025; and (ii) the continuous coordination with the Fiscal Policy Body of the Ministry of Finance to reach competitive biofuel prices, especially as bioethanol prices for food industry use are more profitable for producers.

MEMR Regulation No. 12 Year 2015 set blending percentage targets of biofuels in various applications.

Table 1.3. Mandatory Minimal Blend of Pure Biodiesel (B100) in the Total Pure Diesel Demand, %

Application	April 2015	January 2016	January 2020	January 2025
Microenterprise, fishery, agriculture, transportation, public service obligation (PSO)	15	20	30	30
Non-PSO transportation	15	20	30	30
Industry and commerce	15	20	30	30
Power plant	25	30	30	30

Source: MEMR Regulation No. 12 Year 2015.

Table 1.4. Mandatory Minimal Blend of Pure Bioethanol (E100) in the Total Pure Gasoline Demand, %

Application	April 2015	January 2016	January 2020	January 2025
Microenterprise, fishery, agriculture, transportation, public service obligation (PSO)	1	2	5	20
Non-PSO transportation	2	5	10	20
Industry and commerce	2	5	10	20

Source: MEMR Regulation No. 12 Year 2015.

Table 1.5. Mandatory Minimal Blend of Pure Bio-oil (O100) in Pure Gasoline, %

Application		April 2015	January 2016	January 2020	January 2025
Industry and transportation (low- and medium-speed engine)	Industry	10	20	20	20
	Maritime transport	10	20	20	20
Air transport			2	3	5
Power plant		15	20	20	20

Source: MEMR Regulation No. 12 Year 2015.

1.4. Objectives of the Study

The study aims (i) to estimate the possible level of advancement of the different levels of biofuel blend in Indonesia and their impacts based on various economic and energy market situations; and (ii) to develop a framework for policy recommendations to optimise the penetration level of biofuels and FFVs by 2040.

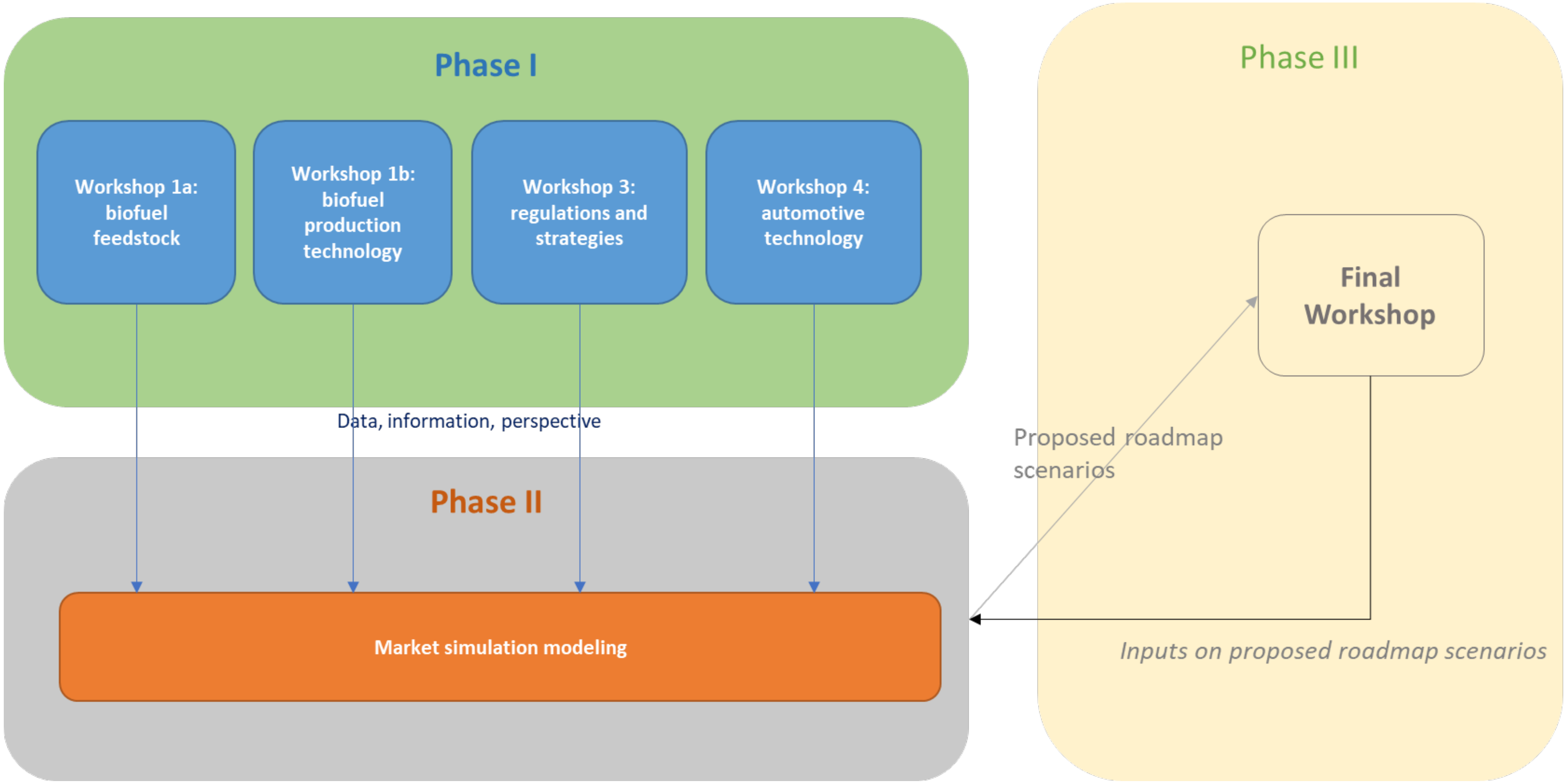
1.5. Methodology

This study covers four sub-themes:

- The existing biofuel production technologies and paths globally and in Indonesia
- Strategy and regulation to promote the use of biofuels
- Automotive technology and the preparedness of the automotive sector to accommodate biofuel policies
- Market simulation through modelling.

Chronologically and methodologically, this study will have three phases (Figure 1.2).

Figure 1.2. Three Phases of the Project



Source: Authors' elaboration.

Phase I Workshops and Audiences

The first phase will consist of organising three workshops to gather information, data, and perspectives of all involved stakeholders in the first four sub-themes. The first step's final objective is to collect information and data for developing a roadmap of biofuel policy implementation in Indonesia, emphasising the possible penetration of high-blended biofuels and flex-fuel engine vehicles.

The second phase will consist of a market simulation through a modelling activity based on data, information, findings, and targets, resulting from the first step. The third phase will consist of an analysis of the market simulation results. In this phase, we shall compare the impacts of various policy measure sets that include the different mandatory and non-mandatory biofuel programmes implemented in the various economic and energy situations represented in several scenarios using data and information gathered in phase 1. The results would be discussed with experts, and feedback on the proposed scenarios would be gathered to produce the final set of proposed roadmaps based on the framework.

Phase II Market Simulation Modelling

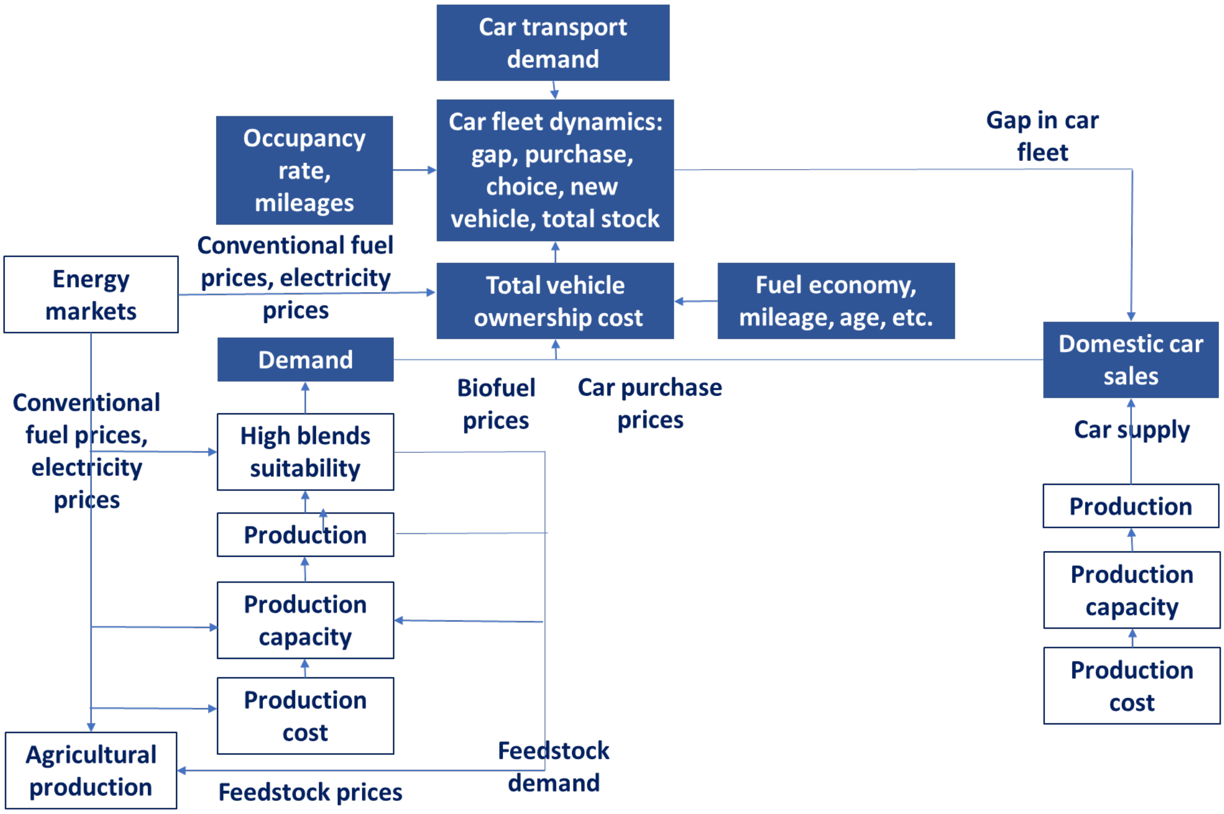
We shall assume several biofuel policy measures to be implemented in three different economic and energy situations that include mandatory and non-mandatory biofuel programmes. The mandatory programmes oblige the blending of pure diesel and pure gasoline with a certain percentage of biofuels that would take place in different years during the whole period. In the non-mandatory programmes, we assume that both high-blend biofuels and FFVs would enter the Indonesian market soon (simultaneously in a particular year) as new alternative fuels and vehicle technology that would compete against existing car vehicle technologies (conventional, electric vehicles, etc.). High-blend biofuels mean that the different biofuel blending rates would require significant changes in vehicle technologies compared to existing ones. From the workshops and data collection, we could collect data and information to build a set of proposed scenarios to be simulated.

Simulation using a model would be performed using data and information obtained in the study's first phase. The VEIA Model (VEIA-ID), currently being developed by the Economic Research Institute for ASEAN and East Asia (ERIA), would be used for that purpose. The modelling aims to estimate the penetration level of each vehicle technology (including flex-fuel engine vehicles) based on a logit model used to estimate user choice of technology when purchasing a new vehicle. The main assumption is that each consumer would select a vehicle technology that minimises the total ownership cost. The model can then simulate the impact on the various fiscal policies related to vehicle purchasing and operations.

Based on the economic and demographic framework, using the model, we shall estimate transport demand, the total number of vehicle units in operation, and the number of new and scrapped vehicles each year during the simulation period. With fuel economy and efficiency, and emission factor data, we could calculate the use of fuels and their related air pollutions and emissions.

Figure 1.3 shows the main blocks of the model. Blue blocks are the different market simulation blocks of the model, whilst the white ones are input elements obtained from phase I activities.

Figure 1.3. Modelling Concept



EV = electric vehicle, FF = flex fuel, ICE = internal combustion engine.
Source: Authors' elaboration.

1.6. Working Plan

The first phase of the project comprises the organisation of three workshops. Those workshops have been and would be organised by the Directorate of Maritime, Transportation, and Military Industry (IMATAP) of the Ministry of Industry.

Table 1.6 shows the name of the organised and future workshops by the directorate.

Table 1.6. Workshop in Phase I

Workshop No.	Date	Theme	Objective	Invited Experts
1a	9 December 2019, 09.30–12.30	Biofuel feedstocks	To obtain data and perspectives from producers and other stakeholders involved in the overall biofuel feedstock or raw material supply chain	- Ministry of Industry – Directorate Forestry and Agroindustry - The Indonesian Association of Biofuel Producers (APROBI) - Indonesian Spirits and Ethanol Association (ASENDO)
1b	9 December 2019, 14.00–17.00	Biofuel production technologies	To obtain data and perspectives from producers and other stakeholders involved in the biofuel production	- Pertamina - Faculty of Industry Technology of Institute Technology of Bandung (ITB) - Idemitsu Lube Techno Indonesia - Ministry of Energy and Mineral Resources - Centre of Oil and Natural Gas Research and Development (LEMIGAS)
2	10 December 2019, 09.30–13.00	Biofuel regulations and strategies	To obtain projections, strategies, and plans related to advanced biodiesel supply	- Ministry of Energy and Mineral Resources – Directorate Bioenergy - Kepala BPDP - Ministry of Energy and Mineral Resources – National Energy Council
3	15 January 2020,	Flex-fuel vehicle technology	To obtain car manufacturer's data, perspectives, projections, and	- PT Toyota Motor Manufacturing Indonesia

Workshop No.	Date	Theme	Objective	Invited Experts
	09.00–15.00		strategies to deal with advanced biofuel regulations	- PT Hino Motor Manufacturing Indonesia - PT Isuzu Astra Motor Indonesia

Source: Authors' compilation.

Chapter 2

State-of-the-Art of Biofuel Development: A Review of International Experiences

This chapter summarises how biofuel policies are implemented in different parts of the world. We selected four world regions or countries where policies on biofuels for road transport exist and where the implementation has resulted in significant blend rates: Brazil, the United States (US), the European Union (EU), and Thailand.

2.1. Brazil

Brazil is currently the world's largest producer and exporter of biofuels worldwide, particularly bioethanol. Brazil succeeded in developing bioethanol as the leading biofuel for transportation, making it the second-largest bioethanol producer after the US and the world's greatest exporter (Worldwatch Institute, 2007; Basso et al., 2012). The Brazilian government's commitment and long-term role in promoting biofuels are key factors to this success. Government-funded research agencies have played a strategic role in consolidating knowledge and human capacity to maintain leadership in the bioenergy sector (Cortez et al., 2014). It is necessary to allocate more private research and development (R&D) expenditure and implement government actions to train human resources in bioenergy. Thus, increasing competency at all stages of bioenergy development is crucial to ensure its sustainability.

2.1.1. Brazilian bioethanol programme – *ProŻlcool*

Brazil has implemented successful renewable energy over the last 30 years, called *Proálcool*, also the world's first large-scale biofuel programme. *Proálcool* was the country's response to the international oil crisis. It was launched in 1975 to reduce the dependency on imported oil and promote bioethanol production using sugarcane as feedstock (Cortez et al., 2014). The low price of sugar in the international market also supported this decision, creating an attractive policy.

Proálcool regulated two main actions: (i) a mandatory programme to use 10% anhydrous ethanol as an additive to gasoline not requiring changes in the motors, and (ii) a voluntary programme to use 100% hydrated ethanol (95% ethanol + 5% water) in modified Otto-cycle motors (Goldemberg, 2006). According to Cortez et al. (2014), the government proposed a particular standard, 'standard distillery', to determine a minimum capacity production of ethanol per day, around 120,000 litres of alcohol. Recently, Brazil improved the standard of up to approximately 1 million litres of ethanol per day.

Regarding the readiness of the automobile industry in response to the *Proálcool* programme, the multinational automobile industries based in Brazil have produced all the necessary engine and vehicle modifications for bioethanol use. Thus, almost no change was required in the engine of the E10 fuel type (Goldemberg, 2006). However, minor adaptations needed to be developed for fuel blend ranging from 20% to 26% of bioethanol. In the 1980s, the major car companies agreed to install assembly lines for 100% bioethanol, and resulted in reaching the highest demand of bioethanol. Simultaneously, the supply of bioethanol as fuel was half of the total fuel consumed in the country (Basso et al., 2012).

Under the *Proálcool* regulation, the government combined tax breaks and blended mandates that drove investment in bioethanol production and resulted in rapid programmes in the nation's bioethanol industry. Furthermore, in the early stages, the Brazilian government created several subsidy programmes, including low-interest or 'soft' loans to sugarcane refinery contractors, to build ethanol distilleries. The programmes encouraged people to purchase pure ethanol vehicles by setting an attractive price for bioethanol to gain a competitive advantage (Goldemberg, 2006; Basso et al., 2012). As a result, Brazilian state-owned oil company Petrobras started investing in distributing bioethanol throughout the country. Bioethanol production then boomed more than 500% during that period (Sandalow, 2006). Additionally, the government strictly regulated bioethanol's price to be lower than gasoline based on energy content and its distribution to all petrol stations (Basso et al., 2012; Cortez et al., 2014).

From the mid-1990s to 2002, the government cut its support to price controls and subsidies for sugar and bioethanol production and logistics (Goldemberg, 2006; Worldwatch Institute, 2007). This restructured policy did not occur overnight. The government gradually deregulated this subsidy scheme, which allowed Brazil to become a major exporter of sugar (Cortez et al., 2014). During that period, the automotive industry had already begun favouring the sale of cars running on gasoline-ethanol blends (ranging from E20 to E25).

At the beginning of the 21st century, the automobile industry identified a need to produce a flexible engine that would work with any proportion of bioethanol in fuel mixture to address the ethanol supply fluctuations. Thus, in 2003, the first Brazilian flex-fuel vehicle (FFV), Volkswagen car, was launched. Up to these days, most of the produced ethanol is consumed domestically, and approximately 90% of the new vehicles sold in Brazil are FFVs (Basso et al., 2012; Cortez et al., 2014).

2.1.2. Bioethanol feedstocks

Bioethanol is produced from a wide variety of renewable feedstocks, roughly classified into three distinct groups: (i) fermented sugars (sugarcane, sugar beets, sweet sorghum); (ii) starches and fructose (corn, potatoes, rice, wheat, agave); and (iii) cellulosic (stoves, grasses, corn cobs, wood, sugarcane bagasse). Sugarcane presents higher economic and environmental benefits than other crops based on the ethanol production process (Basso et al., 2012). Additionally, its drought tolerance also contributes to some agricultural advantages.

Sugarcane bagasse also plays an essential role in the energy balance of sugarcane ethanol. It can be used to generate steam for milling, heating, distilling, and electricity cogeneration, making an ethanol plan benefit energy security and energy export (Goldemberg, 2006; Basso et al., 2012). This bagasse can generate energy and avoid using any fossil fuel in industrial activities, reducing the cost of ethanol production.

Moreover, various research conducted by multiple Brazilian universities and research centres provided important information, including plant nutrition, agricultural practices, sugarcane varieties, and technology transfer for the agriculture and industry sectors to maximise sugarcane production for bioethanol. Through R&D, studies discovered specific techniques to maximise the interaction of soil quality, weather condition, agricultural practices, and satellite images for species identification in cultivated areas. These significantly increased the sugarcane yield for biofuel (Goldemberg, 2006). Technological advancements associated with sugarcane farming and bioethanol production have incredibly played a crucial role in yielding significant benefits in sugarcane-based ethanol. Research funding came not only from the government but also from the private sector.

2.1.3. Replication of bioethanol production in other developing countries

Most developing countries have sugarcane plantations and can produce bioethanol for domestic supply and export. Table 2.1 shows the top 10 sugarcane producers globally in 2018, confirming the significant potential for bioethanol production.

Table 2.1. Top Producers of Sugarcane, 2018

No.	Country	Sugar Cane Production (million tonnes annually)	Harvested Area (thousand hectares)
1	**Brazil**	**746.83**	**10,042**
2	India	376.90	4,730
3	China	108.72	1,415
4	Thailand	104.36	1,372
5	Pakistan	67.17	1,102
6	Mexico	56.84	786
7	Colombia	36.28	409
8	Guatemala	35.57	300
9	Australia	33.51	443
10	United States of America	31.34	364
13	**Indonesia**	**21.74**	**417**

Source: FAOSTAT (2018).

It is possible to maximise sugarcane production to supply bioethanol to other developing countries. If each country could introduce 10% of bioethanol to substitute for gasoline, nearly 30 million hectares of land, around 3% of the total area of harvested crops worldwide, would be needed. Furthermore, this will contribute significantly to reducing GHG emissions (Goldemberg, 2006).

2.2. The United States of America

The US Biofuels Policy came about sometime in 2005–2006 due to the increased concerns about clean energy, agricultural surpluses, and climate change impacts. Biofuels development aimed to stimulate the production and use of biofuels under the assumption that its use would decrease imported oil dependency, decrease GHG emissions, and increase rural incomes (Tyner, 2008). As a significant part of the US economy, mobility, and livelihood, the transport sector becomes the main reason for developing biofuels. This sector consumes around 70% of imported oil (US EIA, 2012), and passenger vehicles accounted for roughly 20% of CO_2 emissions in the US (US DOT, 2015). Thus, cleaner sources of transport fuel are needed.

Ethanol and biodiesel are the most widely available biofuels to date. From 2009 to 2013, the government strongly supported the US biofuel industry to increase its output and prepare to fulfil an expanded Renewable Fuel Standard (RFS2) (US EIA, 2012), requiring increasing volumes of biofuel use. The following sections elaborate the development of bioethanol and biodiesel, followed by supported policies in biofuels in the US.

Ethanol utilisation

Most ethanol in the US is distilled from corn. The starch is broken down to obtain glucose syrup, which is fermented to produce ethanol. This process has a significantly lower energy ratio than sugarcane-based ethanol (Brightman and Sivell, 2007).

Historically, the US has been blending ethanol into gasoline since the late 1970s. It gradually increased in the early 2000s and became a significant portion of the gasoline pool.

Table 2.2 and Figure 2.1 provide an overview of fuel ethanol in the US from 2000 to 2019. In the early era, ethanol production was allocated to fulfil the specific demand for ethanol. In 2004, according to the Committee on a Framework for Assessing the Health, Environmental, and Social Effects of the Food System (2015), the 2004 enactment of the volumetric ethanol excise tax credit changed the gas excise tax exemption into a tax credit for ethanol producers, set initially at 51 cents per gallon. When 2004 oil prices started climbing in 2005, the government published the Energy Policy Act, which subsidised fuel ethanol and mandated ethanol use under a renewable fuel standard (RFSI1) to reach 7.5 billion gallons by 2012 (Tyner, 2008). Multiple incentives and financing credits regulated by the government resulted in ethanol production; consumption rose significantly in 2007–2008.

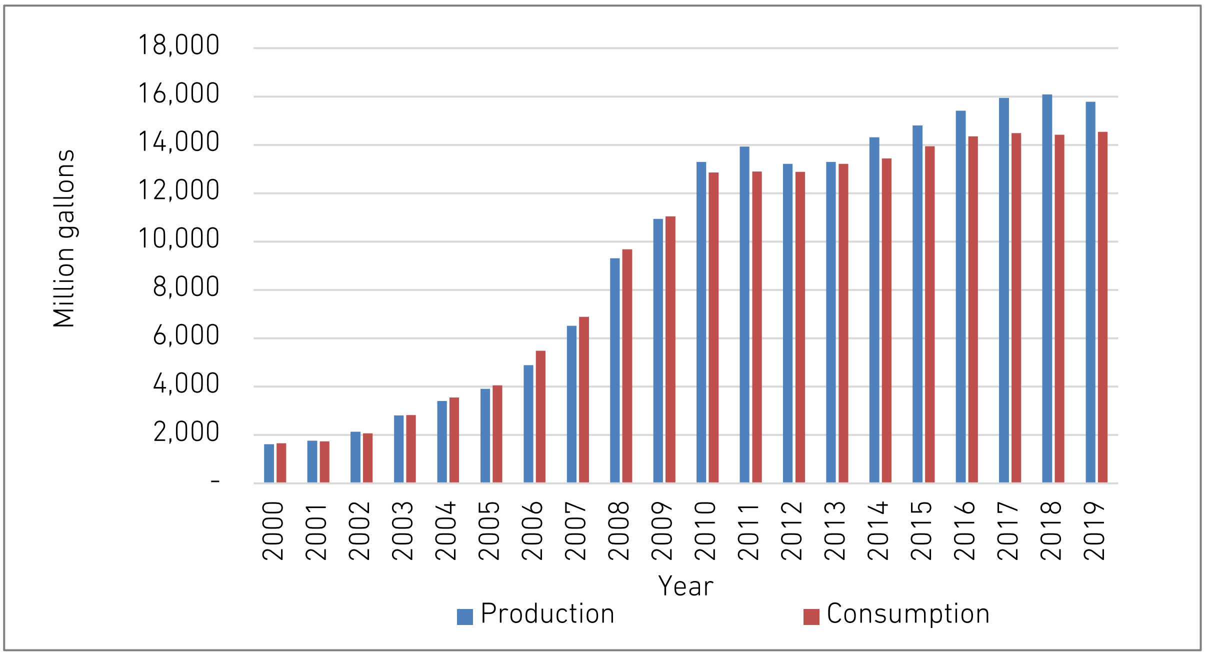
Ethanol production grew consistently from around 200 million to 300 million gallons of total per year in 2008 through 2011. In 2012, the US gasoline market's saturation with E10, coupled with less favourable export markets, forced the industry to stop and reduce ethanol production (US EIA, 2012). It was also caused by a major drought across the Midwest, where most US corn crops are planted, lowered production for crops, and higher prices. Nonetheless, the market started growing back in 2014 and kept rising to the latest data in 2019.

Table 2.2. The US Fuel Ethanol Overview, 2000–2019
(million gallons)

Year	Production	Consumption
2000	38,627	39,367
2001	42,028	41,445
2002	50,956	49,360
2003	66,772	67,286
2004	81,058	84,576
2005	92,961	96,634
2006	116,294	130,505
2007	155,263	163,945
2008	221,637	230,556
2009	260,424	262,776
2010	316,617	306,155
2011	331,646	306,984
2012	314,714	306,711
2013	316,493	314,658
2014	340,781	320,095
2015	352,553	332,064
2016	366,981	341,817
2017	379,435	344,882
2018	383,127	343,342
2019	375,629	346,091

Source: US EIA (2020c).

Figure 2.1. The US Fuel Ethanol Overview, 2000–2019



Source: Authors.

Over 99% of gasoline sold in the US contains E10, a blend of 10% ethanol and 90% gasoline by volume. However, it is limited and not suitable to use in non-FFVs made before 2001. Moreover, starting in 2011, a small amount of ethanol was sold as E85, a blend of 51%–93% ethanol by volume and gasoline. Then, the US Environmental Protection Agency ruled that cars and light trucks of the model year 2007 and above can use E15 (gasoline with 15% ethanol).

On the standards specification of ethanol-gasoline blends, the American Society for Testing Materials (ASTM), an international standardisation institution, developed a specification particularly for E85 to ensure proper vehicle starting, operation, and safety in varying temperature conditions. ASTM D5798 – a fuel quality standard for E85 (flex fuel) – regulates that fuel retailers and fleets purchasing E85 should meet quality standards (US DOE, n.d). In the case of the US, the seasonal condition should be considered for ethanol–gasoline blends. For instance, E85 sold during winter should contain lower levels of ethanol to ensure the vehicle can run in freezing temperatures. On the other hand, there is no concern with carrying over winter fuel into the summer months because FFVs can operate on any blend of ethanol and gasoline during warm weather. Therefore, ASTM D5798 allows a range of ethanol content between E51 to E83 due to various circumstances (US DOE, 2016a).

Table 2.3. ASTM D5798-11 Ethanol Flex-Fuel Specification

D5798-11 Standard Specification for Ethanol Fuel Blends for Flexible-Fuel Automotive Spark-Ignition Engines				
Property	Value for Class			
ASTM Volatility Class	1	2	3	4
Vapor pressure, psi	5.5–9.0	7.0–9.5	8.5–12.0	9.5–15.0
	All Classes			
Ethanol content, vol %	51–83			
Methanol, maximum vol %	0.5			
Sulphur, maximum mg/kg	80			
Acidity as acetic acid, maximum mass%	0.005			
Unwashed gum, maximum mg/100 ml	20			
pHe	6.5–9.0			
Inorganic chloride, maximum ppmw	1			
Water, maximum mass %	1			
Appearance	The product shall be visibly free of suspended or precipitated contaminants (shall be clear and bright).			

Source: US DOE (2016a).

Regarding the ethanol price, the government sets a subsidy and other financial schemes to keep ethanol competitive in the market. For 7 years, 2004–2011, the US government promoted the ethanol–gasoline blends through a tax credits programme for the bioethanol industries, called the volumetric ethanol excise tax credit and known as 'blender tax credits' (US EIA, 2012). The schemes were to provide the following:

- 45 US$ cents per gallon credit for blending ethanol in gasoline
- 54 US$ cents per gallon tariff on ethanol imports, and
- 10 US$ cents per gallon credit for small producers of ethanol.

As a clean-burning, high-octane motor fuel, generated from renewable crop resources, the price of ethanol is considerably lower than gasoline. In the US, the average price of ethanol is US$1.8 per gallon from 2011 to 2019, almost half the average price of gas. The prices shown in Table 2.4 illustrate that ethanol price is at the competitive level with gasoline.

Table 2.4. Price Comparison between Ethanol and Gasoline in the US, 2011–2019
(US$/gallon)

Year	Ethanol	Gasoline	Price Differences*
2011	2.70	2.90	-0.20
2012	2.37	2.93	-0.56
2013	2.47	2.90	-0.43
2014	2.34	2.66	-0.32
2015	1.61	1.88	-0.28
2016	1.55	1.56	-0.01
2017	1.45	1.81	-0.36
2018	1.23	2.11	-0.87
2019	1.26	1.94	-0.68

*Negative numbers represent the average ethanol prices that are lower than gasoline.
Source: USDA (2020).

The US distributes most ethanol across the country through rail shipment, which contains about 100 cars in a unit train. All cars are loaded with ethanol and sent to a single destination from its refineries. This method is considerably more cost-effective for transporting large volumes of biofuels.

Low-level blends ethanol, such as E10, can be sold in most conventional gasoline stations. In general, fuel providers can offer E15, E85, and other ethanol–gasoline blends in their station. However, they must upgrade their existing service station pumps, such as storage tanks and other associated systems, if they want to include E15 or E85 in their retail. There are over 2,000 and 3,600 stations for E15 and E85, respectively, throughout the US. All retail stations must follow the minimum standard of retail station equipment, which ASTM D5798 standardisation regulates.

Biodiesel development

Decades after the development of ethanol, the US consumed only small amounts of biodiesel before 2001. Since then, the US began producing biodiesel commercially mainly due to the availability of various government incentives and requirements to produce, sell, and utilise biodiesel. In 2001, around 9 million gallons of biodiesel were produced primarily from soybean oil. In 2018, about 54% of soybean oil was utilised to make biodiesel in the US. This was followed by corn oil (15%), recycled feedstocks such as used cooking oils and yellow grease (13%), and canola and animal fats, each contributing 9% to biodiesel production (US EIA, 2019).

Biodiesel production doubled, reaching around 250 million gallons in 2006, and gradually rose to 2010, where the production plummeted to 340 million gallons (Table 2.5 and Figure 2.2). Declining production was due to the expiration of the biodiesel tax credit at the end of 2009 (US EIA, 2012). Like the financial incentives for ethanol, the US government created the biodiesel tax credit in 2005, amended it in 2010, and extended it until the end of 2013. This scheme regulated products of pure biodiesel and renewable diesel that meet ASTM specifications; these products are eligible for a US$1.00/gallon tax credit upon use or sale of said fuel (Carriquiry, 2007). The credits included were:

- 1 US$/gallon biodiesel tax credit for producers or blenders of pure biodiesel
- 1 US$/gallon renewable diesel tax credit for producers or blenders of biomass-based diesel or renewable diesel blends, and
- 10 US$ cents/gallon tax credit for small producers or agri-biodiesel (biodiesel produced from virgin agricultural products such as soybean oil or animal fats).

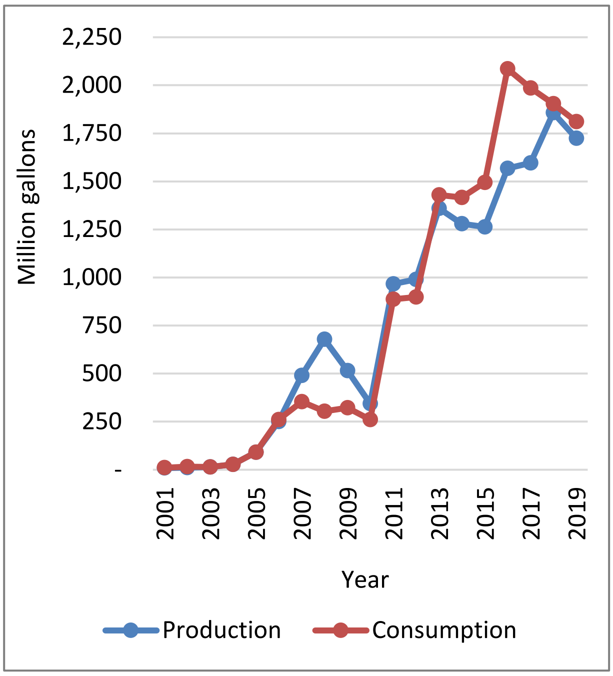
Nonetheless, the government reinstated the credit retroactive in late 2010, thus assisting the biodiesel industry to recover. This brought back the production levels in 2011 fulfilled the adjustment of RFS2 with a volume of 1 billion gallons of biomass-based diesel (US EIA (2012).

Table 2.5. The US Biodiesel Overview, 2001–2019 (million gallons)

Year	Production	Consumption
2001	8.58	10.27
2002	10.48	16.36
2003	14.21	13.51
2004	27.98	26.84
2005	90.79	90.83
2006	250.44	260.93
2007	489.83	353.71
2008	678.11	303.56
2009	515.81	321.83
2010	343.45	260.08
2011	967.48	886.17
2012	990.71	899.05
2013	1,359.46	1,428.84
2014	1,278.98	1,416.86
2015	1,263.35	1,494.16
2016	1,567.73	2,085.44
2017	1,595.71	1,985.28
2018	1,857.32	1,903.71
2019	1,724.29	1,810.70

Source: US EIA (2020c).

Figure 2.2. The US Biodiesel Overview, 2001–2019



Source: EIA (2020c), modified by authors.

The federal renewable fuel standard (RFS) has played a vital role in biodiesel development in the US since 2001. Biodiesel consumption reached its peak in 2016, with about 2,000 million gallons of biodiesel used throughout the US. However, it started declining in 2017 due to tariffs imposed on biodiesel imports from Argentina and Indonesia, two of the largest sources of US biodiesel imports, which effectively removed all those volumes from US supply.

Furthermore, US domestic consumption of biodiesel is majorly allocated for transport fuel. Most trucks, buses, and tractors use diesel fuel, which is a non-renewable fuel. Yet, biodiesel can practically be operated on diesel fuel–based vehicles. Any diesel engine can run using biodiesel at different bend levels by volume – 5% (B5), 20% of biodiesel with 80% of petroleum diesel (B20), or pure biodiesel (B100). Indeed, each level needs an upgrading system to ensure that the biodiesel will not damage the engine. Some US federal and state government fleets, such as school and transit buses, garbage trucks, mail trucks, and military vehicles, had been using B20 and higher. Meanwhile, lower-level biodiesel blends, such as B2 and B5, are more prevalent in the trucking industry due to their excellent lubricating properties, which are beneficial for engine performance.

In the case of B100, technical procedures for handling it vary and are distinguished from diesel fuel. B100 has specific attributes that should be considered when handling, storing, and using it (US DOE, 2016b). Firstly, B100 is a good solvent; it can dissolve varnish and sediments in fuel tanks and fuelling systems left by conventional diesel over time. Secondly, B100 gels at higher temperatures than most diesel fuels. Then, B100 is incompatible with some hoses and gaskets, as well as some metals and plastics.

Biodiesel fuel blend stock (B100) for middle distillate fuels are regulated under ASTM D6751-20 on standard specifications. Table 2.6 explains the requirements for biodiesel (B100) blend stock.

Table 2.6. ASTM D6751-20, US B100 Requirements

Requirements for Biodiesel (B100) Blend Stock as Listed in ASTM D6751					
Property	Test Method	Grade No. 1-B, S15	Grade No. 1-B, S500	Grade No. 2B, S15	Grade No. 2-B, S500
Sulphur, % mass (ppm), max	D5453	0.0015 (15)	0.05 (500)	0.0015 (15)	0.050 (500)
Cold soak filterability, s, max	D7501	200	200	360	360
Monoglycerides, % mass, max	D6584	0.40	0.40	-	-
		Requirements for All Grades			
Calcium and magnesium combined, ppm, max	EN14538	5			
Flashpoint (closed cup), °C, min	D93	93			
Alcohol control One of the following shall be met: 1. Methanol content, mass %, max 2. Flashpoint, °C, min	EN14110 D93	0.2 130			
Water and sediment, % volume, max	D2709	0.050			
Kinematic viscosity, mm^2/s, 40°C	D445	1.9 – 6.0			
Sulfated ash, % mass, max	D874	0.020			
Copper strip corrosion, max	D130	No. 3			
Cetane number, min	D613	47			
Cloud point, °C	D2500	Report			
Carbon residue, % mass, max	D4530	0.050			
Acid number, mg KOH/g, max	D664	0.50			
Free glycerine, % mass, max	D6584	0.020			
Total glycerine, % mass, max	D6584	0.240			
Phosphorus content, % mass, max	D4951	0.001			

Requirements for Biodiesel (B100) Blend Stock as Listed in ASTM D6751		
Distillation temperature 90% recovered, °C, max	D1160	360
Sodium and potassium, combined, ppm, max	EN14538	5
Oxidation stability, hr, min	EN15751	3

Source: US DOE (2016b).

In terms of biodiesel regulation in the US, the country has experienced multiple policy and program adjustments since 2000. Energy policy and the industry, environmental, and agricultural sectors influenced biodiesel development (Carryquiry, 2007).

The rapid extension of biodiesel production in early 2000 was mainly triggered by a 1998 amendment to the 1992 Energy Policy Act, requiring a portion of new vehicle purchases by particular fleets to be alternative fuel vehicles. It allows new alternative fuel vehicles to comply with biodiesel use, including at least B20.

Cash support from the USDA Commodity Credit Corporation's Bioenergy Program to producers encouraged biodiesel production. A reimbursement system was applied in this programme. Initially, the payments were eligible only for oil crops–based biodiesel, yet it expanded, allowing other feedstocks, including animal by-products, fats, and recycled oils of an agricultural origin. The programme ended in mid-2006.

Further support was created through the American Jobs Creation Act (the Jobs Act) of 2004, or so-called 'blender tax credit', which was discussed earlier. Lastly, the Energy Policy Act of 2005 provided incentives to both the supply and demand sides, including grants, income tax credits, subsidies, and loans to promote biofuel R&D.

2.3. The European Union (EU)

The Renewable Energy Directive (RED) is the main policy reference on renewable energy issues, including biofuel use for road transport, to be implemented by EU member states.

The current and the first RED was issued in 2009 (2009/28/EC Directive). It mandated 20% of EU's total energy to be filled with renewables and 10% renewable energy blending target for the transport sector by 2020. These were mainly to be achieved through the national targets of the member states required to individually submit a planned share in the national renewable energy action plans.

RED defines specific sustainability requirements for conventional liquid biofuels. According to USDA (2018), the European Commission (EC) amended these sustainability requirements in the Indirect Land Use Change Directive 2015/1513 (9 September 2015). Notably, the EC capped the use of conventional (food-based) biofuels at 7% and set non-binding national targets for advanced biofuels (non-food based) at 0.5% for overall energy use.

RED stipulates that biofuels can only be counted against the EU and/or member state targets if biofuels fulfil the following minimum percentage of GHG savings of each biofuel compared to the respective fossil fuel (Article 7 of EU Directive 98/70/EC as revised by EU Directive 2015/1513):

- 2009–2017 period: 35%
- 2018 and onwards: 50% for biofuels produced in installations that started production on or before 5 October 2015 or 60% for biofuels produced in installations that started production after 5 October 2015.

According to the EU's most recent biannual progress report (European Commission, 2020), the EU is on track to meet its 20% targets but will likely not meet the binding 10% renewable energy target for the transport sector. In more detail, the transport sector is slightly below the planned share in the national renewable energy action plan, i.e. 8.03% actual versus 8.50% planned.

RED 2009/28/CE allowed waste-based biofuels to be counted twice in calculating the shares of renewable energies in transport. This aimed to encourage the use of second-generation waste-based biofuels produced from feedstocks as used cooking oil or animal fat not intended for consumption, representing great saving potential and considerable environmental advantages, such as reduced GHG emissions.

Table 2.7 shows the updated biodiesel and bioethanol mandates as of 2020 of the 28 EU member states. The list shows that EU member states use two different units to calculate biofuel penetration: percentage of energy content (% calorie) and percentage of volume (% volume). At least 14 countries also implement the double-counting system to promote waste-based biofuels and animal fat or other regulated feedstocks.

Table 2.7. Biodiesel and Bioethanol Mandates by the 28 EU Member States

Country	Overall	Biodiesel		Bioethanol		Double Counting
	Percentage (% calorie)	Starting Year	Percentage (% cal)	Starting Year	Percentage (% cal)	
Austria	5.75 plus 0.5 advanced biofuel	2020	6.3	2020	3.4	No
Belgium		2020	9.9	2017	9.9	Possible upon approval
Bulgaria		2012	5.0 (1st generation) 1.0 (2nd generation)	2020	7.0 (cap on crop-based biodiesel) 1.0 (2nd generation)	No
Croatia	8.81	2020	7.49	2020	1.0	2nd generation and waste-based biofuels
Czech Republic		2020	6.0	2020	4.1	Yes
Denmark	5.75 plus 0.91 advanced biofuels (2020)					
Finland	20 (2020)					
France		2020	8.2	2020	8	Yes
Germany	6.5 (cap on crop-based biofuels) with 0.05 2nd generation biofuels					
Greece		2020	7.0	2020	3.3	No
Hungary		2020	8.2	2020	6.1	Waste-based biofuels produced from used cooking oil (UCO) or

Country	Overall	Biodiesel		Bioethanol		Double Counting
	Percentage (% calorie)	Starting Year	Percentage (% cal)	Starting Year	Percentage (% cal)	
						non-intended for consumption animal fat
Ireland	11 (2020)					UCO, cat 1 Tallow, spent bleached earth (SBE), palm oil mill effluent (POME), whey permeates
Italy	9 of which advanced biofuel 1.0 (0.68 biomethane and 0.23 other advanced biofuels) (2020)					
The Netherlands	16.4 of which advanced biofuel 1.0 with cap on conventional crop-based biofuel 3.0 (2020)					Yes
Poland	8.5 (2020)					Yes
Portugal	10 (2020)					Yes
Romania	10	2020	6.5	2020	8.0	Yes

Country	Overall	Biodiesel		Bioethanol		Double Counting
	Percentage (% calorie)	Starting Year	Percentage (% cal)	Starting Year	Percentage (% cal)	
Slovak	8.0 of which 0.5 advanced biofuels (2020)					yes
Slovenia	7.5 (2015)					Yes
Spain	8.5 (2020)					Yes
United Kingdom	9.180 (% volume) Or 0.109 (% calorie)	2019				Certain waste or residue feedstocks determined by scheme administrator; plus energy crops and renewable fuels of non-biological origin; also development fuels

Source: USDA Foreign Agricultural Service (2020).

RED II or Directive (EU) 2018/2001 issued in December 2018 (European Parliament, 2018) raised the overall EU target for renewable energy sources consumption by 2030 to 32%. The European Commission's original proposal did not include a transport sub-target, which co-legislators introduced in the final agreement. Member states must require fuel suppliers a minimum of 14% of the energy consumed in road and rail transport by 2030 as renewable energy.

RED II shall also limit the share of food-based biofuels for each member state to 1% above each state's consumption level in 2020, and impose an overall cap of 7% of the final consumption of road and rail transport for each member state. RED II also sets ambitious binding targets for the use of advanced, non-food-based biofuels (not derived from fats and oils) to 3.5 % by 2030 and a blending cap of 1.7% for advanced biofuels produced with waste fats and oils. If approved, RED II would introduce new minimum GHG savings for biofuel compared to fossil fuel of 70% for biofuels produced in installations that started production after 1 January 2021.

According to the European Commission (2020), most biofuels consumed in the EU comprise biodiesel (77% FAME or HVO [hydrogenated or hydrotreated vegetable oil) or bioethanol (16%), whilst other liquid biofuels (6%) are not specified. Still, about 59% of the feedstock used for biodiesel consumed in the EU in 2018 was imported or produced from imported feedstock, whilst 41% came from EU feedstock, mainly rapeseed (26%), used cooking oil (8%), and animal fat (5%) (European Commission, 2020). The main non-EU countries of origin are Indonesia (17%) and Malaysia (8%), whose palm oil is used for biodiesel in the EU, and Argentina (9%), which exports biodiesel made from soybeans. Ethanol consumed in the EU is produced mainly from EU feedstock (73%), including from wheat (34%), maize (24%), and sugar beets (14%), and only a small amount from cellulosic ethanol. Non-EU feedstock accounts for about 27% of the EU bioethanol market, mainly maize from Ukraine, Brazil, the US, and Canada.

The European Parliament (2017) issued a resolution on 4 April 2017, calling on the European Commission to phase out vegetable oils that drive deforestation, including palm oil, as a component of biofuels, preferably by 2020. RED II or Directive (EU) 2018/2001 (European Parliament, 2018) called for a specific limit to biofuels, bioliquids, and biomass fuels produced from food and feed crops with high indirect land-use change risk, and for which a significant expansion of their feedstock production area into land with high carbon stock is observed, based on the amount of the concerned member state's consumption level in 2019. The European Commission Delegation Regulation Act on March 2019 (European Commission, 2019) completed the Directive (EU) 2018/2001 with a timeline to gradually phase out those types of biofuels starting 2023 to 0% by 2030 at the latest. EU member states must transpose RED II into national law by 30 June 2021.

On 9 December 2019, Indonesia consulted with the EU at the World Trade Organization (WTO) regarding specific measures imposed by the EU and its member states concerning palm oil and oil palm crop–based biofuels from Indonesia. Several other palm oil–exporting countries – Colombia, Costa Rica, Guatemala, Malaysia, and Thailand – followed Indonesia. By 12 November 2020, WTO's Dispute Settlement Body established a panel on the dispute of palm oil and oil palm crop–based biofuels at the request in Indonesia (World Trade Organization, 2020).

2.4. Thailand

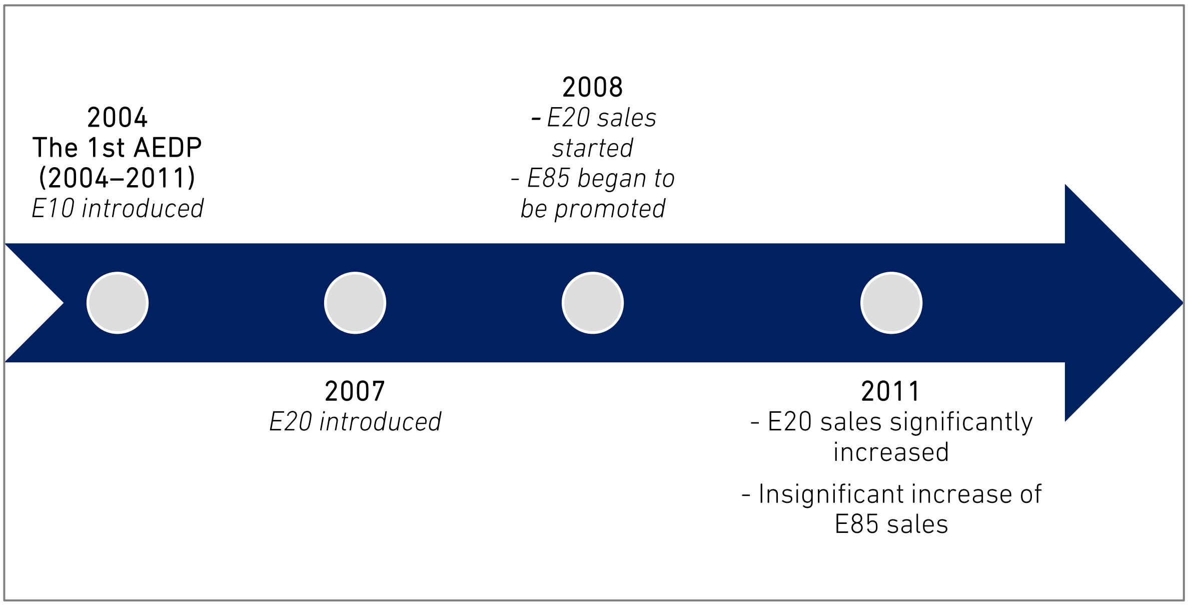
Limited fossil fuel resources in Thailand force the government to find alternative fuel sources for the future. The transport sector consumed around 60% of the country's final energy consumption (Padrem, 2019). Therefore, government policies continue to enhance alternative fuels, especially biofuels, to curb CO_2 emissions from transportation. The latest Alternative Energy Development Plan (AEDP) 2015–2036 (replacing AEDP 2012–2021) sets an overall goal to generate 30% of total energy consumption from renewable energy by 2036, whilst biofuel is targeted to increase from 7% of total fuel energy use in 2015 to 25% in 2036 (Preechajarn and Prasertsri, 2018). To accomplish the target, the Thai government set the ethanol consumption target of 4.1 billion litres by 2036, and the biodiesel consumption target at 5.1 billion litres by 2036.

2.4.1. Bioethanol

In 2004, the Thai government established the first AEDP (2004–2011) to increase biofuel production, its R&D, and public awareness of biofuels use. The Thai government generated ethanol mainly from cassava and sugarcane. E10 was the first biofuel commercially introduced in this period. It is gasohol blended from 10% ethanol and 90% gasoline, with octane number 95 RON (Wattana, 2014).

After a year of ethanol sales, several issues emerged: unclear information about types of compatible vehicles for E10, consumer perception of E10 could damage their vehicle, and the relatively high price of ethanol charged by ethanol manufacturers. In response, the government adjusted the policy by setting E10 prices lower than regular gasoline. As a result, E10 sales significantly increased about fourfold, from 3.5 million litres/day in 2006 to 12 million litres/day in 2009 (Wattana, 2014). The success of E10 implementation inspired the Thai government to promote E20 and E85 production in 2007 and 2008, respectively. E20 sales were as successful as E10; meanwhile, E85 implementation faced difficulties due to the technical incompatibility to the older vehicles and the limited number of new E85 vehicles. Figure 2.3 shows the early development of ethanol in Thailand.

Figure 2.3. Bioethanol Production under the AEDP 2004–2011



Source: Authors (2020).

In terms of ethanol generation standards and specifications, Thailand established a regional standard for ethanol-blended gasoline, led by the Thai Industrial Standards Institute (Worldwatch Institute, 2007; Rehnlund, 2008). Most (95%) of the ethanol produced is used as solvents for general purposes. However, anhydrous ethanol (99.5% ethanol content) is blended with gasoline (a mixture known as gasohol in Thailand) for gasoline engines. Moreover, Thailand has two different technical specifications for gasoline: gasohol octane 91 and octane 95. Both demand a minimum content of 9% volume per volume (v/v) denatured ethanol and maximum ethanol content of 10% v/v/ (Bloyd, 2009).

Regarding biofuel pricing, the government set price subsidies for ethanol and biodiesel, which are paid by the State Oil Fund (Rehnlund, 2008; Wattana, 2014; Tongroon, 2018). For ethanol, at the early stage, its price referred to the ethanol FOB price at the Brazilian Commodity Exchange San Paolo in Brazil, with some modifications considering freight insurance, loss, and other costs (Bloyd, 2009).

Furthermore, the government set gasohol price 20%–40% cheaper than premium gasoline and maintained E20 and E85 retail prices at approximately 30%–40% below premium gasoline (Preechajarn and Prasertsri, 2018). The government also supports the manufacturing of vehicles that are compatible with E20 and E85 gasohol.

Up to September 2018, there were already 4,085 stations for E20 and 1,258 stations for E85 nationwide (Preechajarn and Prasertsri, 2018). Regarding fuel efficiency, the government promotes vehicle fleet's improvements by setting the excise tax rate for eco-cars (less than 1,300 cc engines with a fuel consumption rate of no more than 5 litres/100 kilometres) at 17% compared to 30% for E10 vehicles. Moreover, the government provides an additional 3% reduction in the excise tax rate for the manufacture of eco-cars, which can use E85 gasohol (Preechajarn and Prasertsri, 2018). Table 2.8 shows the price structure of gasoline and gasohol in November 2018.

Table 2.8. Price Structure of Premium Gasoline and Gasohol in Bangkok, as of November 2018

(baht per litre)

	Premium Gasoline (Octane 95) (baht)	Gasohol (baht)			
		E10 Octane 95	E10 Octane 91	E20	E85
Ex-refinery factory price	16.43	17.05	16.63	17.73	21.59
Excise tax	6.50	5.85	5.85	5.2	0.98
Municipal tax	0.65	0.59	05.85	0.52	0.098
State Oil Fund	7.68	1.72	1.72	-1.18	-6.78
Conservation Fund	0.10	0.10	0.10	0.10	0.10
Wholesale price (WS)	31.36	25.30	24.88	22.37	15.98
Value-added tax (VAT)	2.20	1.77	1.74	1.57	1.12
WS+VAT	33.56	27.07	26.62	23.94	17.1
Marketing margin	3.07	2.22	2.39	2.34	3.59
VAT	0.22	0.16	0.17	0.16	0.25
Retail price	**36.84**	**29.45**	**29.18**	**26.44**	**20.94**
In IDR	18,427.44	14,730.95	14,595.89	13,225.34	10,474.23

Note: Exchange rate = 33.13 baht/US$; baht to IDR= 500.202 IDR/baht.
Source: Preechajarn and Prasertsri (2018).

2.4.2. Biodiesel

The government introduced biodiesel production and consumption in 2005, starting from B5 (a blend of 5% of methyl ester (B100) and 95% regular diesel). However, it did not work well due to unclear pricing policy, unclear appropriate standards of biodiesel, ambitious enforcement of B100 standards, and refusal by automobile companies to use B5 because of vehicle compatibility (Wattana, 2014). Furthermore, in 2008, the government ordered the production of B2 biodiesel to allow relevant parties to make fuel adjustments. In 2010, B2 was replaced by B3 since there was enough CPO raw material to produce biodiesel (Wattana, 2014; Preechajarn and Prasertsri, 2018). To promote the use of a higher percentage of biodiesel, the Thai government allocated price subsidies from the State Oil Fund that allowed the lower price of B5 compared to B2 and B3 blends.

Additionally, the Ministry of Agriculture and Cooperatives and the Ministry of Energy established the Committee on Biodiesel Development and Promotion in 2008 to expand the palm-growing area and increase palm oil's domestic production (Wattana, 2014). A decade later, in 2016, the Thai government instructed to promote B10 use in the transport and industry sectors. Meanwhile, B100 is used in agricultural machineries (Tongroon, 2018).

Under the Ministry of Energy, the Department of Energy Business developed fatty acid methyl or B100 by applying EN 14214:2003 (European standards) guidelines and ASTM for parameter-testing methods for commercial- and community-based biodiesel. Commercial-based biodiesel was intended to be blended into diesel oils and distributed to every oil service station. Meanwhile, community-based biodiesel was targeted for agricultural engines in the communities and was not allowed to be distributed to any fuel service station. Both standards were established in 2006. The differences of both standards lie in several parameters (Table 2.9).

Table 2.9. Comparison of Example Parameters between Community-Based and Commercial-Based Biodiesel in Thailand's Specification Standards

	Community-Based Biodiesel	Commercial-Based Biodiesel	Test Method
Parameter	Value	Value	
Methyl ester, min	N/A	96.6 % (v/v)	EN 14103
Density at 15°C, min	860 kg/m^3	860 kg/m^3	ASTM D 1298
Viscosity at 40°C, min	1.9 CSt	3.5 CSt	ASTM D 445
Flash point, min	120°C	120°C	ASTM D 93
Sulphur, max	0.0015 % (v/v)	0.0010 % (v/v)	ASTM D 2622
Cetane number, min	47	51	ASTM D 613
Water and sediment, max	0.2 % (v/v)	0.050 % (v/v)	EN ISO 12937

	Community-Based Biodiesel	Commercial-Based Biodiesel	Test Method
Parameter	Value	Value	
Oxidation stability at 110°, min	N/A	6 – 10 hours	EN 14112
Methanol, max	N/A	0.2 % (v/v)	EN 14110
Acid number, max	0.8 mg KOH/g	0.5 mg KOH/g	ASTM D 664
Monoglyceride, max	N/A	0.80 % (v/v)	EN 14105
Di glyceride, max	N/A	0.20 % (v/v)	EN 14105
Tri glycerin, max	N/A	0.20 % (v/v)	EN 14105
Free glycerin, max	0.02 % (v/v)	0.02 % (v/v)	EN 14105
Total glycerin, max	1.5 % (v/v)	0.25 % (v/v)	EN 14105

Source: Rehnlund (2008), ERIA (2010).

For its pricing, the government enacted new initiatives in 2018 to promote B20 by subsidising the retail price for B20, resulting in a lower retail price compared to B7 (Table 2.10). The Energy Policy and Planning Officer under the Ministry of Energy calculates biodiesel's reference prices based on actual biodiesel production costs and announces them weekly (Preechajarn and Prasertsri, 2018).

Table 2.10. Price Structure of Biodiesel in Thailand (baht per litre)

	As per November 2017	As per November 2018	
	Biodiesel B7 (baht/year)	Biodiesel B7 (baht/year)	Biodiesel B20 (baht/year)
Ex-refinery factory price	16.72	18.87	19.31
Excise tax	5.85	5.98	5.1520
Municipal tax	0.585	0.598	0.5152
State Oil Fund	0.01	0.2	-2.5
Conservation Fund	0.25	0.2	0.1
Wholesale price (WS)	23.42	25.73	22.57
Value-added tax (VAT)	1.62	1.80	1.58
WS+VAT	25.05	27.54	24.15
Marketing margin	1.25	1.92	2.28
VAT	0.0874	0.1344	0.16
Retail price	**26.39**	**29.59**	**26.59**
In IDR	13,200.38	14,650.97	13,300.32

Note: Exchange rate = 33.13 baht/US$; baht to IDR= 500.202 IDR/baht.
Source: Preechajarn and Prasertsri (2018).

The urgency behind using alternative fuel sources, ethanol and biodiesel, is due to limited domestic energy resources and high dependency on energy imports. Additionally, the uncertainty of oil prices and the increase of imported oil will put the country at risk in energy security. Therefore, substituting fossil fuels by diversifying the energy sources from biofuels, renewable energy, and hydro can strengthen energy security. This effort is also aligned with the Thai government's energy policy, or AEDP. Additionally, there is a surplus of palm oil and believed to be enough for biodiesel.

Chapter 3

Existing Production Paths in Indonesia: Feedstock, Technologies, Standards, and Issues

3.1. Introduction

In principle, we need to look at two elements in determining how biofuels should be categorised into their production generation: feedstocks and conversion technologies.

Based on their feedstocks, we can classify liquid biofuels into two main categories: food and non-food sources. The food sources of biofuels range from sugar crops (sugarcane, sugar beets); edible-oilseed crops (soybean, sunflower, Brassica, canola, coconut, oil palm, rapeseed, peanuts, rice, cotton, algae, etc.); cereals (corn, wheat); and edible animal fats. The non-food sources comprise lignocellulosic biomass (oil palm empty fruit bunch, corn stover, crop residues, forest residues, paper mill residues, wood chips, switchgrass, Napier grass, etc.); non-edible oilseed crops (jatropha and soapnuts); and non-edible animal fats.

Biofuels are also produced through various conversion technologies. In principle, there are four ways: chemical, biochemical, gasification, and pyrolysis.

The chemical process produces biofuels through homogenous or heterogenous catalysis. Trans-esterification is one of the most common chemical processes used to make biodiesel, such as reacting triacylglycerol from CPO with methanol in the presence of a catalyst, such as sodium hydroxide or potassium hydroxide. The biochemical process occurs through enzymatic catalysis, such as fermentation of biomass as in bioethanol production from sugarcane or corn. Finally, the gasification and pyrolysis processes generate synthetic gas, such as carbon monoxide or hydrogen that can be turned into hydrocarbons as fuels.

Scientists have been proposing many ways of grouping biofuels based on the above feedstocks' sources. For example, the European Technology and Innovation Platform or ETIP-B-SABS (2020) states that

- conventional (first-generation) biofuels are produced from food crops (sugar, starch, oil) such as palm, rapeseed, soy, beets, and cereals (corn, wheat, etc.) whilst
- the advanced (second-generation and third-generation) biofuels are produced from feedstock that 'do not compete directly with food and feed crops, such as wastes and agricultural residues (i.e. wheat straw, municipal waste); non-food crops (i.e. miscanthus and short rotation coppice); and algae'.

ERIA (2017) also distinguishes biofuel resources into conventional and non-conventional. Conventional resources are edible biomass whilst non-conventional resources are non-edible biomass. However, ERIA (2017) also considers conversion procedures or technologies to produce biofuels as another element to classify biofuel generation types.

Conventional procedures or technologies include trans-esterification to produce biodiesel, fermentation to produce bio-alcohol (such as ethanol). The non-conventional procedures include using petroleum refinery facilities to produce hydrocarbon-type biofuels by hydro-processing (hydrodeoxygenation) methods. Table 3.1 shows a schematic definition of the biofuel generations based on this classification.

Table 3.1. Generations of Biofuel Production

Resources	Conversion Technologies or Procedures	Generation Category	Examples
Conventional	Conventional	First generation	• Trans-esterification of crude palm oil (CPO) to produce biodiesel • Fermentation of sugarcane-based molasse to produce bioethanol
Non-conventional	Conventional	First generation	• Trans-esterification of microalgae, Philippine tung, or jatropha oil to produce biodiesel • Fermentation of agro-industrial or forest waste to produce bioethanol
Conventional	Non-conventional	Next generation	• Hydrogenation of CPO to produce green diesel • Trans-esterification with catalytic cracking of CPO to produce green gasoline
Non-conventional	Non-conventional	Next generation	• Lignocellulosic biomass gasification to produce syngas (as a based to produce gas-to-liquid bioethanol) • Lignocellulosic biomass hydrolysation followed by fermentation to produce bioethanol • Fischer-Tropsch processing of biomass-based synthetic gas to produce green diesel

Source: Author elaboration of ERIA (2017) definition.

Not all the mentioned pathways currently exist in Indonesia, and the existing ones do not reach the same development stages.

Furthermore, biofuel generation classification is country- or region-specific. Schwaiger et al. (2011) pointed out that a particular country or region might have considerable experience with a specific feedstock or conversion process. This may be considered the first generation in that nation. However, in other countries, this remains the second generation due to greater costs, risks, or technological challenges.

In terms of first-generation biofuels, Indonesia's main production pathway that has already reached the market or commercial stage is the 'conventional' – conventional' pathway in producing CPO-based biodiesel and sugarcane-based bioethanol. Several pilot plants exist in another type of first-generation biofuel, i.e. 'non-conventional – conventional', such as producing biodiesel from microalgae,[5] jatropha,[6] and Philippine tung[7] (*kemiri sunan*). In terms of the next-generation biofuels, Pertamina is currently running several demonstration projects on producing CPO-based green diesel and green gasoline (Issetiabudi, 2019).

Table 3.2. Biomass-to-Biofuel Pathways in Indonesia: Current Development Stages

Feedstock	Conversion Technology	Pathway	Stage		
			Pilot	Demonstration	Commercial
Conventional	Conventional	CPO-based biodiesel production	🟩	🟩	🟩
Conventional	Conventional	Sugarcane-based bioethanol production	🟩	🟩	🟩
Non-conventional	Conventional	Non-conventional feedstock-based biodiesel	🟩		

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[5] For example, Nogotirto Algae Park in Jogjakarta.

[6] For example, in Ogan Komering Ulu Timur, South of Sumatera Province, a jatropha-based biodiesel industry was in operation with a production capacity around 6 tonnes of biodiesel per day between 2007 and 2013. This pilot project was under the coordination of the Technology and Research Ministry. The factory was closed due to the difficulty in obtaining jatropha as the main feedstock (Tasmalinda, 2019).

[7] For example: pilot projects in Sukabumi under the coordination of the Ministry of Agriculture (Lestari, 2019) and in Boyolali (Marwoto, 2014).

Feedstock	Conversion Technology	Pathway	Stage		
			Pilot	Demonstration	Commercial
Conventional	Non-conventional	CPO hydrogenation to produce green diesel	🟩	🟩	
Conventional	Non-conventional	Trans-esterification with catalytic cracking of CPO to produce green gasoline	🟩	🟩	

Source: Authors' elaboration.

In the next sections, we will discuss each of the above pathways (Table 3.2). We will briefly describe the feedstock and the conversion technology, benefits, issues and solutions, production costs, eventual fiscal policy from the government, and the current and potential production capacity, demand, or potential demand of each pathway.

We also recognise the possibility of other biofuel pathways in Indonesia. Examples are the fermentation of lignocellulosic biomass; the fermentation of agro-industrial or forest waste to produce bioethanol such as oil palm empty fruit bunch as 'the non-conventional feedstock with conventional procedure' pathway, and 'the non-conventional feedstock with conventional procedure pathway', and the lignocellulosic biomass gasification to produce syngas (as a base to produce gas-to-liquid bioethanol); lignocellulosic biomass hydrolysation followed by fermentation to produce bioethanol; or Fischer-Tropsch processing of biomass based synthetic gas to produce green diesel, etc. Nevertheless, we consider that those pathways are still in the laboratory stages and will not penetrate the market before 2040.

3.2. CPO-Based Biodiesel Production

3.2.1. Description

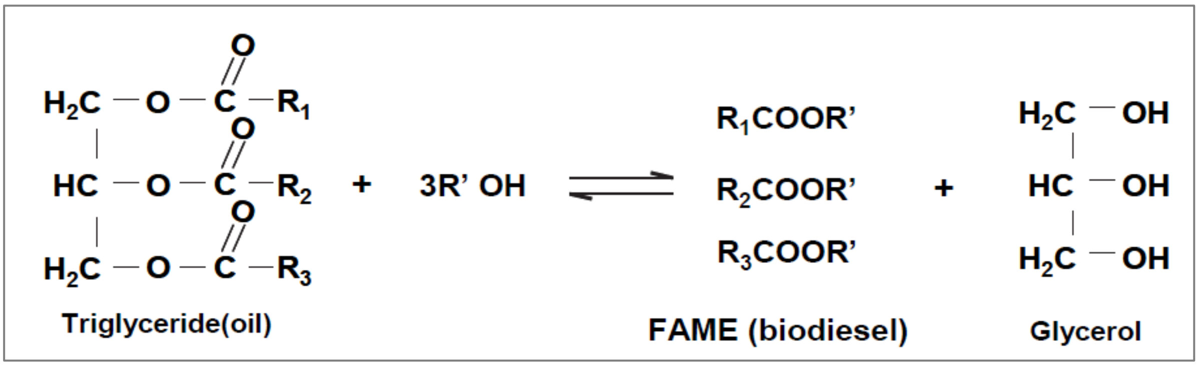
CPO-based biodiesel currently constitutes the highest biofuel-type share produced and used in Indonesia. According to Purba (2019), Indonesia's oil palm plantations reached 14.3 million hectares in 2018. The Ministry of Agriculture (2018) reported that more than half (53%) are smallholder oil palm plantations. Furthermore, with around 55.7% share of world CPO production, Indonesia is currently the biggest CPO producer globally, followed by Malaysia with a 28.9% share (USDA, 2018).

The main feedstock is CPO obtained by pressing and extracting from seeds. Apart from oil palm, other plants categorised as vegetable oils such as soybean, cottonseed, peanut, rapeseed/canola, sunflower, coconut, rice bran, etc. can produce biodiesel. So do waste oils such as used cooking oil and brown grease, and animal fats such as tallow. Vegetable oils, animal fats, and waste oils have triglycerides as their main components. For this reason, these are often classified as triglyceride feedstocks. Triglycerides contain glycerine in their structure, and that includes glycerol and three fatty acids.

Biodiesel in this pathway is produced by trans-esterification, a method known for more than 80 years. According to Randoux (2017), George Chavanne, professor of chemistry at the *Université Libre de Bruxelles* in Belgium, in 1937 submitted a patent for a trans-esterification of vegetable oils to produce transport fuels, amongst which is biodiesel, for the internal combustion piston engine of cars.

Esterification separates the fatty acids – hydrocarbon chains – from a glycerine molecule to which they are attached and attaches them to a short chain alcohol, in most cases, methanol. The overall trans-esterification reaction of the oil with alcohol is a three-step reversible reaction Figure 3.1) (Xiao and Gao, 2011). This reaction occurs essentially by mixing the reactants and can be accelerated with either base or acid catalyst. Sodium or potassium hydroxide is usually used as a catalyst in this process, resulting in fatty acid methyl ester (FAME).

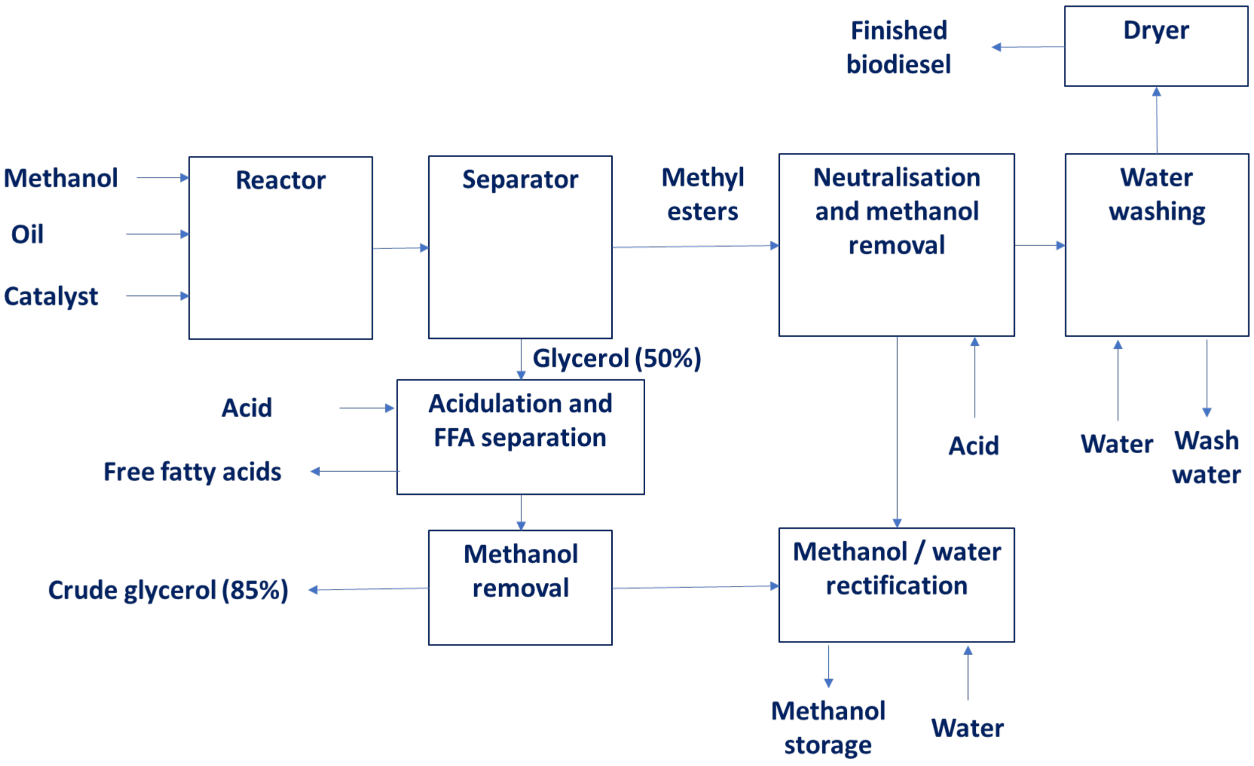
Figure 3.1. The Overall Trans-esterification Reaction of Oil with Alcohol



Source: Xiao and Gao (2011).

Knothe et al. (2005) presented a biodiesel production schema from low-level FFA (free fatty) containing feedstocks via base catalyst trans-esterification (Figure 3.1). Reactants – methanol, oil, and catalyst – are mixed in the reactor and agitated for an hour at 60%. After the reaction is completed, with either a settling tank or a centrifuge, glycerol is separated from methyl esters, which are FAME products. Any remaining catalyst soap, salts, methanol, or free glycerol is removed from FAME in the water-washing step. Biodiesel is produced after the drying process.

Figure 3.2. Process Flow Diagram for Biodiesel Production



Source: Knothe et al. (2005).

Schwaiger et al. (2011) noted that plant materials that remain after pressing could be used to produce animal feeds. The glycerine separated during esterification can be used to make glycerol, a versatile compound used in various industries.

3.2.2. Production capacity, supply, and demand

Table as an elaborated data from the USDA (2019a) shows that the biodiesel blending rate in pure diesel fuel has been gradually increasing since 2010. The actual biofuel blending percentage has been running behind the blending targets, as defined in the mandatory biodiesel blending regulation that started in 2014. The blending rate was around 5.4% in 2014 when the B10 mandate was implemented. It grew to around 10.3% in 2016 when the B20 was initiated. The last recorded real blending rate was 19.9% in 2019.

However, in nominal terms, the total on-road use of diesel and biodiesel increased by 30%, from around 27,300 million litres in 2010 to about 35,500 million litres in 2019. With the increasing mandatory target, on-road biodiesel use increased by more than 33 times between 2010 and 2019 from approximately 180 million litres in 2010 to around 5,900 million litres in 2019. Pure on-road diesel use increased only by 10% during the same observed period.

Table 3.3. Biodiesel Production, Supply, and Demand Statistics

Biodiesel (million litres)										
Calendar Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Beginning stocks	22	16	29	27	11	97	94	110	152	58
Production	780	1,812	2,270	2,950	3,500	1,200	3,500	2,800	5,600	8,000
Imports	0	0	5	24	0	0	0	0	28	0
Exports	563	1,440	1,608	1,942	1,569	343	476	187	1,772	1,800
Consumption	223	359	669	1,048	1,845	860	3,008	2,572	3,950	6,200
Ending stocks	16	29	27	11	97	94	110	152	58	58
Balance check	0	0	0	0	0	0	0	0	0	0
Production capacity (million litres)										
Number of biorefineries	22	22	22	26	26	27	30	32	31	31
Nameplate capacity	3,921	3,921	4,881	5,670	5,670	6,887	10,898	11,547	11,357	11,357
Capacity use (%)	19.9	46.2	46.5	52	61.7	17.4	32.1	24.2	49.3	70.4
Feedstock use for fuel (1,000 MT)										
Crude palm oil (CPO)	718	1667	2,088	2,714	3,220	1,104	3,220	2,576	5,152	7,360
Market penetration (million litres)										
Biodiesel, on-road use	178	287	535	838	1,476	665	2,621	2,272	3,650	5,900
Diesel, on-road use	27,125	26,030	29,528	28,649	27,220	25,433	25,372	27,843	28,785	29,621
Blend rate (%)	0.7	1.1	1.8	2.9	5.4	2.6	10.3	8.2	12.7	19.9
Diesel, total use	36450	37497	37743	36124	34651	30912	30039	31441	32196	33033

Source: MEMR, Global Trade Atlas (GTA) Data, as cited and elaborated in USDA (2019a).

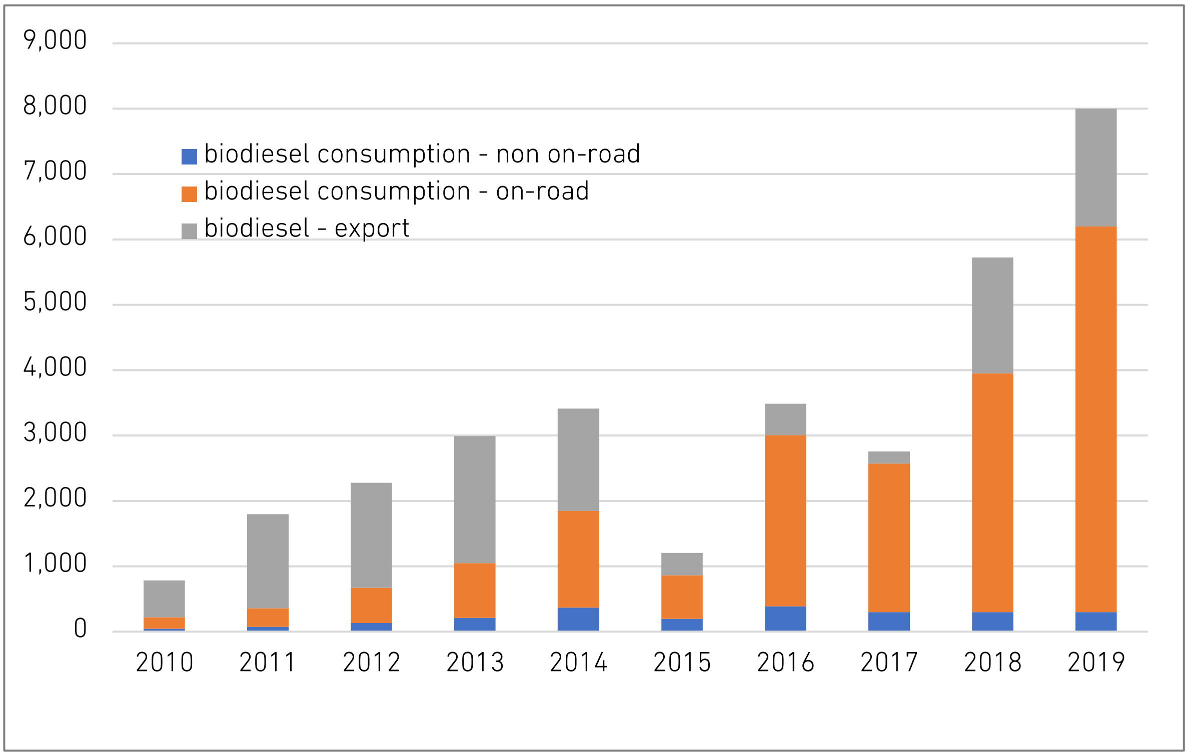
Table 3.3 and Figure 3.3 show that total biodiesel consumption increased by more than 10 times from about 780 million kilolitres (kl) in 2010 to 8,000 million kl in 2019. Some decreases, such as in 2015 and 2017, were caused mainly by the sharp drops in the world oil market price that induced some reduction in the actual biodiesel blending percentage and demand for biodiesel export.

To catch up with biodiesel production, the number of biodiesel refineries increased from 22 in 2010 to 31 in 2019, resulting in a growth in installed capacity from around 3,900 million litres/year in 2010 to almost 11,400 million litres/year in 2019.

Biodiesel in Indonesia was initially produced for export. As in 2010, the export share of total biodiesel demand reached more than 71%. However, the share for on-road use was only 22.6%, and for other use, around 5.7%. We can see the inverse situation in 2019 when the export share dropped to 22.5%, and the on-road use share reached almost 74%.

Finally, Indonesian CPO production dedicated to biodiesel grew proportionally with biodiesel production. It increased by more than 10 times from around 720 thousand metric tonnes in 2010 to almost 7,400 thousand metric tons in 2019. This means a constant conversion rate of around 1,086 litres of biodiesel per metric tonne of CPO.

Figure 3.3. Biodiesel Demand in Indonesia
(million kl)

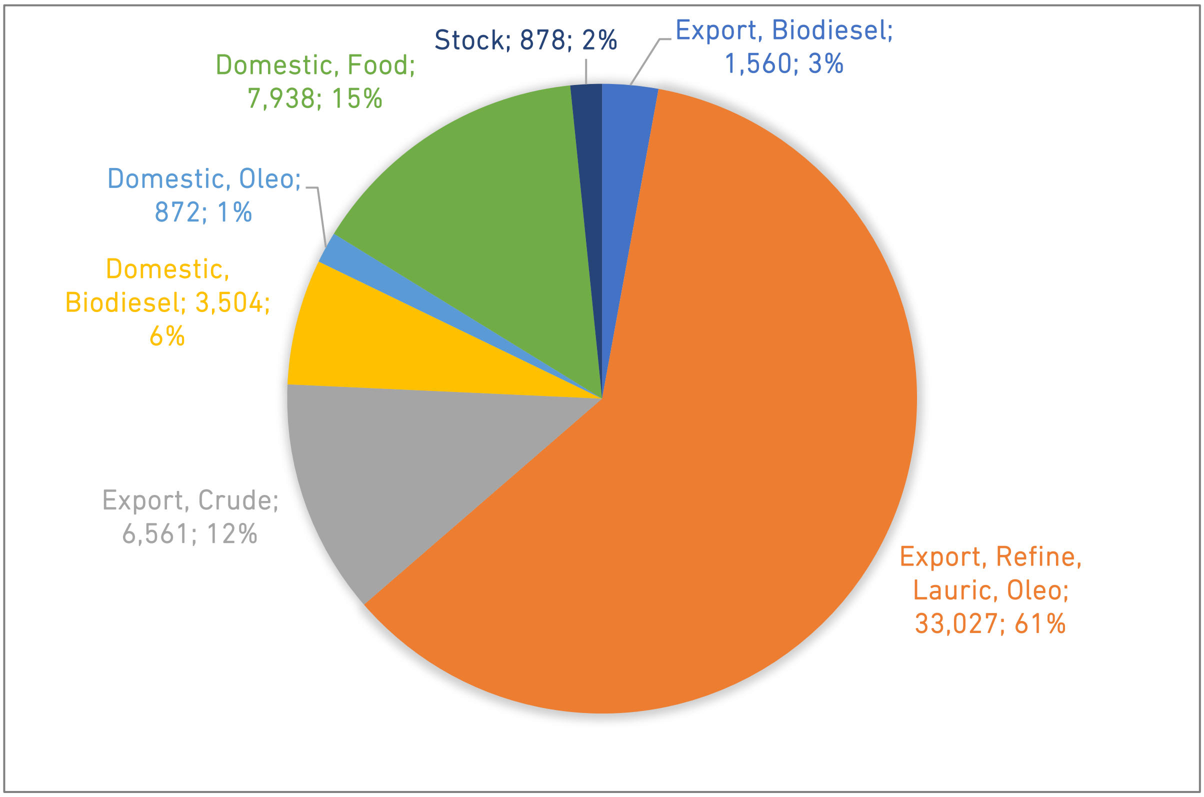


Source: Elaboration of USDA (2019a) figures based on MEMR and GTA data.

In 2018, national oil palm plantations' productivity reached 3.69 tonnes CPO/ha, a weighted average of state oil productivity (PTPN) of 3.97 tonnes CPO/ha and private plantation productivity of 3.37 tonnes CPO/ha (Purba, 2019). In the meantime, the productivity of new oil palm plantations averaged 2.82 tonnes CPO/ha.

Oil palm production in 2018 reached around 43,709 million tonnes, of which about 6% or 3,500 million tonnes were dedicated to producing domestic biodiesel, and more than 77% of the produced CPO was exported (Tjakrawan, 2019) (Figure 3.4). Tjakrawan (2019) stated that biodiesel in Indonesia is currently produced by around 19 refining companies, with a total installed production capacity of about 11,600 million litres of biodiesel per year.

Figure 3.4. Indonesia CPO Feedstock Position in 2018 (million tonnes)



Source: GAPKI, GIMNI, AIMMI, APOLIN, APROBI, as cited in Tjakrawan (2019).

The Indonesian Biofuel Producers Association or APROBI foresees the possibility of utilising unused empty land to increase feedstock production capacity. Another possibility seen by the association is coconut plants in several regions, such as Sulawesi and East Nusa Tenggara.

APROBI estimated that there would be no problem for the CPO feedstock need to meet the production demand to produce FAME-based biodiesel when the B50 programme would become mandatory by early 2021. APROBI's assessment results assured that feedstock production would be enough for the B50 mandatory programme until 2030.

However, increasing the blending percentage of biodiesel beyond B50 would probably need increased CPO feedstock. According to APROBI, a further increase of feedstock supply shall require an increased oil palm plantation productivity without further expansion of oil palm plantation land.

Whilst the main challenge to increase CPO production would be CPO market price volatility, a challenge in producing biodiesel is the need for methanol. Methanol is important since it can make up 50% of total biodiesel production costs. Methanol supply in Indonesia is limited since most local methanol industries are already engaged to supply up to 75% of its production.

The Directorate of New and Renewable Energy and Energy Conservation of the Ministry of Energy and Mineral (MEMR) assured that there would be no supply-side problems to continue with the currently implemented B30 mandatory programme.[8]

According to APROBI, the current biodiesel production capacity reaches 11.6 million kl, of which 85% meets the requested biodiesel standard. During the B20 mandatory programme, around 6.2 million kl of biodiesel have been produced yearly. APROBI estimates that with B30 becoming mandatory by 2020, the demand shall increase to 9.8 million kl of biodiesel. With the current production capacity, there would be no problem meeting the increased demand. However, biodiesel export must be stopped to ensure fulfilment of domestic needs.

Should the government implement the B50 mandatory programme by early 2021, APROBI estimates that production capacity would need to be raised by another 7.9 million kl. Another possibility to meet the increasing demand due to the hypothetical B50 mandatory programme would be to use HVO green diesel or H-FAME–based biodiesel.

3.2.3. Current fiscal instrument: biodiesel subsidy from biodiesel financing fund

Indonesia has been taxing palm oil export since 1994, whose revenues were collected as palm oil fund. Article 93 (4) of Regulation No. 39 Year 2014 provides that the levy fund collected from the plantation should be used for human resource development, R&D, plantation promotion, rejuvenation of plantation, and development of plantation facilities and infrastructures.

Nevertheless, based on Presidential Regulation 61 Year 2015, Indonesia has a funding mechanism to support its biofuels subsidy. Article 11 (1) states that the collected fund is used to (i) improve human resource in the oil palm plantation, (ii) conduct R&D of oil palm plantation, (iii) promote oil palm plantation, (iv) rejuvenate oil palm plantation, and (v)

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[8] According to Effendi Manurung during the workshop held on 9 December 2019.

establish and improve infrastructure and facilities of oil palm plantation. Paragraph 2 states that the funding was to improve oil palm plantation's products to meet food demand, downstream the palm oil industry, and provide and use biodiesel.

A series of regulations were issued since then to determine the levy on palm oil exports. The latest, Minister of Finance Regulation 23/PMK.05/2019, defines levy that ranges from US$0.00/tonne per tonne CPO export when the CPO price is less than US$570/tonne; US$25/tonne exported CPO when the CPO price is between US$570/tonne and US$619/tonne; and US$50/tonne of exported CPO when the international CPO price is above US$619/tonne.

The palm oil levy's income is channelled into a biodiesel financing fund (*Dana pembiayaan biodiesel*), whose use is currently regulated under President Regulation 66 Year 2018 on the Oil Palm Plantation Fund Use and Raising. Several principles of President Regulation 66 Year 2018 are as follows:

- The fund is used to close the gap between the diesel oil and biodiesel market price indexes[9] abbreviated as MPI.
- The Indonesian Oil Palm Estate Fund Agency[10] allocates the fund to the biofuel firms.[11]
- With the assistance of a surveyor appointed by the Indonesian Oil Palm Estate Fund Agency, the MEMR verifies the fund allocation.
- Biofuel enterprises sell biodiesel to fuel retailers[12] at the price of diesel fuel.
- Fuel retailers blend biodiesel to diesel fuel in compliance with the mandatory biodiesel regulations issued by the MEMR.
- The MEMR determines diesel and biodiesel MPI.

The MEMR determines the MPIs of biodiesel (in rupiah/litre) monthly using the following equation:

$$\begin{aligned}&\mathit{Biodiesel\ MPI}\\&\qquad = (\mathit{monthly\ average\ CPO\ price}\\&\qquad + \mathit{feedstock\ to\ biodiesel\ conversion\ cost})\\&\qquad * \mathit{feedstock\ to\ biodiesel\ conversion\ factor} + \mathit{transport\ cost}\end{aligned}$$

Where:

- Monthly average CPO price (rupiah/kg): the calculated average during a month preceding the date of price determination. For example, the price for February

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[9] Harga Index Pasar (HIP)

[10] Badan Pengelola Dana Perkebunan Kelapa Sawit (BPDPKS)

[11] Badan Usaha Bahan Bakar Nabati (BU BBN)

[12] Badan Usaha Bahan Bakar Minyak (BU BBM) such as Pertamina, AKR, ExxonMobil, Shell, etc.

2020 is calculated from the CPO price average between 15 December 2019 to 14 January 2020, i.e. Rp9,573/kg

- Feedstock to biodiesel conversion cost is currently US$150/tonne
- Feedstock to biodiesel conversion factor is 870 kg/m^3
- Transport cost is based on MEMR Regulation 148K/10/DJE/2019

For example, the biodiesel price in February 2020 was set at Rp9,539/litre plus transport costs.

The bioethanol market index price, on the other hand, is calculated using the following equation:

$$\begin{aligned} &Bioethanol\ MPI \\ &\qquad = (3 - monthly\ average\ molasse\ price \\ &\qquad * feedstock\ to\ bioethanol\ conversion\ factor) \\ &\qquad + feedstock\ to\ bioethanol\ conversion\ cost \end{aligned}$$

Where:

- The 3-monthly average price is calculated as the average molasse price of the 3-month period preceding the price determination date. For example, for February 2020, the average price is calculated between 15 September 2019 to 14 December 2019, i.e. Rp1,674/kg.
- Feedstock to bioethanol conversion factor is 4,125 kg/litre.
- The current feedstock to bioethanol cost is US$0.25/litre.

3.3. First-Generation Bioethanol Production

3.3.1. Description

Sugarcane-based bioethanol

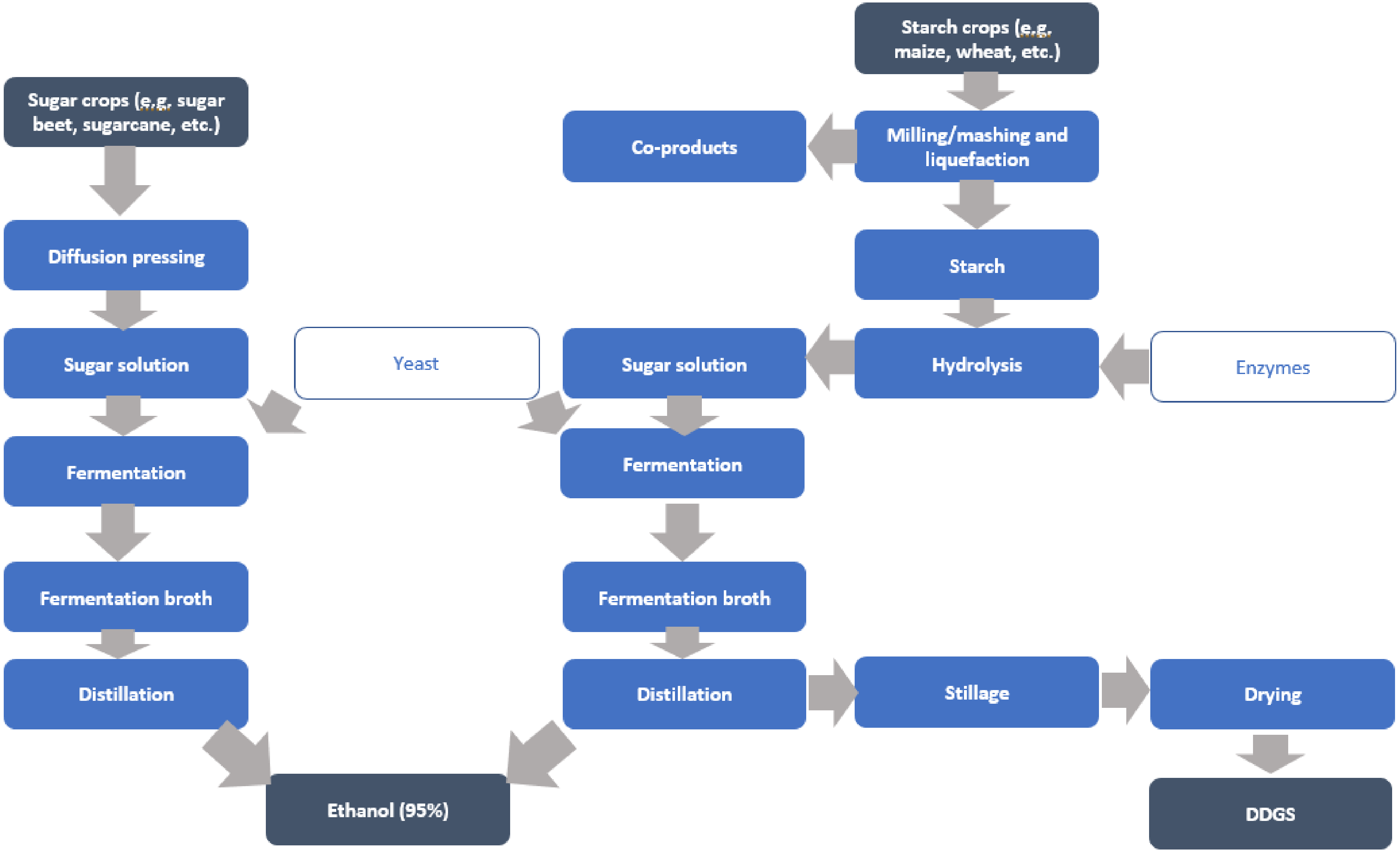
There is an urgent need to develop the bioethanol production sector in Indonesia as fast as possible since gasoline fuel consumption reaches 75% of the total transport fuel consumption whilst diesel is only 25%. High-blended bioethanol can also be combined with the production of CPO-based green gasoline.

Schwaiger et al. (2011) summarised the bioethanol production process. In sugarcane, the cane is cut into small pieces, and the juice is squeezed out, leaving solids called ‘bagasse’. The bagasse is used as fuel for the remaining steps. Non-sucrose impurities in the juice are filtered out, the juice is heated and centrifuged to separate sugars from molasses, and the sugars are fermented to alcohol.

Sugarcane molasses is a by-product of sugarcane products that can also produce bioethanol. The use of molasses for ethanol production has attracted great interest because they are low cost and rich in sucrose, which presents a substrate not requiring pretreatment before fermentation (Raharja et al., 2019). Various microorganisms, such as fungi, bacteria, and yeast, can ferment molasses. The *Saccharomyces cerevisiae* microorganism is the most useful. In the absence of oxygen, *Saccharomyces cerevisiae* metabolises sugar and produces ethanol and CO_2.

Once fermented, the produced (bio-) ethanol must be distilled to remove water. Both fermentation and distillation require heat. In the case of sugarcane-based ethanol, cane residues (bagasse) supply the heat. Since bagasse is a biomass energy source, sugarcane-based ethanol has exceptionally low GHG emissions.

Figure 3.5. Ethanol from Sugar and Starch



DDGS = dried distiller grains with solubles.
Source: Schwaiger et al. (2011).

For starch, such as corn kernels or cassava, the conversion is more complex. Starches must be converted to sugar before fermentation, requiring more heat and the use of enzymes. This process includes milling and liquefaction to break down starch molecules into glucose. Through fermentation, glucose is converted into ethanol. Table 3.4 summarises the main steps in ethanol production from starch.

Table 3.4. Main Starches-Based Ethanol Production Steps

Step	Goal	Type of Process
Milling and liquefaction	Breaking down starch molecules into its building block molecules: glucose	Enzymatic
Fermentation	Convert glucose to ethanol	Yeast
Purification	Separate ethanol from other reaction products and inert materials	Distillation

Source: Kuiper et al. (2007).

On an industrial scale, starch can be converted to ethanol through either a dry or wet process that uses various technologies. Kuiper et al. (2007) pointed out that feedstock preparation steps and the numbers and types of co-products recovered are the two main aspects that distinguish the two processes.

In dry milling, flour or meal is obtained from feedstock grinding. Dextrose is obtained from starch by mixing the meal with water and enzymes. The resulting mix is heated at a high temperature to reduce bacteria levels, and then cooled and fermented.

In wet milling, Sriroth et al. (2012) explained that the chips are ground to obtain fine powder before they are slurried with water in a process called ‘starch milk’, where the starch is extracted from chips by a series of extractors. After de-pulping, the starch slurry is then concentrated by a separator and subjected to a jet cooker for liquefaction.

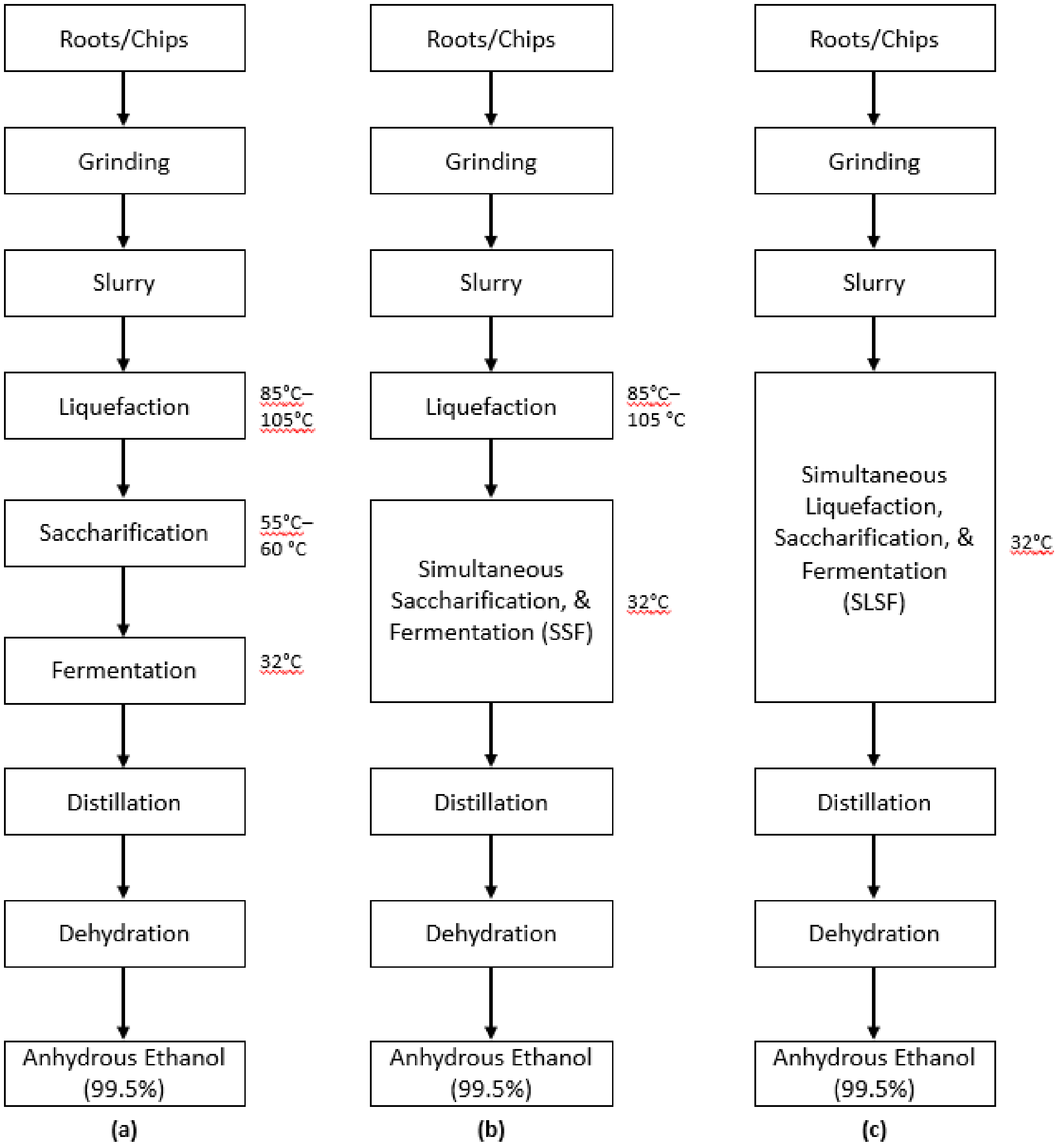
Afterwards, the starch-to-ethanol conversion process and the ethanol recovery are similar in both wet mill and dry-grind facilities. Currently, more plants use dry milling than wet milling as the latter requires a higher investment.

Cassava-based bioethanol

Cassava can be used as bioethanol feedstocks. It is abundant and cheap during harvest time. The abundant supply of cassava can be an advantage and a promising opportunity to secure bioethanol production. Many studies identified cassava as a potential feedstock for bioethanol production (Dillon et al., 2008; Hendrawati et al., 2018; Loupatty, 2014; Restianti and Gheewala, 2012; Sriroth et al., 2012). Various forms of cassava, including fresh roots, chips, starch, and its residues (cassava peel, bagasse, stem, and rhizome), can be used to produce bioethanol. Additionally, cassava can grow in soil with low nutrients and less rainfall (Sivamani et al., 2018). With harvest every 8 months, it can produce 30–60 tonnes per hectare.

Cassava's water content is around 60%, with 25%–35% cassava starch and other components, such as protein, mineral, fibre, calcium, and phosphate (Loupatty, 2014). Its caloric value could reach 250 x 103. The energy generated by cassava is more than rice, corn, sweet potato, and sorghum (Sivamani et al., 2018). There is not much difference between converting cassava into bioethanol and other bioethanol feedstocks, such as molasses, sorghum, etc. According to Restianti and Gheewala (2012), converting cassava to bioethanol involves several processes: pretreatment, hydrolysis, fermentation, and distillation. In the pretreatment process, water is added to cassava to make a slurry, after which the liquefication process is done by adding steam and enzymes. The following process is the fermentation of reducing the sugar by yeast, followed by distillation to make 95% alcohol. The water content must be decreased by dehydration to produce fuel ethanol so that the final content of ethanol will be 99.5%. A study conducted by Sriroth et al. (2012) summarised several steps to process cassava feedstock to produce biofuel (Figure 3.6).

Figure 3.6. Steps of the Bioethanol Production from Cassava Feedstock



Source: Sriroth et al. (2012).

Note: a) conventional steps; b) simultaneous saccharification and fermentation (SSF); and c) simultaneous liquefaction, saccharification, and fermentation (SLSF) process of ethanol production from cassava feedstock.

The SSF process significantly reduces processing time and energy consumption by conducting saccharification and fermentation in the same step. The liquefied slurry is cooled down to 32^0 C, afterwards glucoamylase and yeast are added (Sriroth et al., 2012). Meanwhile, simultaneous liquefaction, saccharification, and fermentation (SLSF) process the uncooked starch granules, allowing liquefaction, saccharification, and, in the presence of yeast, fermentation to occur simultaneously in one step at the ambient temperature without cooking. The SLSF process is saves energy, is easy to operate, and can be applied economically to produce sustainable energy at a small scale (Sriroth et al., 2012).

3.3.2. Potential development in Indonesia

In contrast to the biodiesel blend mandate, the planned bioethanol mandate programme has yet to be implemented. The MEMR has mandated that gasoline fuel be blended with bioethanol, setting targets of 5% by 2020 and 20% by 2025. Nevertheless, the blend percentage of bioethanol in gasoline fuel remains zero.

The following two subsections discuss the issues of sugarcane-based bioethanol and the potential of developing cassava-based bioethanol.

Sugarcane-based bioethanol

The bioethanol transport fuel policy in Indonesia has so far been based on sugarcane feedstock. Purwanto and Arifin (2020) pointed out that the bottleneck hindering the bioethanol mandate, especially concerning sugarcane as feedstock, may be attributed to three factors: the high cost of sugarcane (molasse), fluctuations in the price of molasse, and low production capacity.

First, the high sugarcane production cost resulted in a big gap between bioethanol and gasoline prices. For example, the market ceiling price of bioethanol fuel in August 2020 was Rp14,779 (US$1.1) per litre whilst gasoline ranged from Rp7,650 to Rp9,200 per litre in most provinces.

The second is the fluctuation of molasse prices. MEMR's historical data shows that the average price of molasse jumped by more than 45% between June and August 2020, causing the bioethanol market ceiling price to increase by nearly 30% during the same period, the highest price since the 2016 decree issuance. The stagnating or even reduced production of sugarcane since 2015, combined with the increasing demand for sugar and molasse, may be the main factor behind the price jump. Also, molasse exports increased by 20% between 2017 and 2018 and by 26% between 2018 and 2019. Another factor contributing to the price fluctuation is the sugarcane purchasing system called the 'cut-purchase system'. In this system, factories buy sugarcane from farmers at a fixed reference price that varies only with the measured sugarcane yield but is not connected to sugar prices in the market. As the sugar price fluctuates in the market, sugar factory stakeholders might see this reference price as a risk, resulting in additional costs to cover. Also, sugarcane yield measurement can be problematic. Farmers may tend to trade with the factories that assign a higher yield to their products. As a result, the new purchasing system tends to eliminate small and private factories from the market, thus reducing competition whilst increasing the price. The molasse and sugar yields become less certain.

The third is the low capacity of fuel-grade bioethanol production. Only three factories can produce molasse-based fuel-grade bioethanol in Indonesia, with a total yearly production capacity of 45,000 kilolitres of bioethanol. Thus, if Indonesia implemented the mandated 5% bioethanol, only about 2.6% of the demand could have been met.

Cassava-based bioethanol

Cassava is one of Indonesia's major crops as it can be grown in all provinces throughout the year. Compared with other bioethanol feedstocks, cassava offers a promising potential, after sugarcane (molasses), to be expanded for bioethanol production. Table 3.5 shows various crops of bioethanol feedstock that can be maximised in Indonesia.

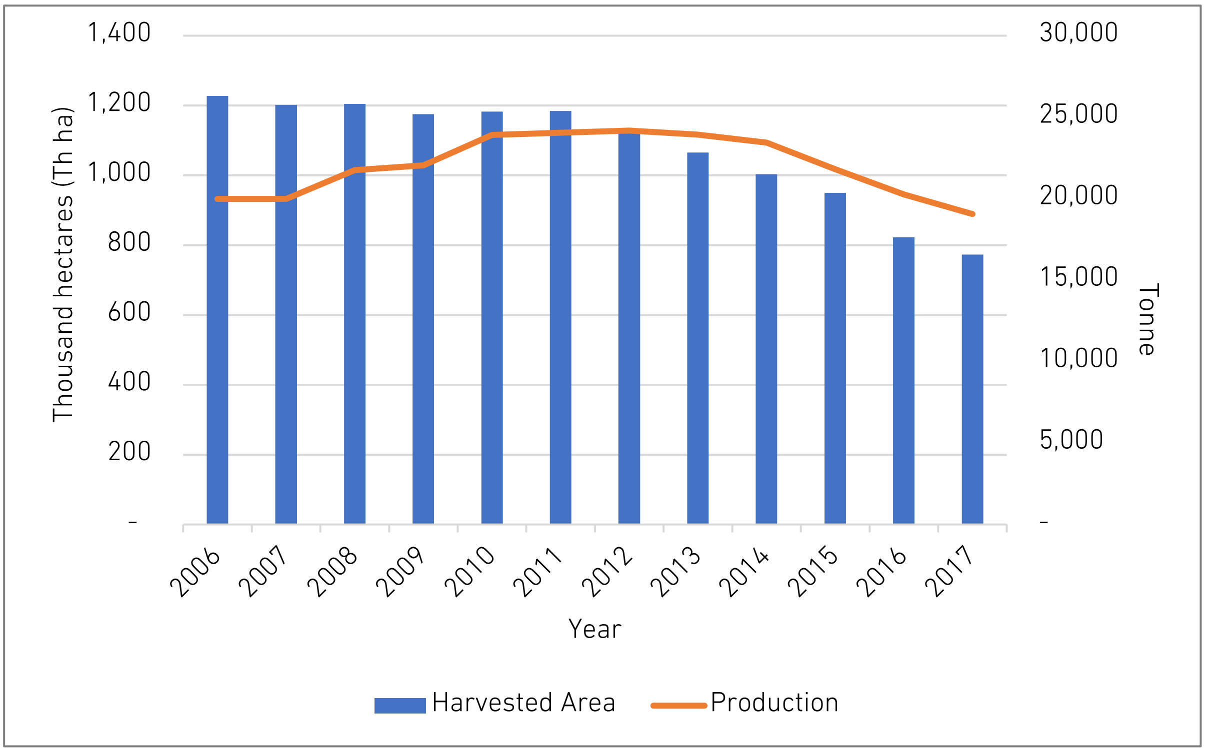
Table 3.5. Potential Feedstocks of Bioethanol in Indonesia

Feedstocks	Potential Yields (tonne per year/hectare)	Bioethanol Production (litre per year/hectare)
Cassava	10–50	2,000–7,000
Sweet potato	10–40	1,200–5,00
Sugarcane (molasses)	40–120	3,000–8,500
Sugar palm (sap)	n/a	40,000
Seaweed	45–60	13,500–30,000

Source: Loupatty (2014).

Since the early 2000s, harvested land of cassava significantly decreased. However, cassava production was relatively stable from 2006 to 2017. Figure 3.7 shows cassava production and the harvested area of cassava in Indonesia. It illustrates that the resiliency of cassava production could be an opportunity to maximise production for bioethanol.

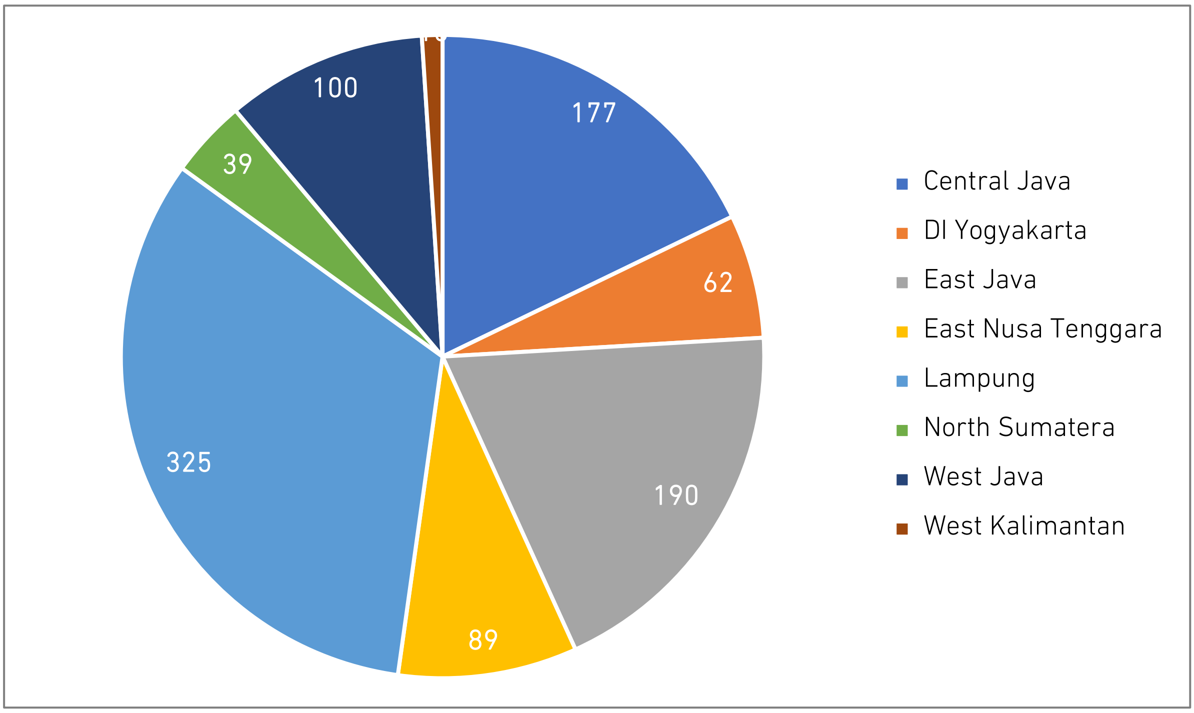
Figure 3.7. Cassava Production and Harvested Area, 2006–2017



Source: CEIC Data (2020), with author modification.

Cassava is mainly grown under intercropping, especially in Sumatera, Java, and Nusa Tenggara. It is usually planted with cereals and grain legumes for food supply throughout the year. In North Sumatera and Lampung, cassava is grown in a monoculture system to fulfil industrial supply (Dillon et al., 2008).

Figure 3.8. Cassava Harvested Area (Th Ha), 2017



Source: CEIC Data (2020), with author modification.

In 2006, the Ministry of Agriculture published an action plan that foresees cassava production for fuel ethanol up to 32 million tonnes in 2025 (yielding 5 billion litres of ethanol). However, these plans were not on track, and as of mid-2008, only two facilities could produce cassava-based bioethanol (compared to the 30 facilities envisaged in the action plan).

A recent study conducted by Hendrawati et al. (2018) analysed the fiscal feasibility of expanding cassava-based bioethanol production based on its production capacity. The study found that the production capacity of cassava-based bioethanol in Indonesia could reach 30,000 kl/year, or 100 kl/day. With a conversion rate of 6.5 of cassava/litre bioethanol, the amount of cassava needed by the ethanol industry is approximately 195,000 tonnes/year or 650 tonnes/day. Around 5.6 ha of cassava's harvested area can supply these amounts.

With the same amount of production, 30,000 kl of cassava-based bioethanol per year, Hendrawati et al. (2018) also calculated the investment eligibility criteria. The net benefit/cost is 1.55; the internal rate of return is greater than 12%, i.e. 23.77%; positive net present value is Rp84,451,334,345; payback period is 6.45 years; and HPP or *harga pokok produksi* (cost of production) of bioethanol is IDR4,058/litre. With an HPP of Rp4,058/litre, cassava bioethanol's selling price is Rp6,100/litre.

Nonetheless, other components, such as farming methods, labour-intensive and time-consuming harvesting processes, and market viability of cassava, should be considered, reflecting on the lack of commercial ethanol production using cassava compared to sugarcane (molasses), which succeeded in Brazil and Thailand.

3.4. Second-Generation Bioethanol Production

Second-generation bioethanol production uses non-edible crops, which are now mainly derived from lignocellulosic plants. In Indonesia, several potential feedstocks are under investigation to be converted as second-generation bioethanol, such as Napier or elephant grass (*Pennisetum purpureum*) and switchgrass (*Panicum virgatum*). Pertamina (2015) showed its plan to convert Napier grass (*rumput gajah*) into biofuel (Figure 3.9). Tempo.co (2017) reported that PT Rajawali Nusantara Indonesia (PT RNI), with PT Pertamina (Persero) and Toyota Motor Corporation, has been developing elephant and Napier grass as bioethanol feedstock in 7 hectares of land of PT RNI in Majalengka, West Java since 2015. However, the authors could not find out the progress of this development plan.

According to ASENDO,[13] the bioethanol production phase from molasse or glucose syrup that needs fermentation still presents a bottleneck as enzyme needs for the fermentation are still costly. The current enzyme price is around Rp18,000/litre of bioethanol. The US has been using second-generation technology to reduce the enzyme price from about US$2.8/litre of bioethanol to US$0.26/litre of bioethanol.

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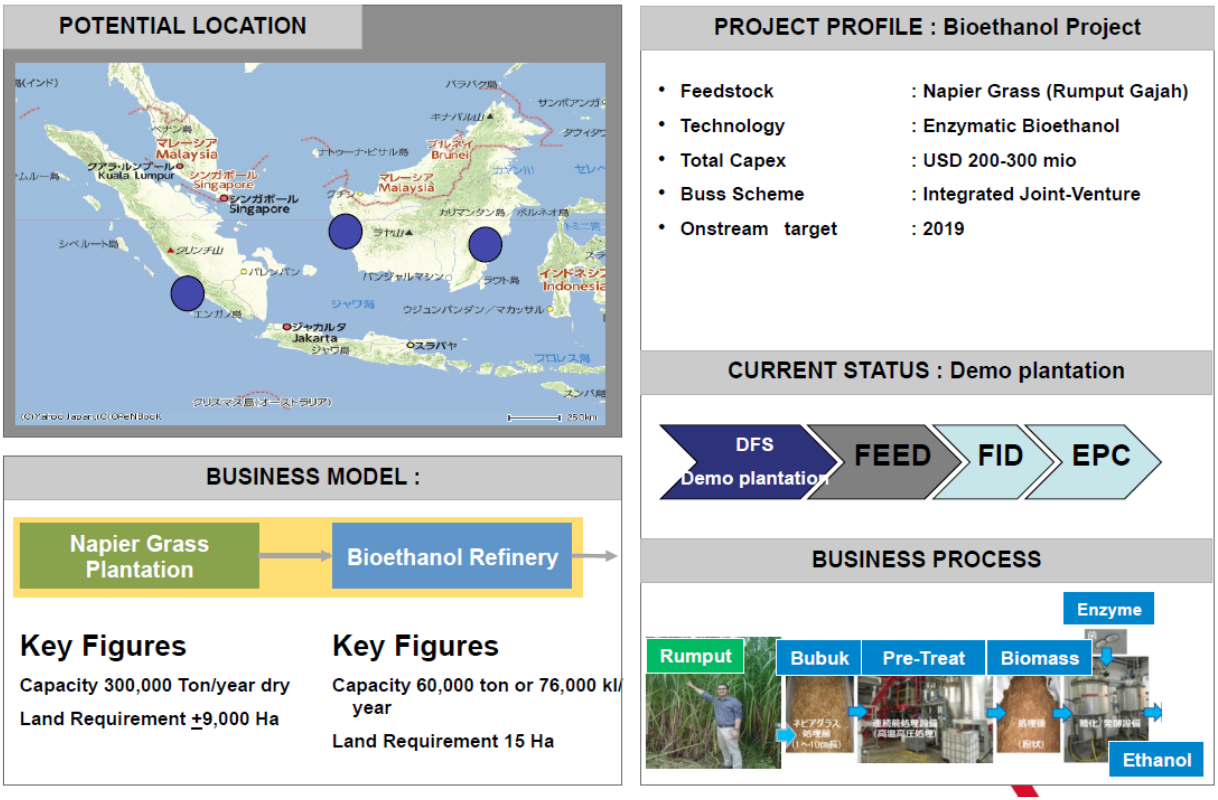
[13] As explained by ASENDO Chairman, Dr Untung Murdiyatmo during the Workshop on 9 December 2019

Figure 3.9. Pertamina Lignocellulosic Second-Generation Bioethanol Project



POTENTIAL LOCATION

PROJECT PROFILE : Bioethanol Project

- **Feedstock** : **Napier Grass (Rumput Gajah)**
- **Technology** : **Enzymatic Bioethanol**
- **Total Capex** : **USD 200-300 mio**
- **Buss Scheme** : **Integrated Joint-Venture**
- **Onstream target** : **2019**

CURRENT STATUS : Demo plantation

BUSINESS MODEL :

Key Figures

Capacity 300,000 Ton/year dry

Land Requirement ±9,000 Ha

Key Figures

Capacity 60,000 ton or 76,000 kl/ year

Land Requirement 15 Ha

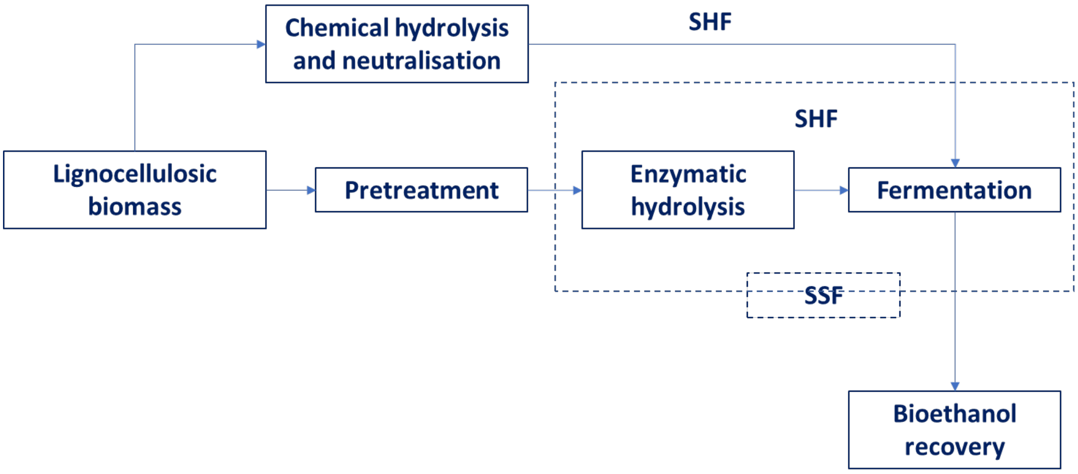
BUSINESS PROCESS

Source: Pertamina (2015).

Thi et al. (2019) summarised the general principle of lignocellulosic ethanol production (Figure 3.10). At the beginning of the process, the lignocellulosic biomass, which is easier to hydrolyse than crystalline cellulose, needs to be pretreated to increase the amorphous regions. This is to increase the porosity of the fibre matrices to promote the penetration of chemicals and enzymes into the structure and liberate cellulose from the surroundings of lignins and hemicelluloses. The pretreatment methods include (i) physical pretreatment (size reduction by grinding, milling, extrusion at elevated temperature, etc.); (ii) chemical pretreatment under alkaline conditions or acidic conditions; (iii) physiochemical pretreatment (steam explosion under acidic conditions, supercritical CO$_2$; and (iv) biological pretreatment (Balan, 2014).

Brodeur et al. (2011) identified the goals of pretreatment as follows: (i) produce highly digestible solids that increase sugar yields during enzymatic hydrolysis; (ii) avoid loss of sugars (mainly pentose sugars), including those derived from hemicellulose through degradation; (iii) reduce the formation of inhibitors, which can impede further fermentation steps; (iv) recover lignin for modification into valuable co-products; and (v) reduce heating and power costs.

Figure 3.10. Scheme of Lignocellulosic Ethanol Production in General Principle



SHF = separate hydrolysis and fermentation, SSF = simultaneous saccharification and fermentation.
Source: Thi et al. (2019).

The pretreatment process should help reduce the sample size, break down the hemicelluloses to single sugars, and open up the cellulose component structure, which is further hydrolysed chemically (by acids or enzymes) into glucose sugar that is fermented to bioethanol (Demirbas, 2009).

Microorganisms are used to metabolise the liberated single sugars from enzymatic hydrolysis to convert them to bioethanol (Thi et al., 2019). Thi et al. (2019) and Balan (2014) suggested that these microbial fermentations be performed separately by fromenzymatic hydrolysis (separate hydrolysis and fermentation or SHF), combined with enzymatic hydrolysis (simultaneous saccharification and fermentation), or combined enzyme production and enzymatic hydrolysis.

The main challenge of second-generation bioethanol development is capital costs. Since cellulosic ethanol production is more complex than first-generation processes, the investment requirements are significantly greater than those of corn-starch or sugarcane-based ethanol. In the US, for example, it would cost around US$225 million to construct a cellulosic ethanol plant with an annual production capacity of approximately 151 million litres in contrast to an investment of around US$80 million to build a corn ethanol plant with a production capacity of around 114 million litres (Bracmort et al., 2015).

Robak and Balcerek (2018) pointed out that the high costs of the second-generation bioethanol production relate to the use of complex technologies at the pretreatment stage and the cellulase cost, i.e. the microorganism-based commercialised mixture of different kinds of enzymes used to hydrolyse cellulose and hemicellulose. They suggested improvements related to the pretreatment, enzymatic hydrolysis, and fermentation stages to increase ethanol production's cost-effectiveness and transition from the laboratory to the industrial or commercial scale.

Finally, the logistic costs are also an issue as low-density biomass or feedstocks involve significant handling and transportation costs (Childs and Bradley, 2007; Ferreira-Leitão et al., 2010). Sudiyani (2019) confirmed the above causes of the second-generation bioethanol production's high costs in Indonesia: (i) the complexity and the high cost of the processing, and (ii) the generally remote locations of the lignocellulosic feedstock.

3.5. Production of Green Fuels from CPO Hydrogenation

3.5.1. Introduction

Hydrotreating lipids from CPO produce green or renewable diesel or drop-in diesel (fuels). This kind of fuel is also known as hydrotreated vegetable oils (HVO), hydrotreated renewable oils, or hydro-processed esters and fatty acids (HEFA).

Green fuels, used as biofuels, have three main benefits: their non-existent blending walls, high-energy density, and compatibility with the existing transport fuel infrastructures.

First, without any need to modify vehicle engines, biodiesel and bioethanol's blending percentages to pure petroleum-based fuels, i.e. diesel and pure gasoline, are limited to certain thresholds.

In the US, for example, this blending wall for bioethanol of 10% (E10) is defined in the RFS programme of the US Environmental Protection Agency (2013). Beyond 10% bioethanol blending percentage, some requirements are needed in terms of the vehicle engine. For example, the E15 fuel can only be used by vehicles manufactured in 2007[14] and beyond; the E85 fuel can only be used in FFVs. In Europe, Directive 2009/30/EC also set the maximum blending percentage for gasoline fuels at 10%, whilst E85 fuels are sold for FFVs in Austria, France, Germany, and Sweden. In Brazil, the highest mandatory blending reached 25% (E25) in 2010.[15] In Southeast Asia, Thailand has the most progressive policy in biofuel. Praiwan (2019) reported that Thailand currently has five types of gasoline fuel: gasohol 91 E10, gasohol 95 E10, gasohol E20, gasohol E85, and premium ULG 95 petrol. The Thai Energy Ministry has set a time frame to transition to phase out E10 fuels and make the E20 the primary gasoline fuel grade by early 2020.

Regarding biodiesel, with its mandatory B30 programme in December 2019, Indonesia currently has the most progressive policy. Biodiesel blending limits in other regions have so far been lower than those of Indonesia. For example, the USDA (2019b) reported that

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[14] US EPA's blending waiver decision on 13 October 2010 to achieve the bioethanol usage target that cannot be achieved by the E10 mandate only.

[15] Regulation No. 7, 11 January 2010, issued by the Ministry of Agriculture and Fishery.

biodiesel blending rate averages never passed 8% in the EU. However, in the US, B5 fuel is available and usable by any diesel engine vehicle; and B20 is usable by buses and heavy-duty vehicles, such as school and transit buses, snow plows, garbage trucks, mail trucks, and military vehicles.

As ‘drop-in’ fuels, green fuels are perfectly mixable with petroleum fuels and technically can be used without any blending walls. Green fuels can then contribute to achieving biofuel use (volume) targets regardless of the gasoline fuel use fluctuations.

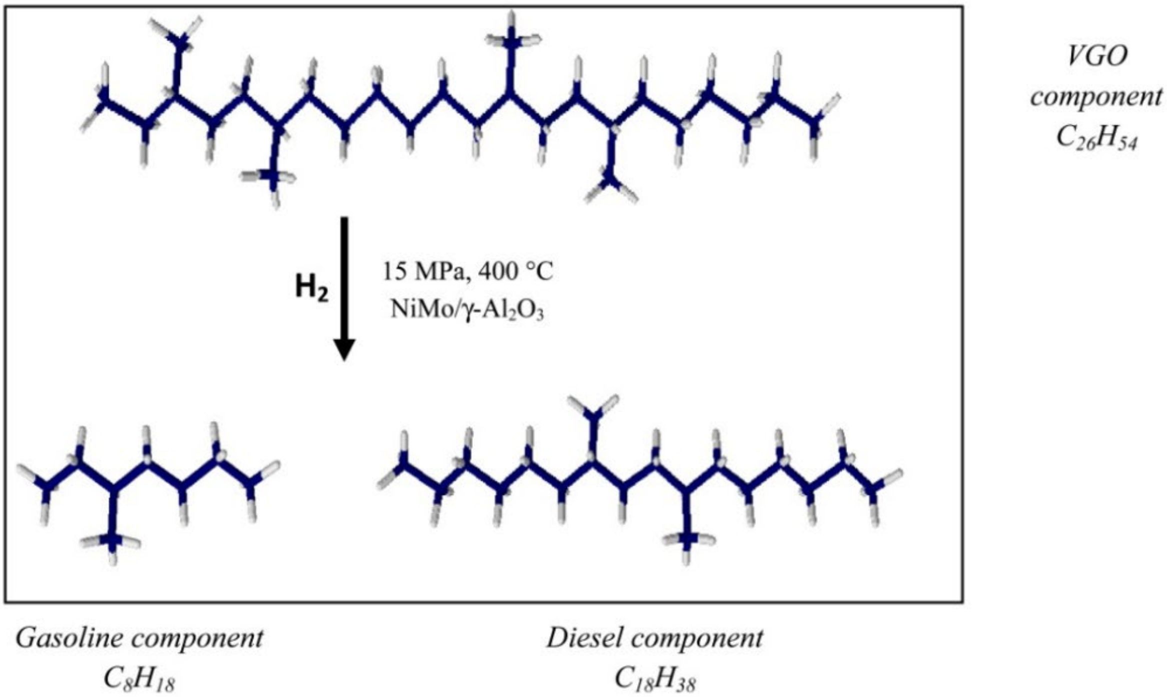
Second, bioethanol and biodiesel should be delivered and blended through separate distribution channels, e.g. trucks, rails, or barges, etc., as they are incompatible with most petroleum infrastructures such as pipelines and storage tanks. Most petroleum distribution infrastructures, such as pipelines, tanks, and related equipment, are composed of low-carbon and low-alloy steels. Controlling rust and corrosion is of primary importance. An ideal drop-in biofuel would have similar (to petroleum) non-corrosive, non-reactive, and non-hydrophilic functional properties so it can fully utilise the existing substantial pipeline network for its distribution (Karatzos et al., 2014).

3.5.2. Hydro-processing

In conventional oil refineries, hydro-processing is the catalytic process in which various petroleum distillates react with hydrogen at elevated temperature and pressure to form transportation fuels and heating oil (Douvartwides et al., 2019). There are two main processes:

1) non-destructive hydrogenation (hydrotreatment or hydrotreating) of the light distillates, i.e. the conversion of triglycerides into green diesel, which improves their quality and is favoured by mild temperatures, mild pressures, and catalysts of mild acidity. Examples are the sulfided Ni–W/Al2O3, Co–Mo/Al2O3, and Ni–Mo/Al2O3, which are also used for the hydrodesulphurisation of petroleum distillates destructive hydrogenation (hydrocracking) of the heavy distillates, such as vacuum gas oils into lighter fuels, such as diesel or gasoline.
2) Figure 3.11 with an appropriate boiling point, which is favoured by high temperatures, high hydrogen pressures, and strong acid catalysts and catalyst supports (alumino-silicates, silico-alumino-phosphates, and zeolites).

Figure 3.11. Hydrocracking of Light and Heavy Gas Oils (VGOs) into Gasoline and Diesel Fuels on a Bifunctional Catalyst



Source: Sotelo-Boyás et al. (2012).

3.5.3. Production of green fuels

Green fuels are produced via catalytic hydro-processing of vegetable oils. As commonly used in petroleum refineries, catalytic hydro-processing is when the hydrogen/carbon ratio is increased, heteroatoms and metals are concentrated, and the boiling point of refinery products is reduced (Amin, 2019). Douvartzides et al. (2019) described hydro-processing in the biofuel industry as the chemical reaction of the triglycerides in biomass lipids with hydrogen to produce liquid hydrocarbon fuels. Hydrogen saturates the double bonds of the triglycerides and, under specific conditions, may provide different liquid fuels such as green diesel (C15–C18), green jet fuel (C11–C13), and green naphtha (C5–C10).

According to Douvartzides et al. (2019)., hydro-processed esters and fatty acids (HEFA) can be produced either in a stand-alone facility or co-processed within an existing gasoline/diesel refinery).

Stand-alone hydro-processing of triglyceride

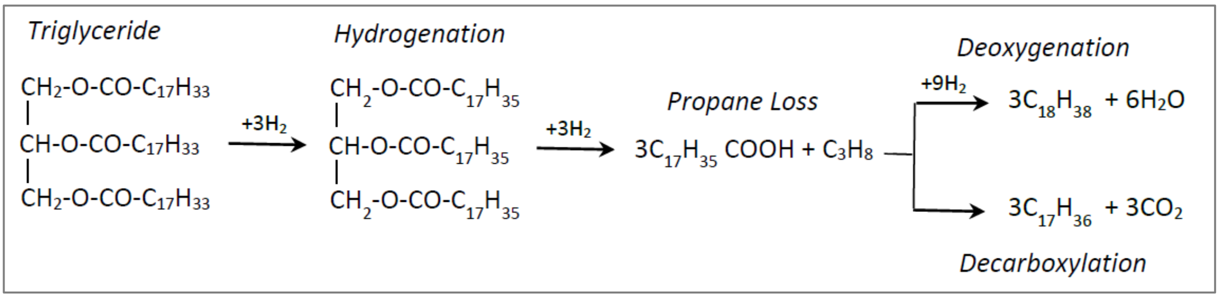
The hydro-processing of a triglyceride starts with the saturation of the double bonds of its fatty acid chains by hydrogen (hydrogenation). It continues with the removal of oxygen from the triglyceride molecules, which converts them into saturated hydrocarbons.

According to ETIP-Bioenergy (2024), in the stand-alone facility, biomass feedstock would go through two processes: (i) hydrotreatment where oxygen is reduced by hydrodeoxygenation (HDO) and decarboxylation (DCO) chemical processes and (ii) hydrocracking/isomerisation where chains are shortened to obtain lighter fuels. The two-process stages are explained in the following two subsections.

a) First stage: hydrotreatment

As shown in Figure 3.12, during the first stage of green fuel production, some hydrogens are used for three purposes: (i) to saturate with hydrogen all carbon–carbon triglyceride or triacyl glyceride, (ii) to remove the propane backbone of triglyceride, and (iii) to get rid of oxygen (deoxygenation).

Figure 3.12. Triacyl Glyceride (TAG) Deoxygenation Process



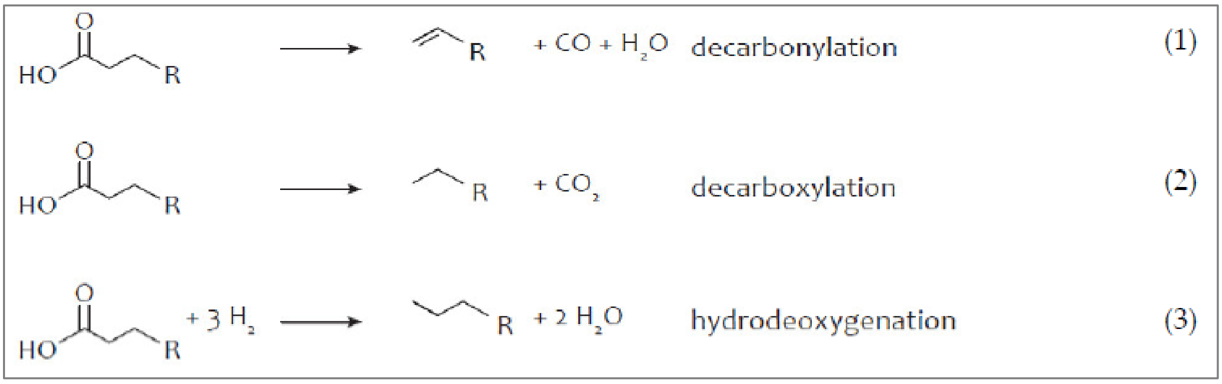
Source: Pearlson (2011).

The saturation with hydrogen aims to increase the hydrogen-to-carbon (H/C) ratio of the biomass feedstock so that it approaches diesel, jet, and gasoline fuels whose H/C ratios are near 2. The oxygen content in biomass consumes hydrogen during the combustion, thus, reducing the H/C ratio. Processing oleochemical feedstock (lipids such as CPO), which already has a high H/C ratio of around 1.8, is beneficial than producing it from biochemical feedstock (sugar starch) or thermochemical feedstock (lignocellulose) that has a very low H/C ratio, i.e. 0 and 0.2, respectively. More hydrogen is needed for a lower H/C ratio.

More hydrogens are added to remove the triglyceride's propane backbone in the second reaction, leaving three free fatty acids per triacyl glyceride molecule. At the final stage, deoxygenation can be achieved by two main chemical reduction processes, i.e. by adding more hydrogen in HDO and by losing carbon in decarboxylation. In HDO, hydrogen already present in the biomass feedstock or externally supplied is oxidised and oxygen is removed as water (H_2O). This process is favoured when hydrogen is accessible at affordable costs, and the yield of the process remains high. In CDO, carbon from the biomass feedstock is oxidised and removed as CO_2; consequently, the yield is reduced. This chemical process does not need hydrogen and is favoured when hydrogen is expensive, not accessible or available only from non-sustainable resources.

The reactions causing the oxygen removal from the triglyceride molecule are commonly termed reactions of selective deoxygenation (SDO) and may be further classified into the reactions of HDO, decarbonylation (deCO), and decarboxylation (deCO$_2$) (Figure 3.13).

Figure 3.13. The Three Deoxygenation (SDO) Reactions: Decarbonylation, Decarboxylation, and Hydrodeoxygenation



Source: Douvartzides et al. (2019).

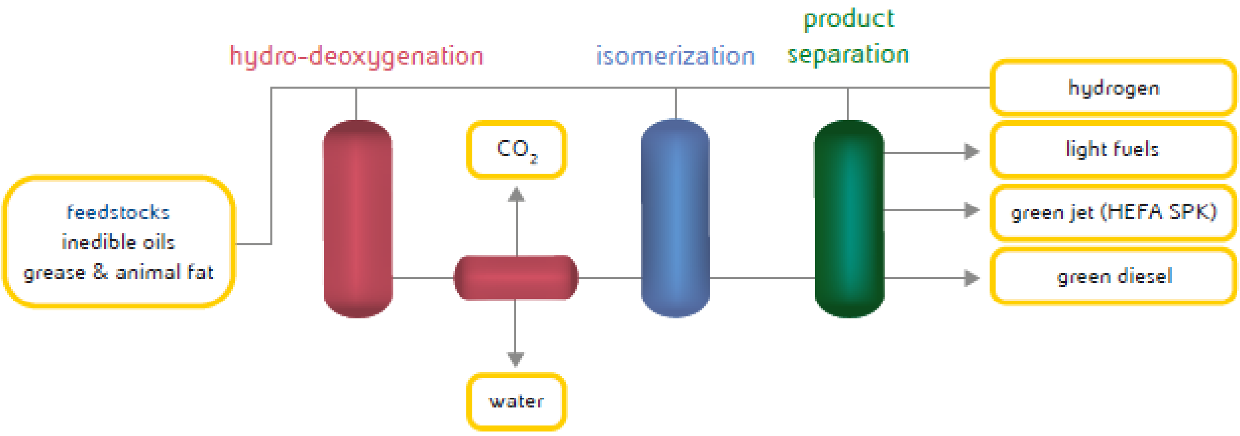
Decarboxylation (deCO$_2$) and decarbonylation (deCO) are commonly referred as deCOx reactions. In deCO$_2$, the O$_2$ molecules are removed in the form of CO$_2$. In decarbonylation (deCO), the oxygen molecules are removed as CO and H$_2$O. In both deCOx cases, the saturated hydrocarbon produced has one C atom less than the parent fatty acid chain in the triglyceride. In HDO, the oxygen molecules are removed exclusively as H$_2$O, and the saturated hydrocarbon has an equal number of C atoms with the corresponding fatty acid bound in the triglyceride. As a result, the saturated hydrocarbons produced by hydro-processing will have about the same C atoms with the fatty acid chains of the triglycerides. The three SDO reactions form a complex mechanism, making it generally difficult to determine their contribution accurately. However, the catalytic preference to deCOx or HDO reactions may be estimated by the distribution of the liquid hydrocarbons. The C17/C18 ratio and the preference between the deCO$_2$ and deCO reactions may be found through the CO$_2$/CO ratio. The triglyceride conversion, the degree of deoxygenation, and the yield of normal saturated hydrocarbons tend to increase with the reaction temperature in both batch and continuous reactors. However, the yield of C15–C18 hydrocarbons maximises at an optimal temperature and then reduces due to hydrocracking and reverse water gas shift reactions. Higher H$_2$ pressures have been observed to enhance the yield of hydrocarbons and the selectivity to green diesel. Also, the higher H$_2$ pressures promote the HDO reaction pathway. The H$_2$ consumption depends on the chemistry of the feedstock. Highly unsaturated oils, such as rapeseed oil and fish oils, require higher H$_2$ consumption since they have more double bonds. Finally, in all cases, propane (C3H8) is produced as a side product, together with H$_2$O, CO, and CO$_2$

from the SDO reactions.

Pearlson (2011) suggested that a combination of the two deoxygenation strategies is usually used in commercial hydrotreating facilities. Egeberg et al. (2011) reported that each pathway's ratio is important to the hydrotreating operations as it determines the hydrogen consumption, product yields, catalyst inhibition, gas consumption, and heat balance. Also, the tuning of the deoxygenation pathway ratio can be achieved via catalyst adjustment, depending on the strategic manufacturing priorities, the feedstock and hydrogen costs, and the value of the fuel product or blend stock being produced.

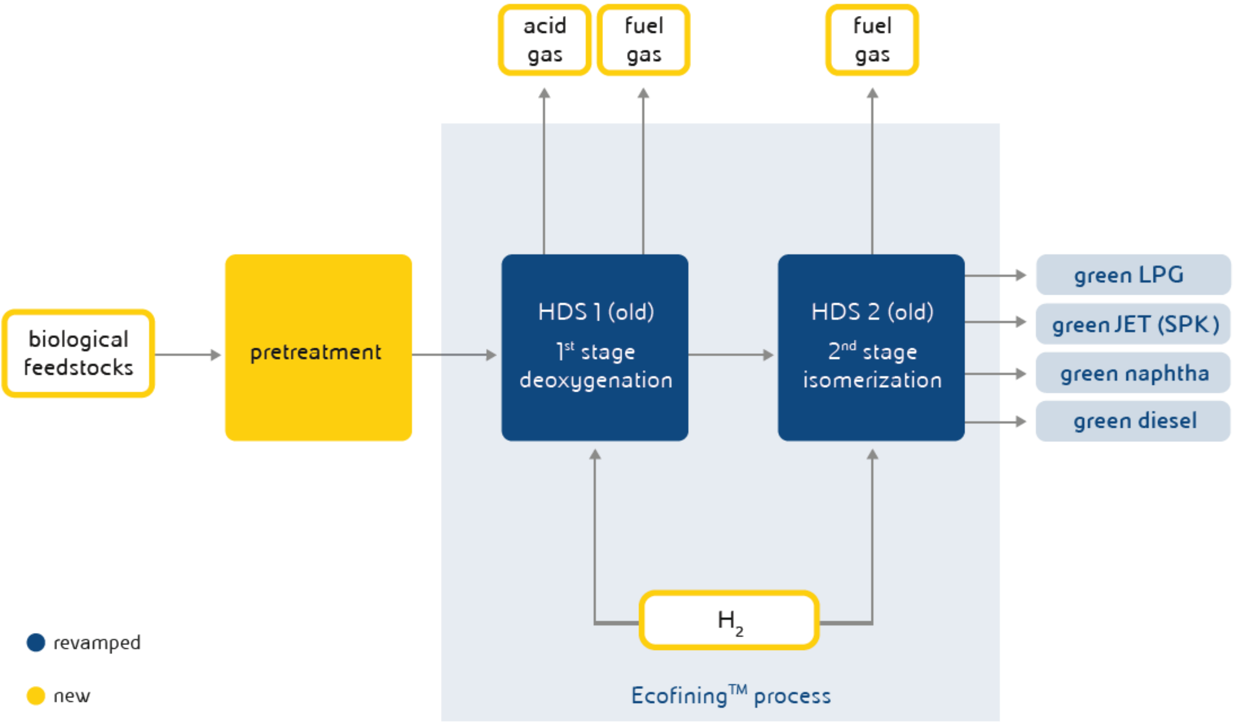
In practice, some retrofitting can be done to convert conventional oil refinery into biorefinery. The Ente Nazionale Idrocarburi or ENI (2014) model, belonging to the ENI S.p.A oil and gas company, consists of a facility with two main parts (Figure 3.14 and Figure 3.15).

Figure 3.14. ENI's Simplified Eco-fining Process Scheme



Source: ENI (2014).

Figure 3.15. HDS Units Rearrangement into Eco-fining

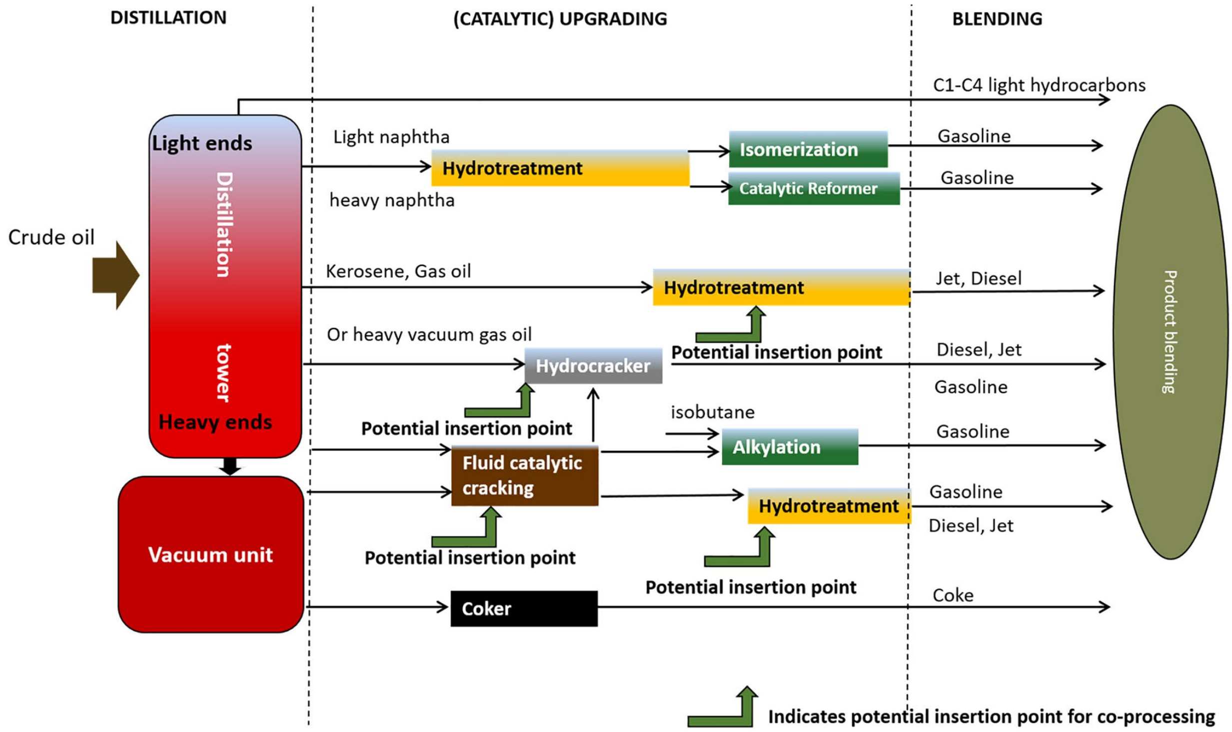


Source: ENI (2014).

Co-processing

Technical challenges, high capital costs, and generally low oil prices have been the main hindrances to the fast penetration of advanced drop-in biofuels. Van Dyk et al. (2019) concluded that it is likely that the co-processing of drop-in biofuels with conventional petroleum refining could considerably reduce capital costs. A simplified hypothetical conventional oil refinery process scheme is given in Figure 3.16 below.

Figure 3.16. Simplified Diagram of an Oil Refinery



Source: van Dyk et al. (2019).

The main objective of producing green fuel is to eliminate oxygen from biomass feedstock using CDO and/or HDO since oxygen limits blending percentage and attracts water to the resulting fuel. However, the CDO method will reduce yield as oxygen will be removed in the form of CO or CO_2 whilst the HDO method will need hydrogen from external resources. Simultaneously, there is a need to increase the H/C ratio of the biomass feedstock, which determines the upgrading level required to be done by the deoxygenation process.

Regarding the engineering challenges, as by-products, with biomass feedstock, CO, CO_2, and H_2O are produced whilst in conventional oil, it is hydrogen sulphides. Biomass feedstock also contains a high concentration of oxygen, considered a contaminant (~10% in vegetable oil and up to 40% in bio-oil). These contaminants in crude oil feedstock are typically very low (average 1.8% sulphur, 0.1% nitrogen in typical crude oil).

Van Dyk et al. (2019) suggested that many biocrudes that might be upgraded at a refinery will contain larger molecules composed of phenols, catechols, guaiacols, and syringols. For this reason, some form of cracking will be required to create shorter molecules that comply with the specifications for specific fuels. As shown in Figure 3.16, this cracking process can occur in one or more of the three processing units of the fluid catalytic cracker, i.e. the hydrocracker or the delayed coker (thermal cracking). Heteroatoms, i.e. oxygen from biocrude as nitrogen and sulphur from the conventional crude, are removed through hydrotreating. In contrast, processes such as isomerisation, catalytic reforming, and alkylation are usually used for any final polishing steps.

3.5.4. The crucial role of hydrogen

As discussed in section 3.5.3, hydrogen use is crucial in the production of green fuels more than in conventional transport fuel production: (i) to increase the H/C ratio of the biomass feedstock, (ii) to deoxygenate the biomass feedstock, (iii) to decontaminate (desulphurise), and (iv) to crack oil to get a good quality, i.e. sweet and light oil. Cracking heavy petroleum products can be done without hydrogen, which uses the catalytic cracking method. However, this will produce tar, which reduces the yield.

3.5.5. Use of green fuels in the world

HVO production globally was set to more than double from around 5.5 billion litres in 2018 to 13 billion litres in 2024 (IEA, 2019). The policy-driven demand of the EU and the US spurt investments of US$5 billion in new projects. As a result, HVO accounts for one-fifth of forecast biofuel output growth, although still less than 10% of cumulative production in 2024. Greenea (2019) estimated that the HVO-installed capacity was expected to reach 13 million tonnes to 20 million tonnes in 2025, with that of the US reaching 37% of the share, followed by the EU (37%) and Asia (18%).

Still, according to the IEA (2019), several factors drive HVO production growth: (i) its 'drop-in' characteristic, which means less blend limit constraint than biodiesel; (ii) its good cold-start properties; and (iii) its low aromatic content, which means it emits lower levels of air pollutants than fossil diesel when used in vehicles with older, less sophisticated engines and exhaust after treatment.

The use of green fuels globally is still minimal. As mentioned in section 2.3, EU's RED 2009/28/CE allowed the double-counting of waste-based biofuels in calculating the shares of renewable energies in transport. USDA Foreign Agricultural Service (2020) recorded that in Germany, this double-counting was also implemented for waste fatty acids–based HVO between 2011 and 2014. In Sweden, HVO increased by 66% in 2016 and, by 2017, accounted for two-thirds of all road transport biofuels used in the country (Sherrard, 2017). The use of pure HVO, HVO100, increased dramatically in Sweden and accounted for 2.7% of the total road transportation fuel market in 2016 to become the third-largest fuel type. Nevertheless, indigenous production of biofuels in Sweden is minimal. HVO, for instance, was imported from Finland, where it was produced from imported feedstocks (Bacovsvky and Brown, 2020).

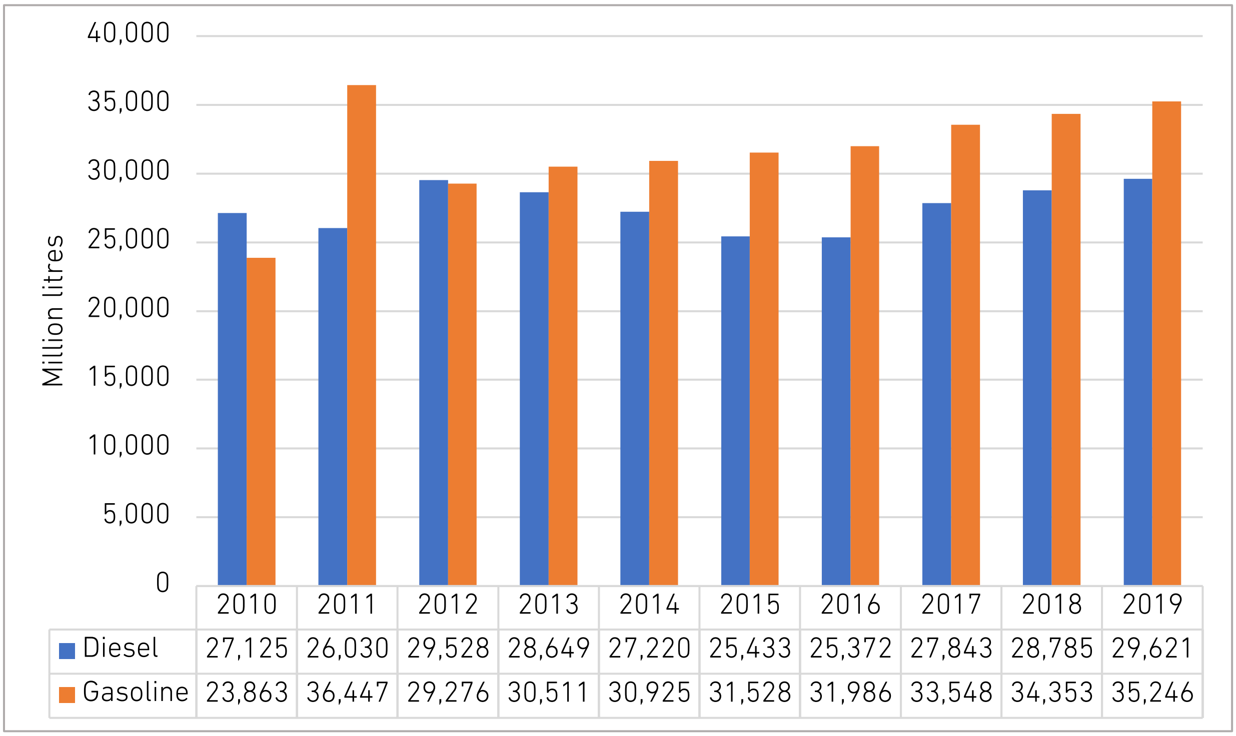
In the US, the use of HVO, together with cellulosic ethanol, so far has made up only a small overall percentage of fuel use (Bacovsvky and Brown, 2020). However, the part of HVO has been recorded to grow.

Chapter 4

Current Situation and Development

In Indonesia, land transport fuel consumption has been increasing from around 50,000 million litres in 2010 to nearly 65,000 million litres in 2019, i.e. a yearly average growth rate of 3%. The consumption shares of gasoline and diesel were in parity in 2012, but gasoline has been overtaking diesel share since then. Since 2015, the diesel–gasoline proportion has been at 55:45 on average (Figure 4.1). Since 2010, gasoline consumption in land transport has been increasing by 5.8% per year, whilst diesel, by 1.2% per year.

Figure 4.1. Diesel (Bxx) and Gasoline Land Transport Fuel Consumption



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
🟦 Diesel	27,125	26,030	29,528	28,649	27,220	25,433	25,372	27,843	28,785	29,621
🟧 Gasoline	23,863	36,447	29,276	30,511	30,925	31,528	31,986	33,548	34,353	35,246

Source: MEMR (2019) and USDA (2019a).

This section performs a stocktaking of the current supply and demand of gasoline and diesel fuels and the related biofuels. It aims to define the possible future challenges, strengths, and opportunities regarding supply and demand of the conventional fuels and the concerned biofuels, namely, biodiesel and bioethanol. We also consider the current events that shall significantly shape the future situation's socio-economic background, especially the COVID-19 pandemic and the drop of world crude oil price because of the Russia–Gulf countries' oil dispute.

4.1. Gasoline and Bioethanol Supply and Demand

Between 2010 and 2018, gasoline fuel demand increased at an annual growth rate of 6.2%. During the same period, production dropped by 2.4% annually, and imports increased by 5.5%. Between 2016 and 2018, the decline in gasoline production was stronger, i.e. 9.2% per year. This incited a more robust rise in imports (8.8%), whilst demand grew weaker at 3.6% per annum.

Despite a higher consumption share than diesel, Indonesia's bioethanol programme to substitute gasoline use has never known actual implementation. Indonesia practically knows only the first-generation bioethanol production method. The process includes producing molasse from sugarcane, followed by the fermentation process.

As reported in Hidayat (2020), APROBI estimates that all-grades ethanol domestic need is around 90 million to 100 million litres per year with the current total annual production capacity of 180 million litres. The maximum yearly installed capacity is about 245 million litres.

ASENDO[16] data shows that three factories can currently produce fuel-grade bioethanol in Indonesia, with a total installed capacity of 45 million litres of bioethanol per year. However, according to the USDA, Indonesia has an installed bioethanol refinery capacity of up to 100 million litres per year. Between 2010 and 2015 (Table 4.1), only 29 million litres were produced, and all were exported. No bioethanol has been produced since then.

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[16] As explained by ASENDO Chairman, Dr Untung Murdiyatmo during the Workshop on 9 December 2019

Table 4.1. Gasoline Supply and Demand Balance (million litres)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Transport use	23,863	36,447	29,276	30,511	30,925	31,528	31,986	33,548	34,353	35,246
Production	11,255	10,754	11,238	11,350	11,925	11,916	11,139	8,130	8,831	n/a
Import	12,712	15,603	17,870	1,668	19,512	18,226	15,739	17,857	18,597	19,080
Export	3.816	13.833	20.511	15.423	2.528	2.385	1.431	0.636	0	n/a

Source: MEMR (2019), USDA (2019a) for transport use in 2019, and Tan et al. (2020b) for import in 2019.

An imaginary implementation of an E2 programme, i.e. 2% national-scale mandatory bioethanol blending, would need around 700 million litres of bioethanol. With the current installed producing capacity of 45 million–100 million litres, only about 6.4% to 14.2% of the required bioethanol can be met. From the supply perspective, we can conclude that it is not feasible to implement even a national-scale low-blending bioethanol mandatory programme at 2%.

Indonesia has approximately 6 million hectares of sugarcane plantation with average productivity of 60 tonnes of sugarcane per hectare. A producer can virtually make around 1.2 barrels of bioethanol from 1 tonne of sugarcane. Harsono and Boediwardhana (2020) recorded that sugarcane supply to bioethanol makers could be an issue as bioethanol makers' prices are generally lower than those of sugar producers. In East Java, bioethanol makers would offer to buy sugarcane at Rp55,000/100 kg whilst sugar factories would offer Rp69,000/100 kg. The authors also noticed difficulties faced by sugarcane farmers, i.e. shrinking farmland, fewer fertiliser subsidies, and lack of high-yield saplings. In East Java, between 2016 and 2018, sugarcane farmland decreased by nearly 12% – from 205,000 to 180,000 hectares – whilst the yield decreased by 14% from 84 tonnes to 72 tonnes of sugarcane per hectare.

Indonesia once exported cassava-based bioethanol to the Philippines. Medco International, for example, between 2009 and 2013, operated a refinery that produced around 60,000 kl of cassava-based bioethanol per year. However, this industry was closed as the bioethanol price from the US was higher. Indonesia currently has an oversupply of molasse, but most of it is industrial and has a food-grade that feeds domestic and export demand. In Thailand and the Philippines, molasse production is fully aimed to meet bioethanol grade.

Table 4.2. Bioethanol Production, Supply, and Demand Statistics

Ethanol Used as Fuel and Other Industrial Chemicals (million litres)										
Calendar year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Beginning stocks	42	36	41	52	39	14	16	15	14	14
Fuel begins stocks	0	0	0	0	0	0	0	0	0	0
Production	175	220	205	207	202	205	205	195	200	195
Fuel production	3	3	2	2	18	1	0	0	0	0
Imports	0	1	0	0	2	0	2	5	96	5
Fuel imports	0	0	0	0	0	0	0	0	95	0
Exports	49	81	59	86	94	67	71	64	158	64
Fuel exports	3	3	2	2	18	1	0	0	95	0
Consumption	132	134	135	135	135	136	137	137	138	139
Fuel consumption	0	0	0	0	0	0	0	0	0	0
Ending stocks	36	41	52	39	14	16	15	14	14	11
Fuel ending stocks	0	0	0	0	0	0	0	0	0	0
Total balance check	0	0	0	0	0	0	0	0	0	0
Fuel balance check	0	0	0	0	0	0	0	0	0	0
Refineries producing fuel ethanol (million litres)										
Number of refineries	3	3	3	3	3	3	3	3	3	3
Nameplate capacity	100	100	100	100	100	100	100	100	100	100

Ethanol Used as Fuel and Other Industrial Chemicals (million litres)										
Calendar year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Capacity use (%)	3	3	2	2	18	1	0	0	0	0
Feedstock use for fuel (1,000 MT)										
Molasses	13	11	6	7	72	4	0	0	0	0
Market penetration (million litres)										
Fuel ethanol	0	0	0	0	0	0	0	0	0	0
Gasoline	23,863	36,447	29,276	30,511	30,925	31,528	31,986	33,548	34,353	35,246
Blend rate (%)	0	0	0	0	0	0	0	0	0	0

Source: MEMR, Global Trade Atlas (GTA) data, as cited and elaborated in USDA (2019a).

Apart from setting a lower target at the provincial (East Java) level, there is also discussion about lifting the ban on bioethanol blended gasoline (Tan et al., 2020a).

4.2. Diesel: Current Production Capacity, Supply, and Demand

The consumption of diesel fuel, used primarily for road freight transport, fluctuated between 2010 and 2019 as freight transport activity correlated with the economic condition (Table 4.3). Diesel consumption in the industry sector decreased significantly, around 10% per year between 2010 and 2019, resulting from the shift to another energy type. During the same period, with some fluctuations, diesel production increased at 3.6% annual growth rate whilst import was cut by half from nearly 13,000 million litres in 2010 to nearly 6,500 million litres in 2018. The biodiesel blending rate increased from only 1% in 2010 to nearly 20% in 2019, representing a growing level of biodiesel mandatory programmes. Apparently, diesel import dropped with the increase of biodiesel (B100) blending rate.

Current biodiesel production capacity is around 12.05 million kl, which means an average monthly capacity of 1 million kl. With the opening of three additional plants in 2020, the total national production capacity should reach 12.85 million kilolitres.

Table 4.3. Pure Diesel Supply and Demand Balance (million litres)

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Transport use	26,947	25,743	28,993	27,811	25,744	24,768	22,751	2,5571	25,135	23,721
Industry use	9,325	11,467	8,215	7,474	7,431	5,479	4,667	3,598	3,411	3,412
Production	17,070	18,509	19,652	19,753	20,650	20,641	19,766	21,384	22,521	n/a
Import	12,712	13,573	12,455	11,947	11,475	7,318	5708	6794	6499	n/a
Export	241.5	18.0	14.6	0.0	23.5	0.0	0.2	1.3	0.6	n/a
B100 blending rate %	0.7%	1.1%	1.8%	2.9%	5.4%	2.6%	10.3%	8.2%	12.7%	19.9%

Source: MEMR (2019) and USDA (2019a) for 2019 figures.

Table 4.4. Biodiesel Production, Supply, and Demand Statistics (million litres)

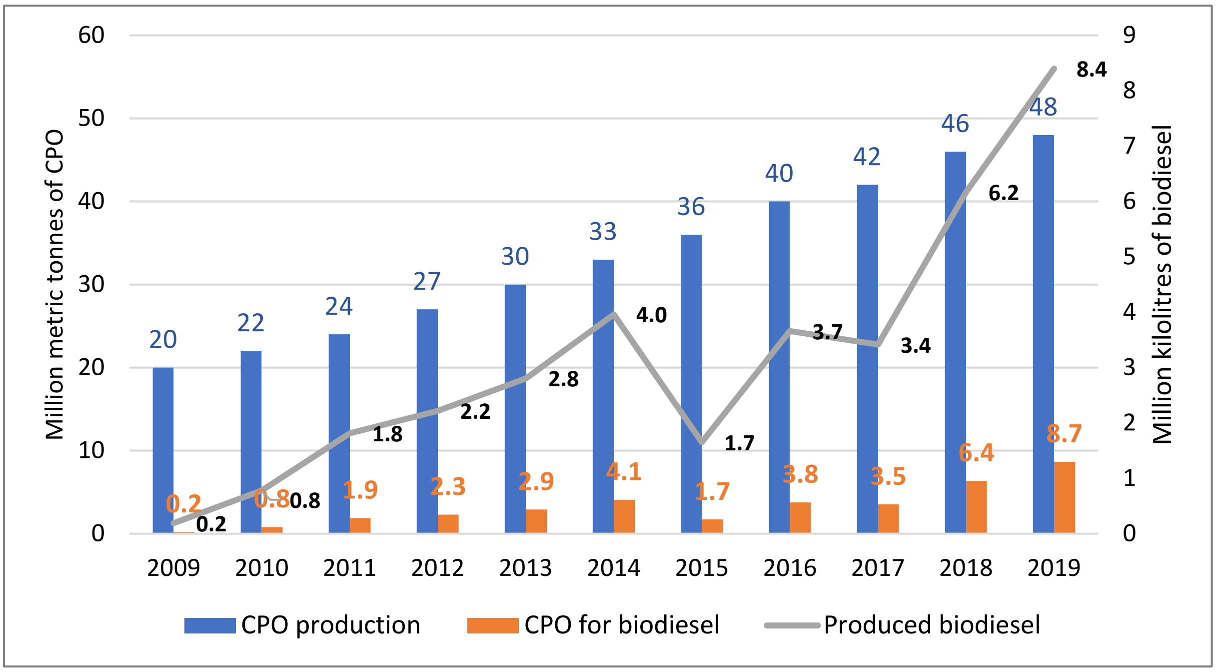
Calendar Year	2010	2011	2012	2013	2014r	2015r	2016r	2017r	2018r	2019e
Beginning stocks	22	16	29	27	11	97	94	110	151	57
Production	780	1,812	2,270	2,950	3,500	1,200	3,500	2,800	5,600	8,000
Imports	0	0	5	24	0	0	0	0	28	0
Exports	563	1,440	1,608	1,942	1,569	343	476	187	1,772	1,800
Consumption	223	359	669	1,048	1,845	860	3,008	2,572	3,950	6,200
Ending stocks	16	29	27	11	97	94	110	151	57	57

Calendar Year	2010	2011	2012	2013	2014r	2015r	2016r	2017r	2018r	2019e
Production Capacity (million litres)										
Number of Biorefineries	22	22	22	26	26	27	30	32	31	31
Nameplate Capacity	3,921	3,921	4,881	5,670	5,670	6,887	10,898	11,547	11,357	11,357
Capacity use (%)	19.9%	46.2%	46.5%	52.0%	61.7%	17.4%	32.1%	24.2%	49.3%	70.4%
Feedstock Use for Fuel (1,000 MT)										
Crude palm oil (CPO)	**804**	**1,868**	**2,340**	**3,041**	**3,608**	**1,237**	**3,608**	**2,887**	**5,773**	**8,247**
Market Penetration (Million litres)										
Biodiesel, on-road use	**178**	**287**	**535**	**838**	1,476	**665**	2,621	2,272	3,650	5,900
Diesel, on-road use	27,125	26,030	29,528	28,649	27,220	25,433	25,372	27,843	28,785	29,621
Blend rate (%)	0.7%	1.1%	1.8%	2.9%	5.4%	2.6%	10.3%	8.2%	12.7%	19.9%
Diesel, total use (all sectors)	36,450	37,497	37,743	36,124	34,651	30,912	30,039	31,441	32,196	33,033

e = estimate, r = revised.

Source: USDA (2019a) with author’s correction on CPO feedstock use.

Figure 4.2. Crude Palm Oil (CPO) and Biodiesel Production



Source: Gabungan Pengusaha Kelapa Sawit Indonesia or GAPKI (Indonesia Palm Oil Association), 2020.

4.3. Green Fuels: Production Capacity, Supply, and Demand[17]

Since 2014, Pertamina Research and Development has been conducting conversion trials of refined bleached deodorised palm oil in its Refinery Unit II (RU II) Dumai Riau to obtain 3% (D3)–10% (D10) bio-blended diesel (Figure 4.3).

Nowadays, Pertamina injects the CPO in the distillate hydrotreating unit facility in its RU II Dumai to produce green diesel or D10 fuel containing 97.5% fossil-based diesel fuel and 12.5% CPO with a cetane number of 58. The refinery has an installed capacity of 12.6 million barrels per stream day. The green fuel production in this facility uses the *Merah Putih* catalyst developed by the Bandung Institute of Technology.

In the short-term, three Pertamina refineries would be ready: Dumai (1,000 barrels/day), Plaju (20,000 barrels/day), and Cilacap (6,000 barrels/day) (Kotrba, 2020). These would result in a total capacity of 27,000 barrels per day or around 1,565 million litres per year, which would need around 1,675 thousand tonnes of CPO per year.

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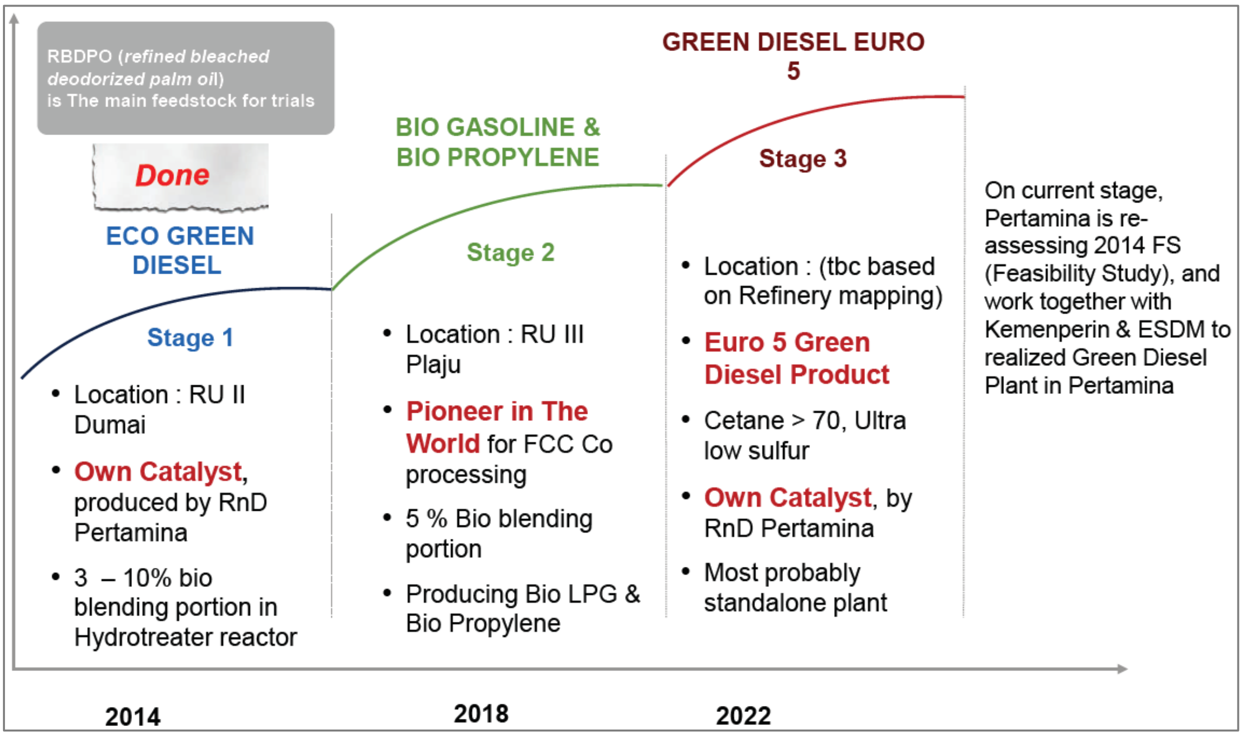
[17] Bioenergy: HEFA costs around US$0.7/litre plus the costs to provide hydrogen that amounts about 3% to 4% of the hydrocarbon produced while FAME only costs around US$0.2/litre and needs no hydrogen.

In terms of green gasoline, since 2018, Pertamina has performed several trials in producing green gasoline and green liquefied petroleum gas (LPG) in the RU II Plaju whilst conducting a feasibility study to build a stand-alone green diesel plant (Figure 4.4).

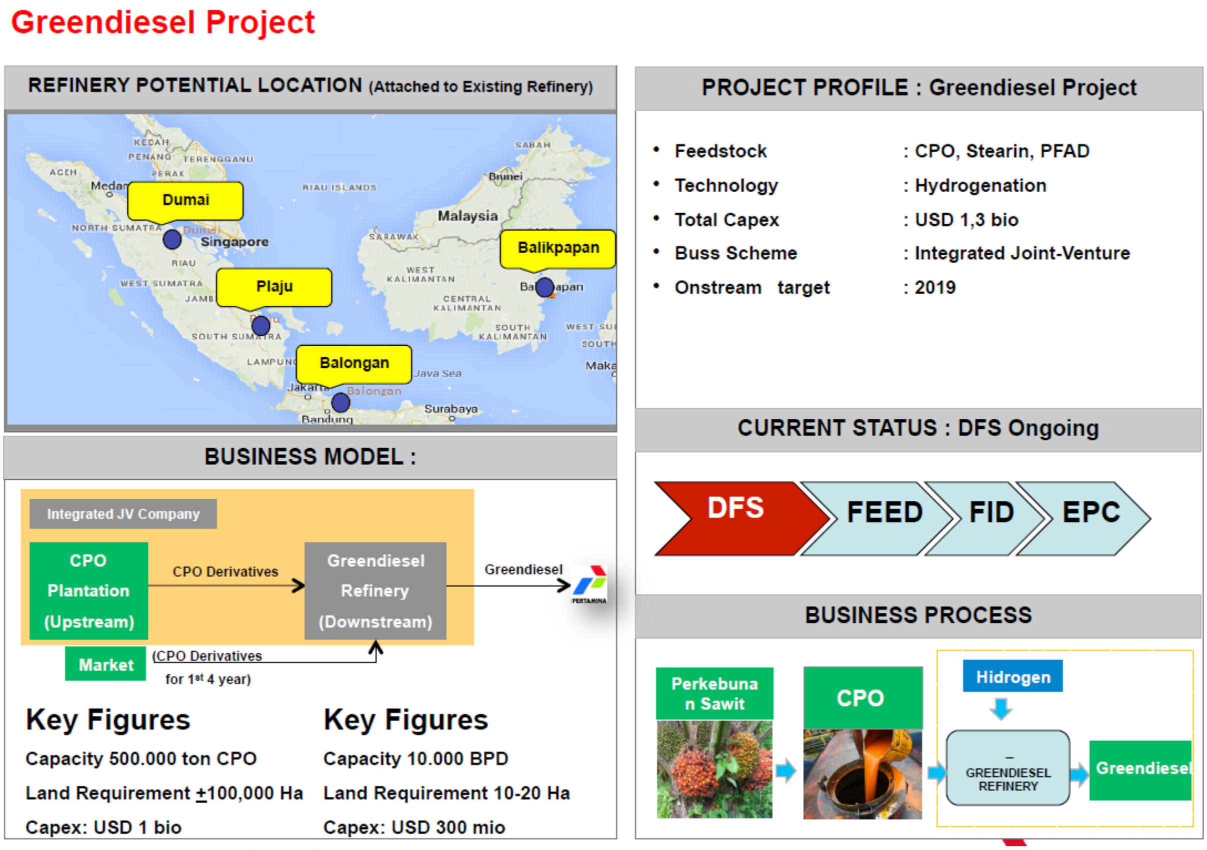
Today Pertamina's Refinery Unit III in Plaju, South Sumatera is the first refinery in Indonesia to produce green gasoline and green LPG. The co-processing is performed in the residual fluid catalytic cracker facility refinery that takes the refined, bleached, and deodorised palm oil as feedstocks. The refinery has an installed production capacity of 20,500 barrels per day. It can produce 405,000 barrels or around 64,500 kilolitres of green gasoline per month or 774 million litres per year and 11,000 tonnes of green LPG per month.

Figure 4.3. Pertamina's Co-processing Roadmap



Source: Pertamina (2015).

Figure 4.4. Pertamina's Green Diesel Projects



Greendiesel Project

REFINERY POTENTIAL LOCATION (Attached to Existing Refinery)

BUSINESS MODEL :

Integrated JV Company

CPO Plantation (Upstream)

CPO Derivatives

Greendiesel Refinery (Downstream)

Greendiesel

Market

(CPO Derivatives for 1st 4 year)

Key Figures

Capacity 500.000 ton CPO

Land Requirement ±100,000 Ha

Capex: USD 1 bio

Key Figures

Capacity 10.000 BPD

Land Requirement 10-20 Ha

Capex: USD 300 mio

PROJECT PROFILE : Greendiesel Project

- Feedstock : CPO, Stearin, PFAD
- Technology : Hydrogenation
- Total Capex : USD 1,3 bio
- Buss Scheme : Integrated Joint-Venture
- Onstream target : 2019

CURRENT STATUS : DFS Ongoing

DFS FEED FID EPC

BUSINESS PROCESS

Perkebunan Sawit

CPO

Hidrogen

– GREENDIESEL REFINERY

Greendiesel

Source: Pertamina (2015).

The *Merah Putih* catalyst invented by the Bandung Institute of Technology or Institut Teknologi Bandung (ITB) can be used to produce high-quality HVO. Green diesel HVO has a property like that of pure diesel and can be used directly on vehicles. The ITB would collaborate with Pupuk Kujang to build a catalyst factory that shall operate in 2021.

For green diesel production, the ITB developed the PIDO 130-1,3T nickel-molibdenum catalyst invented in 2019 for vegetable oil HDO to produce paraffinic hydrocarbon (Subagjo, 2018). The use of CPO as feedstock shall result in green diesel whilst the use of palm kernel oil shall result in green kerosene that can be processed further as feedstock to produce bio-jet fuel. Putra et al. (2018) elaborated that green diesel was produced through HDO from palm oil and processed in a batch-stirred autoclave reactor over natural zeolite (NZ) and NZ modified with 3 weight percent (wt%). A higher conversion of palm oil into diesel-like hydrocarbons reached more than 58% and 89%, when NZ and iron (Fe) modified NZ (Fe/NZ), respectively, were used as catalysts.

As Subagjo (2018) also explained, the ITB developed the ZSM-5 catalyst to produce high-octane green gasoline. Siregar (2005) discussed the methodology on catalytic cracking to produce green gasoline and green LPG production from refined bleached deodorised palm oil (RDBPO) using zeolite-based H-ZSM-5. The use of H-ZSM-5 should produce the best results of 96.12 wt% palm oil conversion and 29.92 wt% of gasoline.

4.4. The Development Plan of Flexible-Fuelled Engine Vehicles

One critical point in biofuel-related technology development is the compatibility between fuel and engine specifications and standards. It is currently hard for original equipment manufacturers (OEMs) to develop future engine technology specifications that can adapt to high-blended biodiesel as no international biodiesel standard can be used as reference. In the absence of national and international standard references and to cope with this issue, the Ministry of Industry issued a decision letter of its Directorate General that can be used as a temporary reference.

OEMs[18] are now assessing the benefits and costs of producing flex-fuel engine vehicles. They are interested in finding out FFVs' basic criteria, especially considering consumer acceptance regarding costs and technology. To develop new fuel and engine technology, i.e. B100, the government should consider long-term implementation time and costs. This process includes the development period (technology specification, regulation, trial and error) and the monitoring and evaluation period. They estimate that the additional cost of flex-fuel engine vehicle technology, especially concerning the B100, would be high.

Some OEMs participated in the off-road vehicle testing of the MEMR for B20 (2015–2016) and B30 (2019). Both B20 and B30 fuel use test results showed no negative impact on engine performance. However, the B30 test results indicated that some engine performance indicators reached their critical thresholds. Some OEMs suggested that to operate a vehicle using biofuels above B30 safely, the engine would need some modifications.

To develop a new technology business plan, Toyota would typically need around 7 to 8 years of development. A slight modification of the engines (such as a retrofit) takes lesser time than developing a new engine technology. Isuzu Astra estimated that it would take around 3 to 4 years to build a new flex-fuel engine vehicle technology to take B100 fuel. This OEM suggested that policymakers consider this development period.

In Argentina, Toyota has been manufacturing and selling flex-fuel engine vehicles tanked with pure gasoline or pure bioethanol (E100). However, currently, no vehicle can accommodate both diesel and pure biodiesel (B100).

Automotive experts gathered during the third workshop on 15 January 2020 estimated several potential additional costs in developing a diesel-based FFV:

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[18] PT Toyota Manufacturing Indonesia, PT Krama Yudha Tiga Berlian Motors (Mitsubishi Fuso), PT Isuzu Astra were present in the workshop organised on 15 January 2020.

- The cost of storing the high-blended biofuels in separate fuel dispensers at the tank stations would mean some additional costs in infrastructure
- The cost of vehicle maintenance because of more frequent fuel filter change
- The cost needed to provide for on-vehicle water-fuel separation facilities

Iman Kartolaksono[19] explained that the B100 biofuel programme conceptually should create a new fuel type for the current vehicle engine technology. This means that high-blend biodiesel should be engineered to meet the fuel specifications of pure diesel fuel. In other words, the high-blend biodiesel should have the same property as the current pure diesel fuel, which would be hard to achieve. The solution for this would be to set biodiesel and biodiesel-suitable engine standards that are compatible.

Consumers need to be informed about the costs and benefits of using high-blended biofuels and flex-fuel engine vehicles. Avoiding information bias shall allow optimal penetration of the fuels and technologies.

Customers need to realise that biofuels' energy content is less than conventional transport fuels. For example, gasoline fuel energy content is almost 1.5 times that of bioethanol. Customers will need to tank more with biofuels than with conventional fuel to run the same mileage. It is then essential to set high-blended biofuel prices lower than conventional transport fuel to compensate for this low fuel inefficiency. One interesting case is the much lower price of E85 in tank stations in Thailand compared to conventional gasoline prices.

The current luxury sale tax level of 8% applied to future flex-fuel engine vehicles (in Regulation PP73/2019) is estimated to be enough to compensate for the additional production costs of vehicles. However, the current luxury sale tax (PPnBM) considers only the future passenger flex-fuel engine vehicles. The regulation needs to be expanded to include commercial vehicles, such as trucks and vans.

Feebate might be a good fiscal measure to be implemented in Indonesia as an accompanying measure, i.e. to set an excise duty to use conventional or low-blended (bio-) fuels and use the revenues to subsidise high-blended biofuels. This way, high-blended biofuel prices would be lower than those of conventional or low-blended biofuel prices.

Thailand managed its state oil fund for gasoline. The revenue obtained from excise duty applied for pure gasoline is used to subsidise bioethanol fuels that range from E10 to E85. The higher the biofuel blending percentage, the higher the subsidy and the lower the biofuel price at pumping stations. Thus, E85 is the cheapest fuel.

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[19] Dr Kartolaksono is a diesel engine expert from the Institut Teknologi Bandung. He participated in the workshop discussion on 15 January 2020.

4.5. Implementation Issues of Euro IV Fuel Standards

To protect health, Indonesia implements the Euro IV equivalent emission standards for light- and heavy-duty vehicles. These are applied to all gasoline-, diesel-, and gas-fuelled vehicles based on Ministry of Environment and Forestry Decree No. 20/2017. The decree applies stricter limits to emissions of carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxide (NOx) of new vehicles. The emission factor limits set by the decree correspond to the Euro IV emission standards, which are much stricter than the Euro II emissions standards set by the previous Decree No. 4 Year 2009.

According to the Ministry of Environment and Forestry (2017), following the decree, new gasoline- and gas-fuelled vehicles registered in Indonesia were to comply with the Euro IV standards by October 2018. The new diesel-fuelled vehicles were to comply by March 2021. The Euro IV emissions standards for new gasoline- and gas-fuelled vehicles were implemented on 7 October 2018; those for new diesel-fuelled vehicles will be implemented in April 2022.

In addition to vehicular emission standards, the new standards also apply to fuels that meet Euro IV requirements in general, including regulating the sulphur content to 50 ppm. However, currently, almost none of Pertamina’s fuel products meet this requirement. The highest quality product, Pertamina Dex diesel fuel, has a sulphur content that meets only Euro III standards (300 ppm), not the higher-level Euro IV standards that Indonesia set. Also, 90% of the market is dominated by lower-quality diesel fuel with a sulphur content of up to 2,500 ppm. For gasoline fuels, the only publicly commercialised product that meets the Euro IV standards is Pertamax Turbo. According to ERIA’s calculation, Pertamina consumption in 2019 was less than 1%, whilst Pertalite share was the majority (55%), followed by Premium (33%) and Pertamax (11%). CNBCIndonesia.com (2019) also revealed that by June 2020, only 18% of gas stations in Indonesia sold Pertamax Turbo.

In other words, for Indonesia to shift to Euro IV means that higher-quality gasoline and diesel fuels must be available in all gas stations to meet the demand. Euro IV fuel price must also be significantly higher than the average price of the current fuel products available in the market. There is no clear evidence of the Euro IV fuel shifting timeline. In this study, we only assumed that a gradual shifting would happen from now to 2025 for both gasoline and diesel.

A meta-analysis of several studies conducted by Searle and Bitnere (2018) concluded that the use of biodiesel produced from CPO leads to decreased CO and HC emissions. This biodiesel has virtually no sulphur, but it tends to increase emissions (NOx, particulate matter) when blended with low-sulphur diesel. Although CPO-based biodiesel can be used when Indonesia’s diesel fuels still contain a high sulphur as in the current situation, it will not support the shift to Euro IV, which requires a low sulphur content.

On bioethanol use, Dardiotis et al. (2015) found that under the New European Driving Cycle, at 22^0C, CO, HC, and NOx emissions from the high biofuel (E85) and E5-fuelled vehicles were both below Euro IV and Euro V limits. E85-fuelled vehicles performed better in CO and NOx than E5.

Not many studies have been conducted to analyse the compatibility of HVO or green fuels to Euro IV or other higher standards. Suarez-Bertoa et al. (2019) found that green diesel has no issue regarding the current EU fuel requirements. These are Euro VI standards that are much stricter than those of Euro IV that Indonesia aims to meet.

We can conclude that whilst other bioethanol and green fuels have no issue with emission standards of Euro IV and beyond, CPO-based biodiesel, to some extent, has some problems when blended with Euro IV standard fuels.

Chapter 5

Development of the Biofuel Roadmap Framework

5.1. Objectives and Methodology

Road-map development activity aims at finding the correct biofuel-related policy measures to be implemented from 2020 to 2035. This is to reduce the dependency on conventional transport fuel with decreasing transport fuel import and improving overall energy trade balance as fast as possible, considering the limited capacity of feedstocks and biofuels production and automotive sectors.

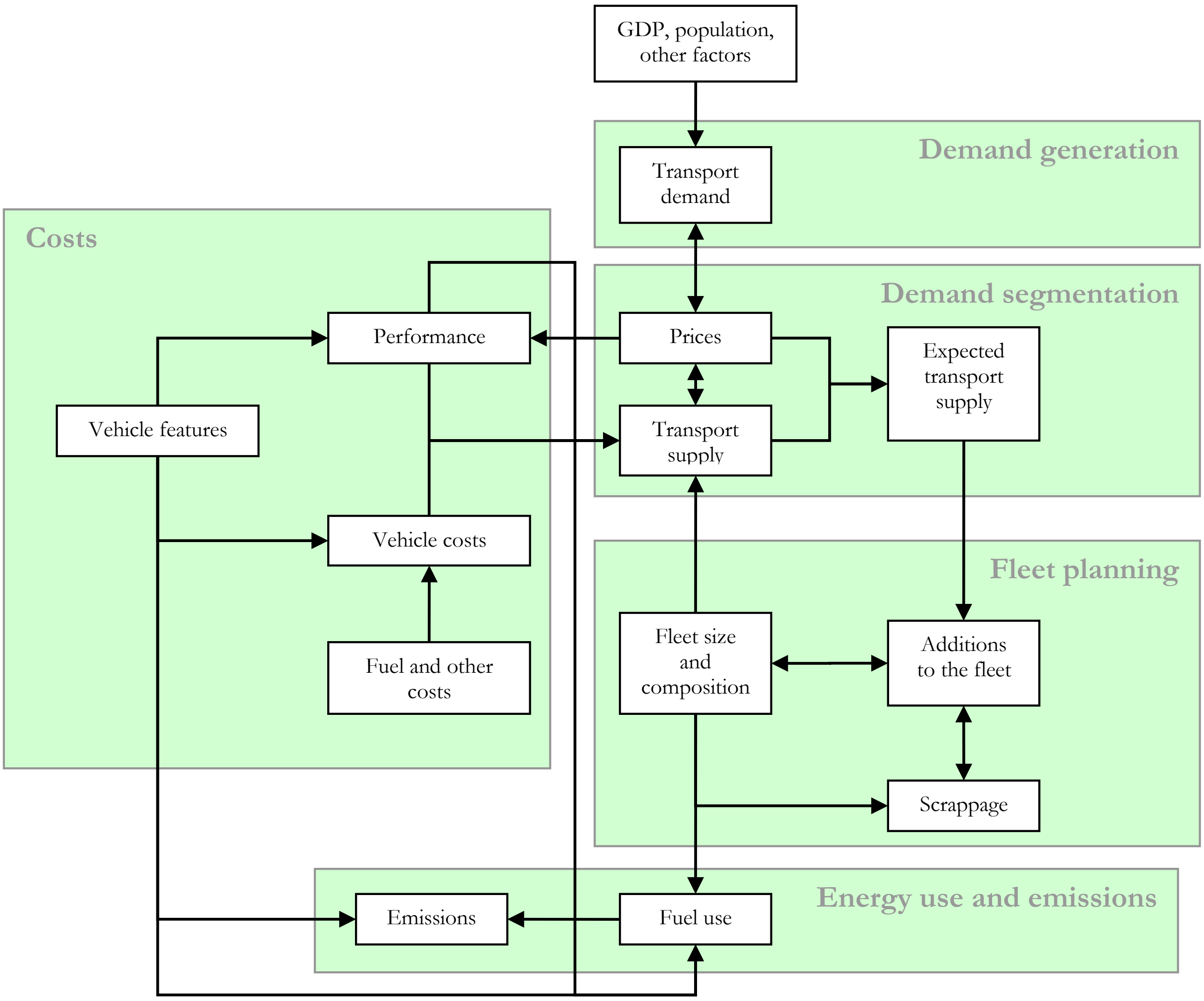
The roadmap would be developed based on the VEIA Model based on Purwanto et al. (2017). The model is divided into four modules – (i) demand (generation and segmentation), (ii) fleet planning, (iii) energy use and emissions, and (iv) costs based on the structure shown in Figure 5.1. The four modules exchange information to provide a consistent picture of the various aspects modelled.

Transport demand is estimated as a function of GDP, trade, population, transport prices, and other relevant driving factors. Motorised transport demand is endogenously generated and segmented according to several dimensions (e.g. national and international, long or short distances, etc.). Also, the choice of mode and road type for each specific context is carried out considering demand–supply interaction. According to the fleet structure estimated in the fleet planning module, transport demand by mode is used as input to calculate vehicle-kilometres by type and technology.

Using a vintage model, which considers the past additions to the fleet and each vehicle type's survival rate, the model establishes the number of vehicles still in service from each vintage. The current fleet by region is then calculated from the balance between added, retired, and remaining vehicles. The expected changes in transport supply are used to determine new vehicles' requirements in the following simulation period.

In the energy use and emission module, fuel consumption and emissions are calculated based on vehicle-kilometres (from the fleet module) and the average speed of each transport mode (from the demand module). Fleet size and composition, together with the vehicles' technical features, determine the amount of energy consumed. Emissions are calculated by applying the appropriate emission indexes.

Figure 5.1. VEIA Module Structure



VEIA = Vehicle Technology Impact Assessment.
Source: Authors' elaboration.

The model has been calibrated to the statistics of road transport fuel consumption produced by the MEMR (2018) and the USDA (2019a). The model shows some consistency with real historical data, i.e. the ability to replicate the statistics with less than 5% error in the base year 2019 despite fluctuations in the road transport energy consumption as shown in the statistics (Table 5.1).

Table 5.1. Road Transport Fuel Consumption Model Calibration Results

(million litres)

	2014	2015	2016	2017	2018	2019
Diesel fuel – statistics	27,220	25,433	25,372	27,843	28,785	29,621
Diesel fuel – model	26,966	27,766	27,873	27,856	26,861	28,229
Error (%)	-0.93%	9.17%	9.86%	0.05%	-6.68%	-4.70%
Gasoline fuel – statistics	30,925	31,528	31,986	33,548	34,353	35,246
Gasoline fuel – model	33,102	34,002	34,867	35,692	36,376	36,755
Error (%)	7.04%	7.85%	9.01%	6.39%	5.89%	4.28%

Source: MEMR (2018), USDA (2019a), and VEIA model results.

This study develops Indonesia's biofuel roadmap based on the VEIA model results running on several elaborated scenarios. A scenario shall consist of assumptions and policy measures. We included two main assumption groups in this study: economic and technological. Policy measures are biofuel-related options that the government could take between 2020 and 2035.

To simplify, we will elaborate on three scenarios: conservative, moderate, and optimistic. In a simplified manner, those three scenarios are defined as follows:

1) Conservative (CON): this scenario represents a future situation where the uptake of biofuels in road transport use would be slow and where further development of biofuel use would be limited compared to the current state. This scenario represents a situation where economic recovery related to the COVID-19 pandemic would be slow, and oil prices and conventional transport fuel prices would remain low, i.e. oil supply is assumed to be high.
2) Moderate (MOD): this scenario assumes a mild uptake of biofuels in road transport use. We expect a better penetration rate than the current rate. Economic recovery due to COVID-19 would occur at a moderate rate whilst oil and transport fuel prices would be at a moderate level.
3) Optimistic (OPT): this scenario assumes a strong uptake of biofuels. This scenario assumes a fast economic recovery from the downturn caused by the COVID-19 pandemic. It also assumes a low world oil supply that makes oil and transport fuel prices high.

In the following subsections, we shall discuss each scenario: first, the economic and energy assumptions and, second, the proposed policy measures assumed to suit the assumptions.

5.2. Assumptions and Policy Measures

5.2.1. Economic assumptions

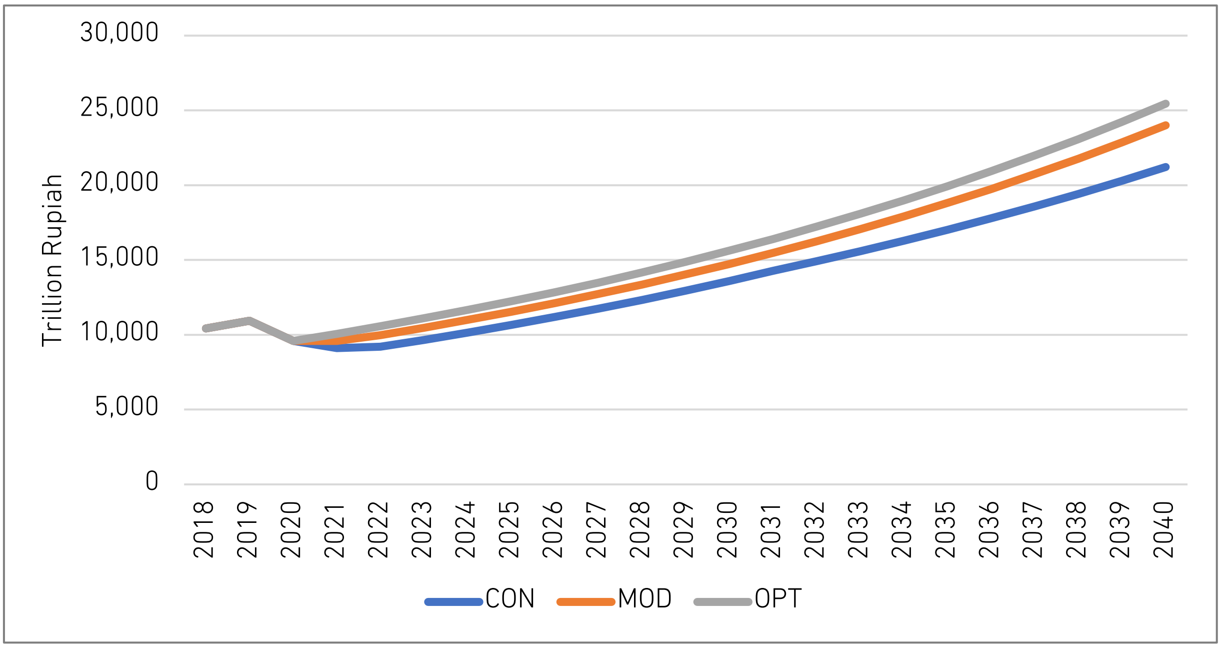
There are two main groups of assumptions, i.e. economic (ECO) and technological (TEC). Economic assumptions can be distinguished into GDP growth rate (GDP) and oil prices (OIL). Here we consider the current COVID-19 pandemic and the oil crisis between Russia and Saudi Arabia that have triggered an oil price drop because of the oil oversupply. The three scenarios are different in the gravity of the impact of both events and the time needed by Indonesia to rebound economically.

Slow economic growth heavily affected by the current pandemic and oil crisis is represented in the CON scenario. GDP growth at -5% per annum (p.a.) between 2019 and 2020 is gradually getting back on track. It has reached again -2.5% p.a. between 2020 and 2021, 1% between 2021 and 2025, and by 5% p.a. for the rest of the simulation period.

For the MOD scenario, we assume that the current pandemic and oil crisis impact 2020 only, i.e. the 2020 GDP growth rate was at -5%. Economic growth gradually gets back on track, reaching 0% p.a. by 2021, and 5% by 2022.

Lastly, the OPT scenario represents fast economic growth and fast rebounding after the pandemic and the oil crisis. GDP growth in 2020 is impacted at -5% p.a. but rebounds back quickly at 5% p.a. by 2021 onwards.

Figure 5.2. Assumed Gross Domestic Product (GDP) Evolutions in Three Scenarios



Source: The World Bank (https://data.worldbank.org/indicator/NY.GDP.MKTP.KN?locations=ID) and authors' estimates.

Table 5.2. Economic Assumptions

Scenario: CON	Unit	2018	2020	2025	2030	2035	2040
Economic growth represented by GDP growth							
GDP	trillion rupiah	10,425	9,591	10,654	13,597	17,025	21,217
Trade	billion rupiah	939	821	821	821	821	821

Scenario: MOD	Unit	2018	2020	2025	2030	2035	2040
Economic growth represented by GDP growth							
GDP	trillion rupiah	10,425	9,591	11,547	14,738	18,809	24,006
Trade	billion rupiah	939	864	864	864	864	864

Scenario: OPT	Unit	2018	2020	2025	2030	2035	2040
Economic growth represented by GDP growth							
GDP	trillion rupiah	10,425	9,591	12,241	15,623	19,940	25,449
Trade	billion rupiah	939	864	864	864	864	864

Source: Authors' elaboration.

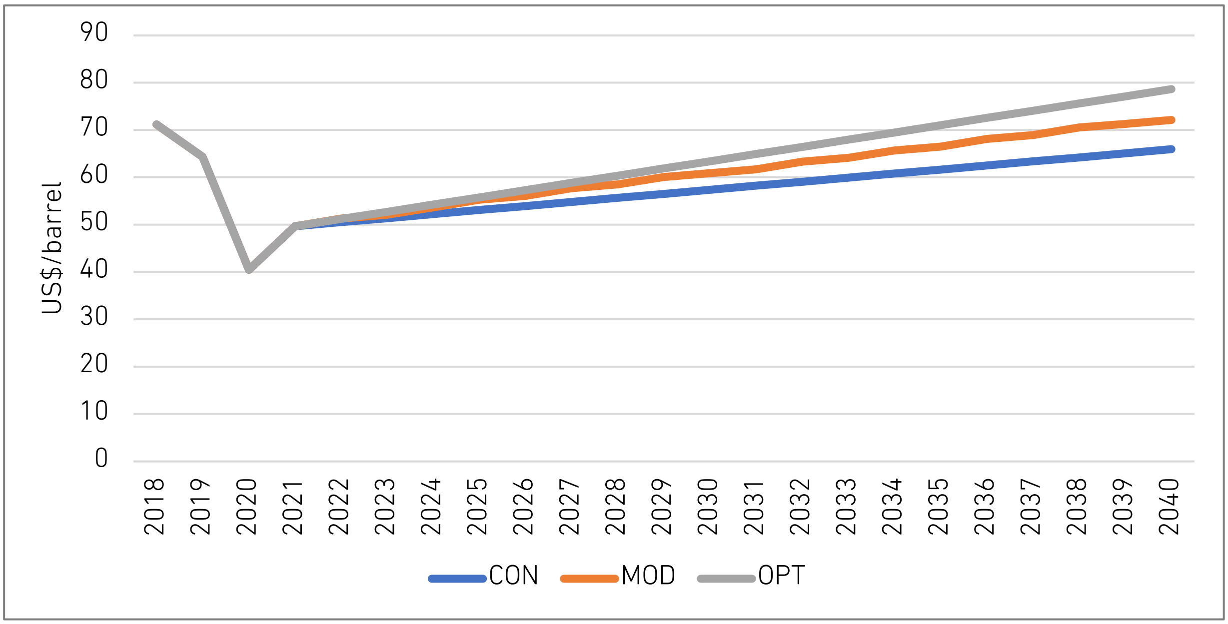
5.2.2. Oil and fuel prices

The assumptions on oil prices are based on the two US Energy Information Administration (EIA) reports: Annual Energy Outlook 2020 (US EIA, 2000a) and Short-Term Energy Outlook (STEO) (US EIA, 2020b).

The STEO report (US EIA, 2020b) estimated that the average North Sea Brent oil price went down from US$71.19/barrel in 2018 to US$64.37/barrel in 2019 and further to US$40.5/barrel in 2020. US EIA (2020a) offered three long-term future scenarios: (i) 'high oil and gas supply' – the world oil and gas supply are assumed to remain high and prices would be at low levels; (ii) 'low oil and gas supply' – the world oil and gas supply are assumed to be low, and prices would be at high levels; and (iii) a 'reference' scenario where supply and prices would be at moderate levels.

We assume that conservative (CON), optimistic (OPT), and moderate (MOD) scenarios' world oil prices follow those of IEA's 'high oil and gas supply', 'low oil and gas supply', and 'reference' scenarios, respectively (Figure 5.3).

Figure 5.3. North Sea Brent Crude Oil Price Assumptions in the Three Scenarios



Source: Author elaboration from US EIA (2020a), US EIA (2020b).

Table 5.3. WTI Crude Oil Price Assumptions

Scenario: CON	Unit	2018	2020	2025	2030	2035	2040
CON	US$ per barrel	71	41	53	57	62	66
MOD	US$ per barrel	71	41	55	61	67	72
OPT	US$ per barrel	71	41	56	63	71	79

Source: Author elaboration from US EIA (2020a), US EIA (2020b).

These assumptions affect the evolution of future average gasoline and diesel prices in Indonesia. We assumed that transport fuel prices in Indonesia would be more reactive to price changes at the global oil market and that Indonesia would improve the environmental performance of its transport fuels, i.e. implementing EURO IV fuel standard.

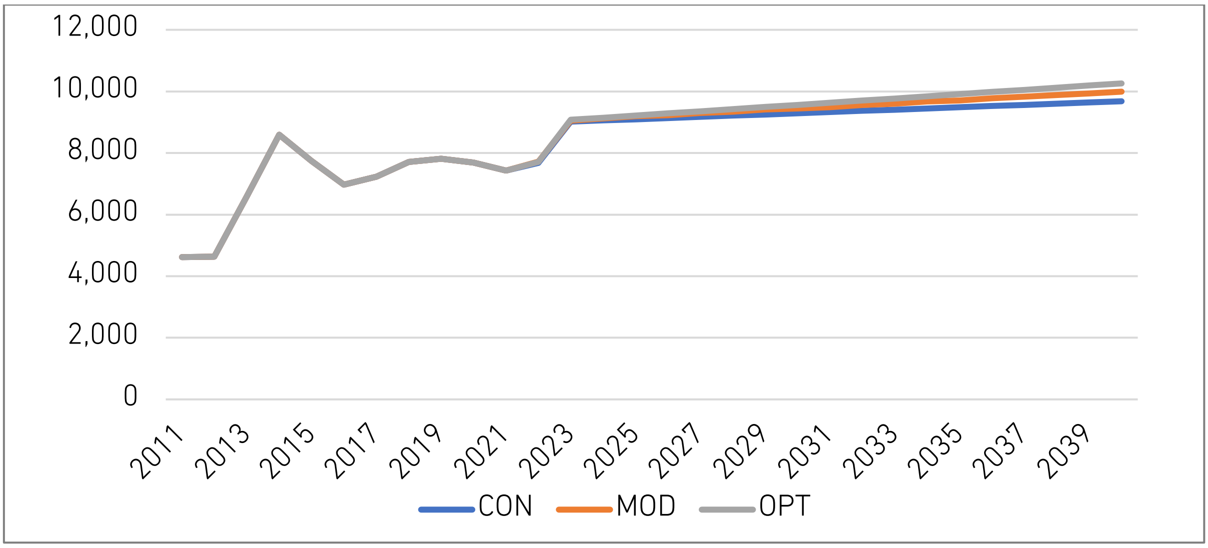
Table 5.4 shows the five types of gasoline sold in the market by the state oil company Pertamina, differentiated by their octane numbers.

We calculated one average gasoline price for each simulated year as inputs for the model. Historical values, i.e. weighted average gasoline prices before 2021 as in Table 5.5, were calculated from the available historical data on Pertamina fuel prices and sales. For 2021 and beyond, we estimated the average gasoline prices as a function of the North Sea Brent crude oil price. We performed a linear regression analysis of the estimated historical average gasoline prices and the historical North Sea Brent crude oil prices to derive a relationship between the future average gasoline prices and the future North Sea Brent crude oil prices.

We assumed that the government would ban Premium (RON 88) and Pertalite (RON 90) fuels completely from the market, respectively, in 2022 and 2023, to go towards Euro IV specifications as indicated in Minister of Environment and Forestry Regulation Number 20 of 2017.[20] Figure 5.4 shows that eliminating the lowest octane fuel types would result in a 17% increase in the average gasoline price between 2022 and 2023.

Table 5.5. shows four types of diesel fuel sold by Pertamina, differentiated by their cetane numbers. As with gasoline prices, we also calculated one average diesel price for each simulated year as inputs for the model.

Figure 5.4. Historical and Forecasted Average Gasoline Price (IDR/litre)



CON = conservative, MOD = moderate, OPT = optimistic.
Source: Authors' calculation.

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[20] In fact, Premium, Pertalite, and Pertamax still have a sulphur content of 500 ppm and above. Only Pertamax turbo has a sulphur content below 50 ppm, which meets Euro IV standard requirements.

Table 5.4. Estimates of the Historical Average Gasoline Prices (IDR)

Gasoline Types	Octane Number	2011	2012	2013	2014	2015	2016	2017	2018	2019
Premium	88	6,644	6,402	8,867	10,764	8,882	7,406	7,079	6,938	7,190
Pertalite (Premix until 2014)	90	6,866	6,615	9,072	10,954	9,758	8,141	8,149	8,180	7,858
Pertamax	92	12,846	12,946	12,687	13,474	10,378	9,057	8,945	9,745	10,298
Pertamax Turbo	95	13,510	14,084	13,505	14,335	11,832	9,668	10,042	11,046	11,915
Pertamax Racing	98	62,014	59,752	57,295	53,188	49,083	47,491	46,095	44,490	43,142
Average gasoline price		**6,821**	**6,590**	**8,998**	**10,875**	**9,049**	**7,881**	**7,936**	**8,162**	**8,026**

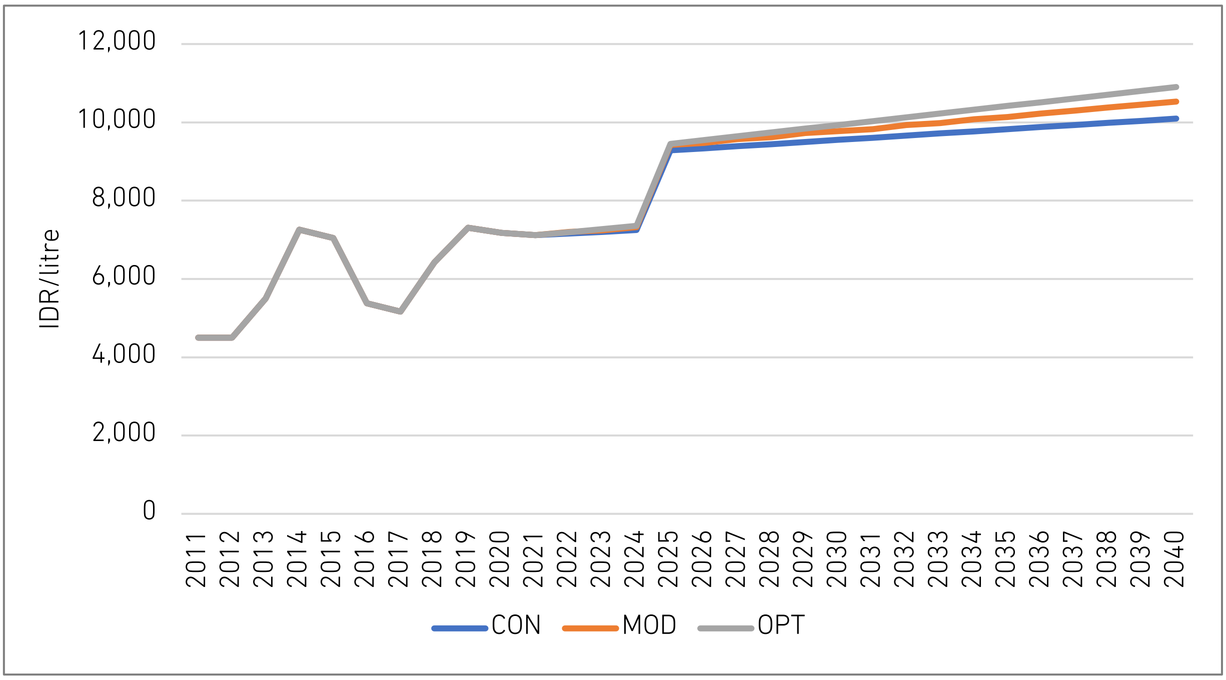
Source: Authors' elaboration based on MEMR (2018), CNBCIndonesia.com (2019), DPR RI (2013), KataData (2017), Kumparan (2018), Tirto.id (2020), and Pertamina '*Daftar Harga BBK TMT*' portal at https://www.pertamina.com/id/news-room/announcement/.

Table 5.5. Estimates of the Historical Average Diesel Prices (IDR)

Diesel Fuel Type	Cetane Number	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Subsidised diesel fuel	48	6,644	6,402	7,503	8,865	8,064	5,823	5,652	5,455	5,290	5,150
Non-subsidised diesel fuel	48	6,644	6,402	7,503	9,498	8,473	6,389	5,652	8,333	9,861	9,333
Dexlite	51	0	0	0	0	0	7,293	7,957	9,016	10,529	9,500
Pertamina dex	53	14,839	14,298	16,848	16,020	12,592	9,950	9,274	10,811	12,044	10,200
Average diesel price		**6,644**	**6,402**	**7,503**	**9,194**	**8,233**	**6,085**	**5,671**	**6,807**	**7,508**	**7,175**

Source: Authors' elaboration based on MEMR (2018), CNBCIndonesia.com (2019), DPR RI (2013), KataData (2017), Kumparan (2018), and Pertamina '*Daftar Harga BBK TMT*' portal at https://www.pertamina.com/id/news-room/announcement/.

Figure 5.5. Historical and Forecasted Average Diesel Fuel Price (IDR/litre)



CON = conservative, MOD = moderate, OPT = optimistic.
Source: Authors' calculation and estimates.

For diesel fuel, we assumed that cetane 48 fuel would disappear from the market in 2025 onwards.[21] The elimination of these lowest cetane diesel fuels should result in a 28% increase of the average diesel fuel price between 2024 and 2025, i.e. a stronger shock than that caused by the disappearance of Premium and Pertalite.

5.2.3. Technological assumptions

Technological assumptions consist of six main groups of assumed progress: (i) FAME or CPO-based biodiesel production, (ii) sugarcane-based bioethanol production, (iii) CPO-based green diesel production, (iv) CPO-based green gasoline production, (v) diesel-based FFV development, and (v) gasoline-based FFV development.

We assumed that conventional biofuel prices would be close to the prices of their main feedstocks. Historical data from the MEMR's site on the biofuel price index (MEMR, 2020b) shows that between 2015 and 2020, CPO-based biodiesel (FAME) prices changed at -0.27%. However, world palm oil (Malaysian palm oil) provided in the Index Mundi commodity price

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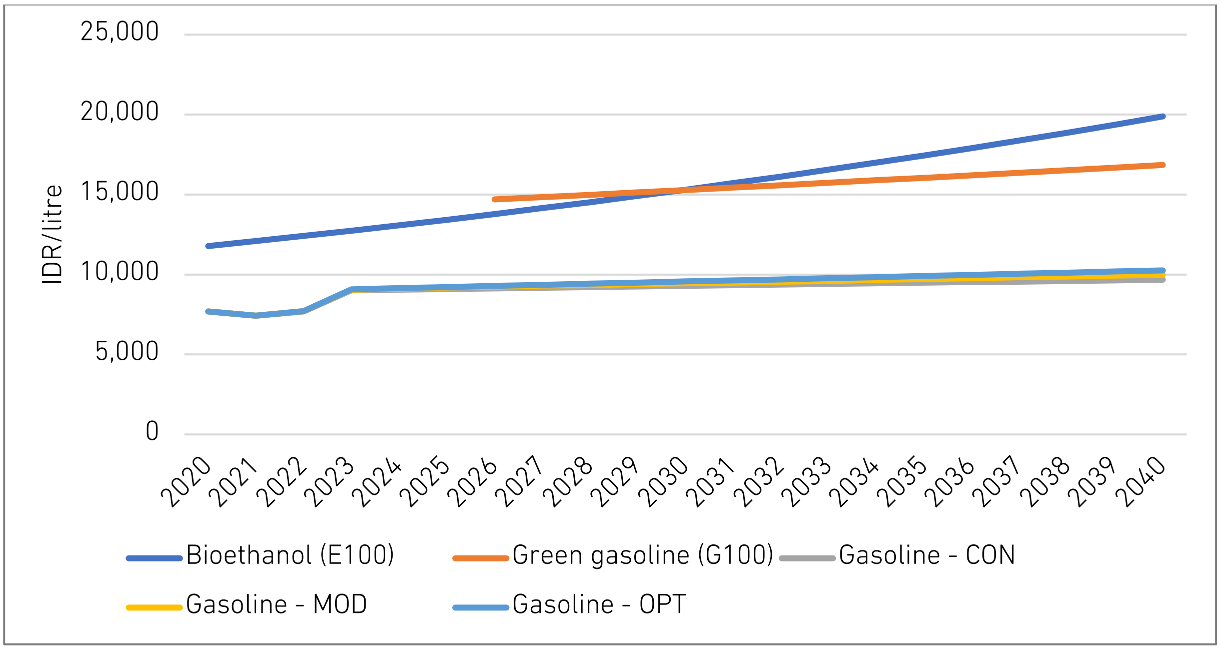
[21] The current diesel fuel with cetane number 51 still has a sulphur content of 500 ppm. This does not meet Euro IV standards, which require a sulphur content of at least 50 ppm.

grew at an average rate of 0.26% in 2015–2020. Commodities price forecast from the World Bank (2020) estimated that palm oil's average annual growth rate in 2020–2030 would be 0.98%. Looking at these various trends, we opted for a more conservative approach where the CPO price would increase in the future. Therefore, we adopted the World Bank (2020) result as the assumption of biodiesel price growth rate of 0.98% per year during the whole simulation period of 2020–2040.

Concerning bioethanol, the historical data of the 2015–2020 period from the MEMR (2020b) shows an average annual growth rate of sugarcane-based bioethanol price at 4.0%. According to the World Bank (2020), the average yearly growth rate of the world sugar price for 2015–2020 was 1.30%. The World Bank (2020) also estimated that in 2020–2030, the average annual growth rate of world sugar price would be 0%. Based on these findings, we estimated the average yearly growth rate of sugarcane-based bioethanol price in 2020–2040 to be lower than 4.0%, i.e. MEMR's (2020b) historical rate. We set that the future average annual growth rate of sugarcane-based bioethanol would be around 2.65%, which is the average of the historical growth rates of the MEMR (2020b) and the World Bank (2020).

Figure 5.6. Estimate of Prices of Gasoline in the Three Scenarios, Bioethanol and Green Gasoline



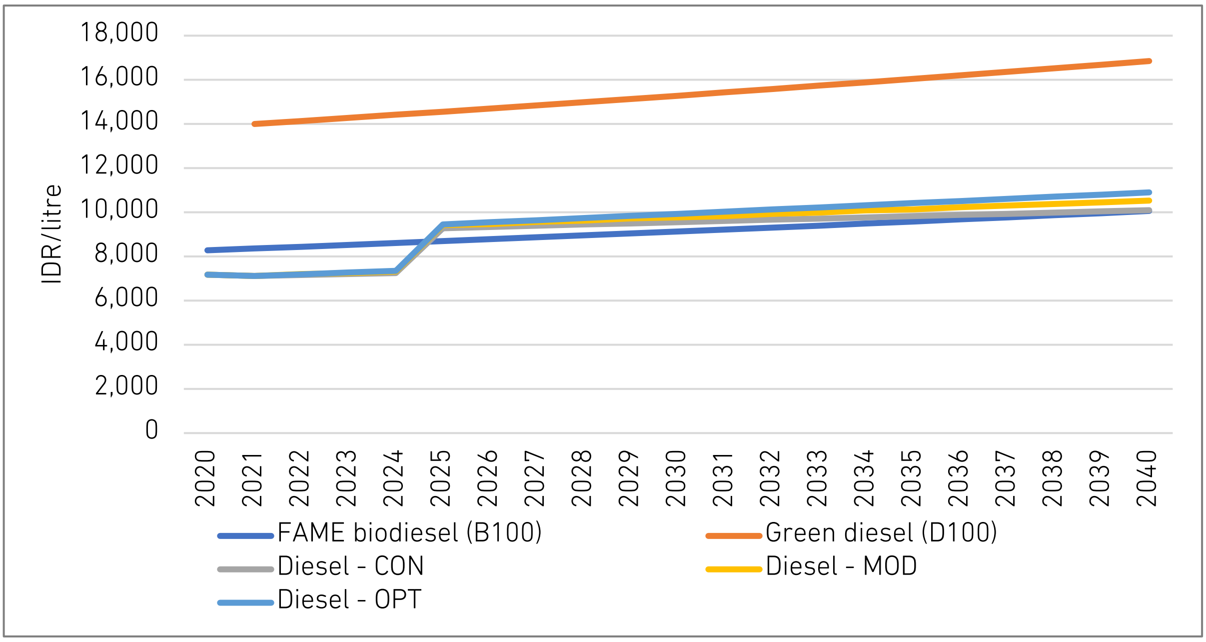
Source: Authors' calculation and estimates.

If the government erased Premium by 2022 and Pertalite by 2023 and would not introduce any subsidy, then the average gasoline price would increase by around 17% during that period, reducing the price gap between the average gasoline and bioethanol. If our assumptions hold, as shown in Figure 5.6, then starting from 2030, green gasoline price would be cheaper than bioethanol. In other words, in 2030 and beyond, green gasoline could become a more economical biofuel substitute for gasoline than bioethanol.

Green diesel and green gasoline fuels are assumed to enter the market in the coming years. The scenarios differ in how fast this new fuel would enter. The OPT scenario represents a situation where economic and technological breakthroughs would be made on the development of those green fuels so they can be available shortly, whilst the opposite situation is represented in the CON scenario. Based on CNN Indonesia (2019), we might expect the initial price of green diesel and green gasoline in the OPT scenario to be at Rp14,000/litre in 2021. This price estimate was also in line with VOI (2020), where the D-100 (green diesel) price was appraised to be far beyond the current Pertamina Dex fuel price of Rp10,200.

Brown et al. (2020) analysed the cost reduction potential of the advanced biofuels, including HVO and HEFA. They estimated that the feedstock costs could make up 65%–80% of the production costs. If green fuels, i.e. green diesel and green gasoline, would be produced from CPO, the growth rate of green fuels would be similar to that of biodiesel, 0.98%.

Figure 5.7. Estimate of Prices of Diesel Fuel in the Three Scenarios, Biodiesel and Green Diesel



Source: Authors' calculation and estimates.

The increase of diesel prices resulting from the disappearance of cetane 48 diesel fuels by 2025 would increase the average diesel prices at the three scenarios by 28%, making them significantly higher than the forecasted biodiesel prices starting from 2025. Should this happen and should the government not introduce any other diesel fuel subsidy, the government can stop subsidising biodiesel.

Table 5.6. Assumptions on Transport Biofuel Price Development (Rp/litre)

	2018	2020	2025	2030	2035	2040	AAGR, %
Biodiesel (B100/FAME)	8,178	8,279	8,693	9,127	9,583	10,062	0.98
Sugarcane-based bioethanol	10,800	11,780	13,428	15,306	17,448	19,888	2.64
CPO-based green diesel	-	-	14,557	15,284	16,048	16,850	0.98
CPO-based green gasoline	-	-	-	15,284	16,048	16,850	0.98

Source: Authors' estimate.

Table 5.7. summarises the above assumptions in each scenario.

Table 5.7. Description of the Proposed Assumptions

ASMP No	Assumption (ASMP)	Conservative	Moderate	Optimistic
ECO1-GDP	Economic growth represented by GDP and trade growth	Slow economic growth heavily affected by the current pandemic and oil crisis. GDP growth at -5% p.a. between 2019 and 2020 that gradually gets back on track, i.e. reaching -2.5% p.a. again between 2020 and 2021, 1% between 2021 and 2025, and 5% p.a. for the rest of the simulation period. Trade experiences the same downturn and recovery as the GDP between 2019 and 2021, and back again to around 2% for the rest of the simulation period.	Moderate economic growth. Current pandemic and oil crisis impact only the year 2020, i.e. 2020 GDP growth rate at -5%. Economic growth gradually gets back on track, i.e. reaching 0% p.a. again by 2021, and 5% by 2022 onwards. Trade experiences the same downturn and recovery as the GDP between 2019 and 2021, and back again to around 2% for the rest of the simulation period	Fast economic growth and fast rebounding after the pandemic and oil crisis. 2020 GDP growth is impacted, i.e. -5% p.a. but rebounds back quickly at 5% p.a. by 2021 onwards. Trade experiences the same downturn and recovery as the GDP between 2019 and 2021 and back again to around 2% for the rest of the simulation period
ECO_2-OIL	World oil fuel price development	To 2021: US EIA historical and short-term North Sea Brent prediction (US EIA, 2020b)	To 2021: US EIA historical and short-term North Sea Brent prediction (US EIA, 2020b)	To 2021: US EIA historical and short-term North Sea Brent prediction (US EIA, 2020b)

ASMP No	Assumption (ASMP)	Conservative	Moderate	Optimistic
		2022 onwards: growth rate from the 'high oil and gas supply' scenario of the US EIA (2020)	2022 onwards: growth rate from the 'Reference' of US EIA (2020)	2022 onwards: growth rate from the 'low oil and gas supply' scenario of the US EIA (2020)
TEC1-BXXFM	Technological progress on FAME-based biodiesel fuel development	Conservative growth in biodiesel production capacity whilst FAME quality remains the same	Moderate growth in biodiesel production capacity accompanied by a moderate improvement of FAME quality	Strong investment in FAME production accompanied by rapid improvement of FAME quality
TEC2-DXX	Technological progress on green diesel fuel development	Slow growth of investment followed by slow growth in production capacity	Moderate growth of investment and moderate growth in production capacity	Strong investment and rapid growth in production capacity
TEC3-BXXFF	Technological progress on B100 and flex-fuel vehicle (FFV) development	No commercial manufacturing of diesel-based FFV before 2036	The automotive sector can manufacture and commercialise diesel-based FFVs in 15 years, accompanied by a moderate reduction in FAME production cost and a moderate increase in FAME production capacity.	The automotive sector can manufacture and commercialise diesel-based FFVs in 10 years, accompanied by a significant reduction in FAME production cost and increase in FAME production capacity
TEC4-EXX	Technological progress on bioethanol fuel development	Low investment in bioethanol production that allows only up to E2 policy implementation at the national scale	Moderate investment in bioethanol production that allows up to E10 policy implementation at the national scale	Strong investment in bioethanol production that allows up to E20 policy implementation at the national scale

ASMP No	Assumption (ASMP)	Conservative	Moderate	Optimistic
TEC5-EXXFF	Technological progress on E85/E100 and flex-fuel development	No commercial manufacturing of gasoline-based FFV before 2036	The automotive sector can manufacture and commercialise gasoline-based FFVs by 2031, accompanied by a moderate reduction in bioethanol production cost and a moderate increase in bioethanol production capacity.	The automotive sector can manufacture and commercialise gasoline-based FFVs by 2028, accompanied by a significant reduction in bioethanol production cost and increased bioethanol production capacity.
TEC6-GXX	Technological progress on green gasoline fuel development	The production cost of green gasoline hardly gets lower that does not induce much investment and slow growth in production capacity.	The production cost of green gasoline gets lower moderately that induces moderate investment and moderate growth in production capacity.	The production cost of green gasoline gets lower significantly that induces strong investment and rapid growth in production capacity.

Source: Authors’ elaboration.

Finally, we assumed that electric vehicles would also be penetrating the total vehicle stock in Indonesia. We estimate that mobility electrification in Indonesia would happen primarily through the penetration of electric-powered two-wheelers (motorcycles) whilst market penetration of electric passenger cars would remain limited.

We estimate that the sale of electric-powered two-wheelers in Indonesia would reach 24%, 47%, and 92% in 2025, 2030, and 2040, respectively. These correspond to shares of electric-powered two-wheelers in the total stock of 7%, 18%, and 53%, consecutively, for 2025, 2030, and 2040.

5.2.4. Policy measures in the scenarios

Scenarios differ not only by the assumed economic and technological assumptions given in the previous section but also by the temporal dimension of implementing the policy measures that include mandatory and non-mandatory biofuel policies. Table 5.8 shows the starting years of the implementation of policy measures in the scenarios.

Table 5.8. Policy Measures and their Starting Year in the Scenarios[a]

PM No.	Policy Measures	Short Description	Conservative	Moderate	Optimistic
DSL1	Biodiesel: B40 (FAME)	FAME-based mandatory 40% biodiesel blending	2024	2022	2022
DSL2	Biodiesel: B50 (FAME)	FAME-based mandatory 50% biodiesel blending	NA	NA	2024
DSL3	Green diesel D10	Mandatory 10% green diesel blending	2030	2026	2021
DSL4	Green diesel D20	Mandatory 20% green diesel blending	2034	2030	2026
DSL5	Non-mandatory biodiesel: B100 + DSL flex-fuel vehicles (FFVs)	Non-mandatory introduction of B100 in gas station accompanied by the introduction of diesel FFVs and high-blended biodiesel	N/A	2035	2030
GSL1	Bioethanol: E2 pilot provincial scale	Mandatory 2% bioethanol blending in several pilot provinces (e.g. East Java and DKI Jakarta)	2023	2022	2022

PM No.	Policy Measures	Short Description	Conservative	Moderate	Optimistic
GSL2	Bioethanol: E2	Mandatory 2% bioethanol blending at the national level	2030	2028	2025
GSL3	Bioethanol: E5 pilot provincial scale	Mandatory 5% bioethanol blending in several pilot provinces (e.g. East Java and DKI Jakarta)	2032	2028	2025
GSL4	Bioethanol: E5	Mandatory 5% bioethanol blending at the national level	N/A	2031	2028
GSL5	Bioethanol: E10	Mandatory 10% bioethanol blending at the national level	N/A	3033	2030
GSL6	Bioethanol: E20	Mandatory 20% bioethanol blending at the national level	N/A	N/A	2032
GSL7	Non-mandatory bioethanol: E85/E100 + FFVs	Non-mandatory introduction of E85 in gas stations, accompanied by the introduction of gasoline FFVs and high blended bioethanol	N/A	2031	2028
DSL6	Green gasoline: G5	Mandatory 5% green diesel blending	2032	2028	2026
DSL7	Green gasoline: G10	Mandatory 10% green diesel blending	2036	2032	2028

[a] All policy measures are assumed to take effect by 1 January of their corresponding starting year.
Source: Author's elaboration.

5.3. Simulation Results

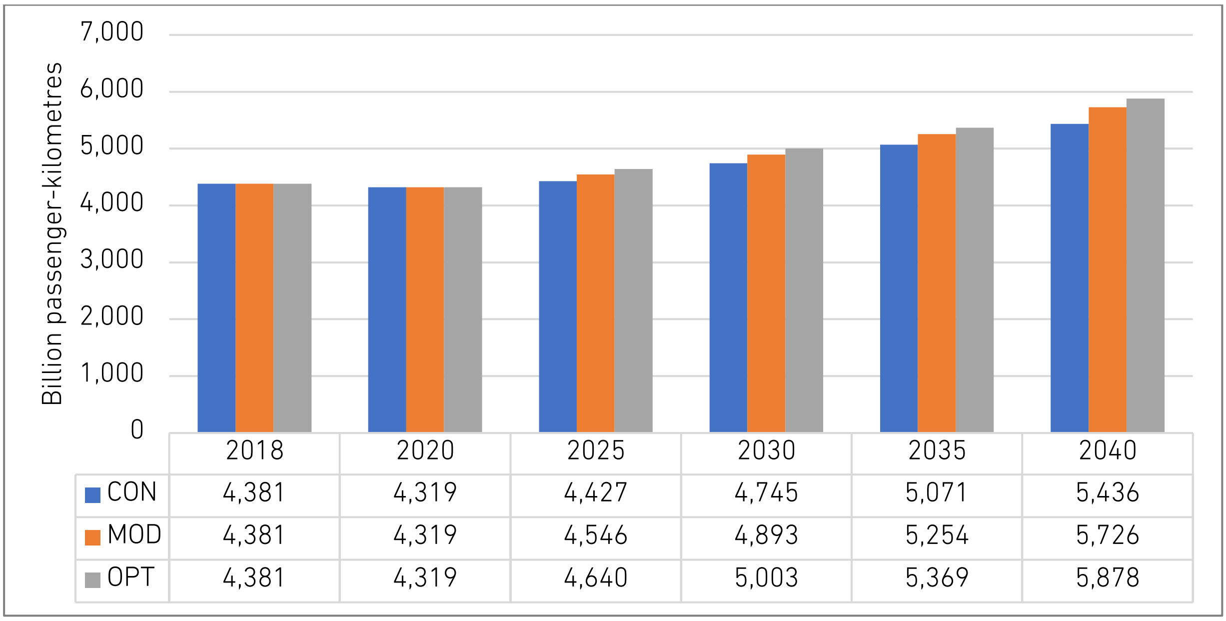
5.3.1. Transport demand

We can expect total passenger road transport demand activity to experience a drop of around 1.5% between 2018 and 2020 in all scenarios due to the pandemic that slowed down economic growth. However, between 2020 and 2025, passenger road transport activity in all three scenarios should bounce back, i.e. CON scenario by around 2.5%, MOD and OPT scenarios by more than 7.5%. The OPT scenario should continue to grow to reach nearly around 5,900 billion passenger-kilometres by 2040 whilst that of MOD and CON would be approximately 5,700 billion and 5,400 billion passenger-kilometres, respectively (Figure 5.8).

The impact of the economic slowdown would be reflected more in road freight transport activity. As in the three scenarios, we could expect a downturn in demand by around 12% between 2018 and 2020, signifying a higher elasticity of freight transport demand regarding economic conditions, such as GDP and trade. In other words, road freight transport activity is heavily linked to the economic situation whilst road passenger transport activity is less linked as passenger travel is not always economic.

In 2020–2025, road freight transport demand (activity) would still decrease by around 6% in the CON scenario. That for MOD and OPT scenarios would bounce back to grow by about 10% and 25% consecutively for 2020–2025. By 2040, we could expect freight road transport demand to reach 2,400 billion ton-km for CON; 3,100 billion ton-km for MOD; and 3,500 billion ton-km for OPT (Figure 5.9).

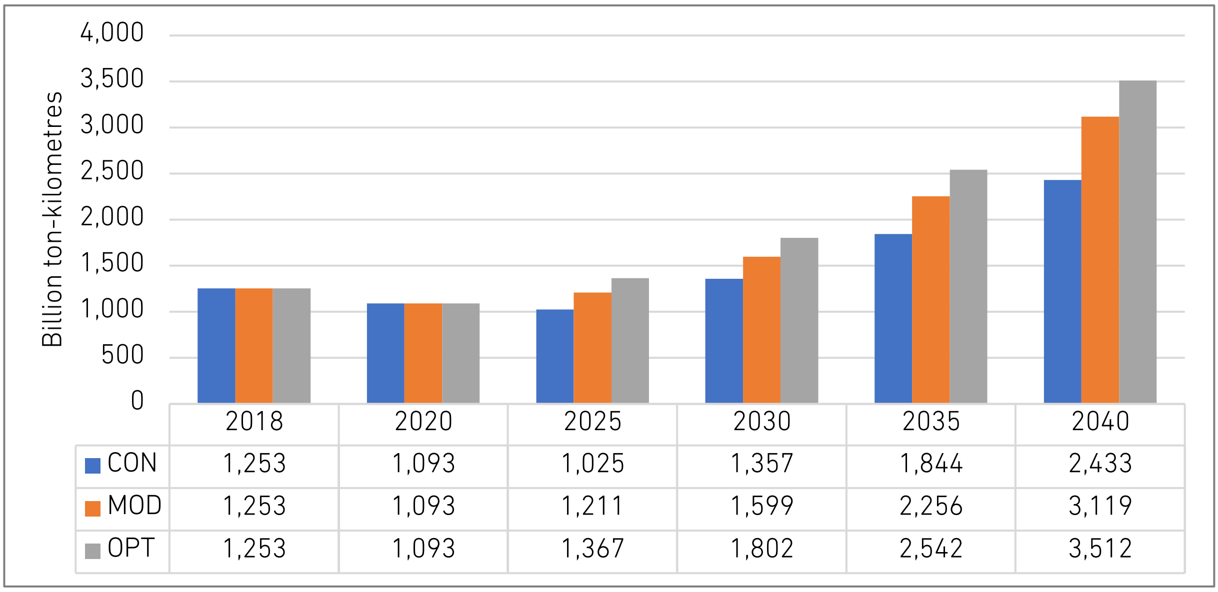
Figure 5.8. Development of Passenger Road Transport Activity



	2018	2020	2025	2030	2035	2040
🟦 CON	4,381	4,319	4,427	4,745	5,071	5,436
🟧 MOD	4,381	4,319	4,546	4,893	5,254	5,726
⬜ OPT	4,381	4,319	4,640	5,003	5,369	5,878

Source: Model result.

Figure 5.9. Development of Freight Road Transport Activity



	2018	2020	2025	2030	2035	2040
CON	1,253	1,093	1,025	1,357	1,844	2,433
MOD	1,253	1,093	1,211	1,599	2,256	3,119
OPT	1,253	1,093	1,367	1,802	2,542	3,512

Source: Model result.

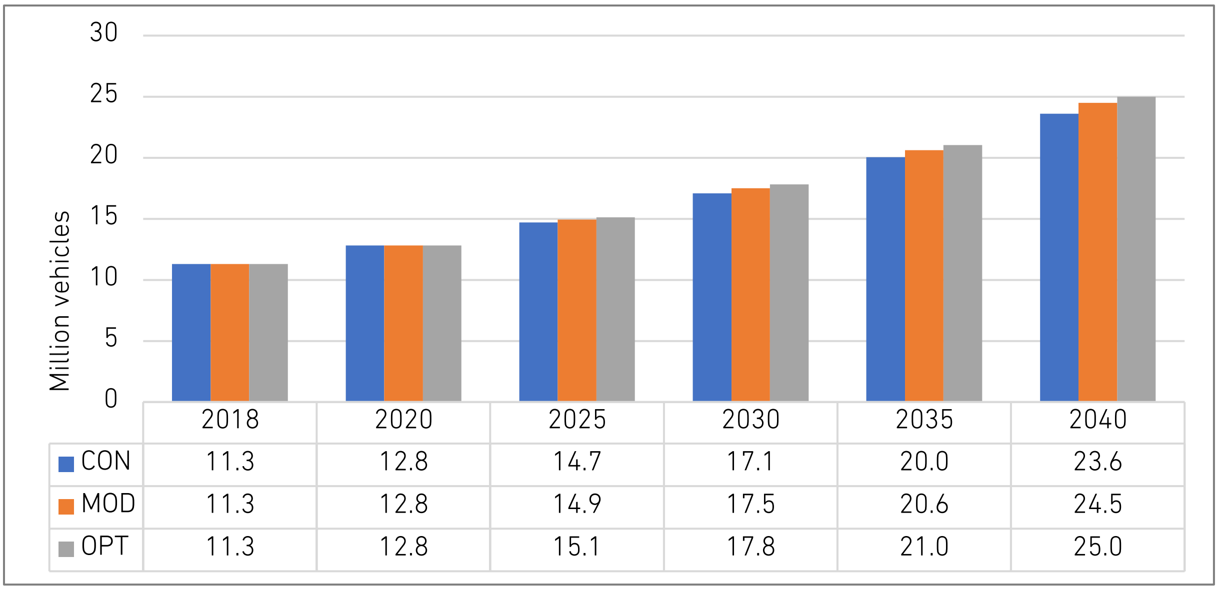
5.3.2. Road vehicle stock

The model converted transport activity (demand) into vehicle stock or, more precisely, the number of effective vehicle units in operation. The stock of two-vehicle categories is calculated in detail by the model, i.e. cars and road freight vehicles.

The number of effective car stocks would increase in all scenarios. The currently estimated 11 million vehicles would reach 23.6 million in the CON scenario, 24.5 million in MOD, and 25 million in OPT in 2040 (Figure 5.10).

During the same simulation period, we could expect the number of effective road freight vehicle stocks to increase from the current 3.8 million units to 6.6 million, 8.2 million, and 9.3 million units of vehicles, respectively, for the CON, MOD, and OPT scenarios (Figure 5.11). As for the demand, the effects of the pandemic and the economic slowdown are more accentuated in the road freight vehicle stocks. In the CON scenario, we could expect a slight reduction in road freight vehicle stocks between 2020 and 2025.

Figure 5.10. Total Effective Road Passenger Car Stock



	2018	2020	2025	2030	2035	2040
🟦 CON	11.3	12.8	14.7	17.1	20.0	23.6
🟧 MOD	11.3	12.8	14.9	17.5	20.6	24.5
⬜ OPT	11.3	12.8	15.1	17.8	21.0	25.0

Source: Model results.

Figure 5.11. Total Effective Road Freight Vehicle Stock

	2018	2020	2025	2030	2035	2040
🟦 CON	3.8	4.4	4.0	4.4	5.3	6.6
🟧 MOD	3.8	4.4	4.3	5.0	6.2	8.2
⬜ OPT	3.8	4.4	4.5	5.5	7.0	9.3

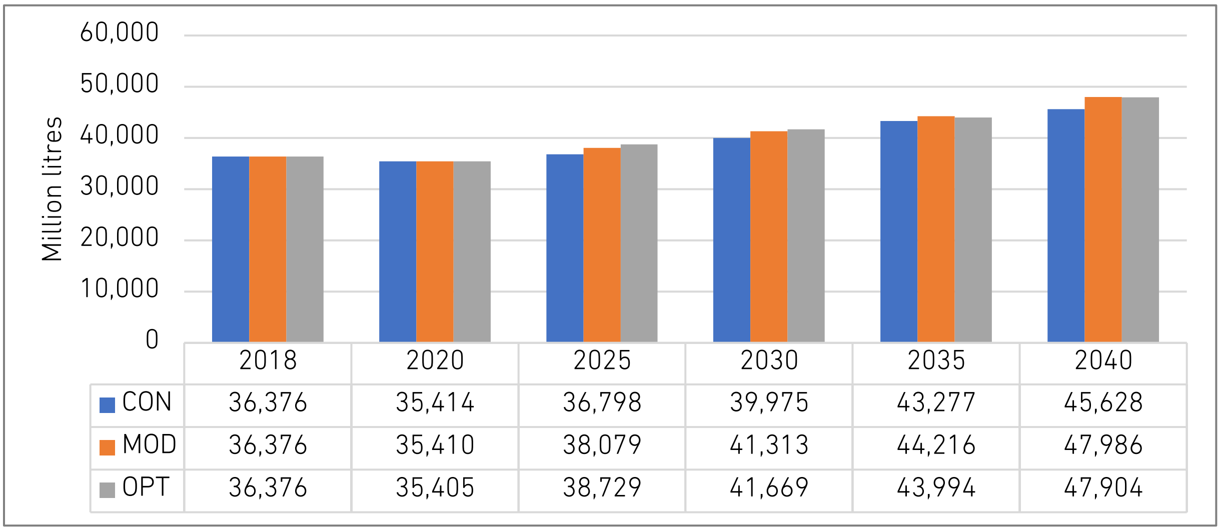
Source: Model results.

5.3.3. Fuel consumption

The economic downturn due to the pandemic should decrease gasoline fuel consumption by around 3% between 2018 and 2020. The bouncing back of gasoline fuel consumption should happen between 2020 and 2025 with growth rates of 4%, 7.5%, and 9.5%, respectively, in the CON, MOD, and OPT scenarios. By 2040, total gasoline fuel consumption should be approximately 45,600 million litres in the CON scenario and about 48,000 million litres in the MOD and OPT scenarios (Figure 5.12).

The drop in diesel fuel consumption due to the economic downturn is stronger than gasoline as most diesel fuel consumption occurs in road freight transport. Around 15% of diesel fuel consumption drop can be expected between 2018 and 2020. Between 2020 and 2025, fuel consumption would still experience a dip in the CON scenario by nearly 9%, whilst fuel consumption in MOD and OPT would bounce back, respectively, by 6.6% and 9.6%. By 2040, total diesel consumption should reach around 45,200 million litres in CON; 57,500 million litres in MOD; and 63,800 million litres in OPT (Figure 5.13).

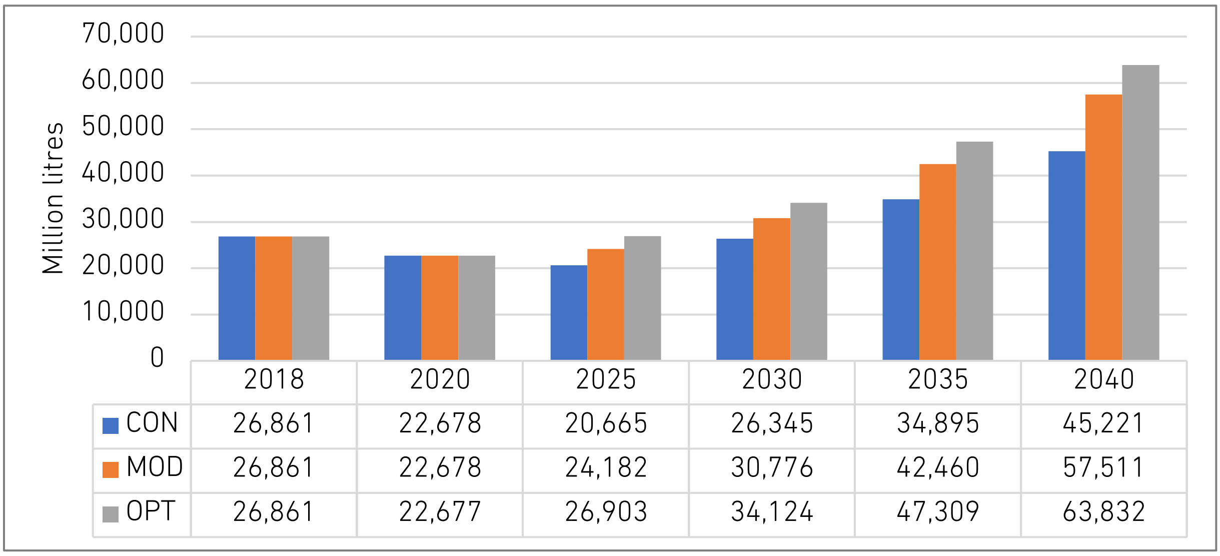
Figure 5.12. Gasoline Fuel Consumption from Road Transport Activity



	2018	2020	2025	2030	2035	2040
🟦 CON	36,376	35,414	36,798	39,975	43,277	45,628
🟧 MOD	36,376	35,410	38,079	41,313	44,216	47,986
⬜ OPT	36,376	35,405	38,729	41,669	43,994	47,904

Source: Model results.

Figure 5.13. Diesel Fuel Consumption from Road Transport Activity



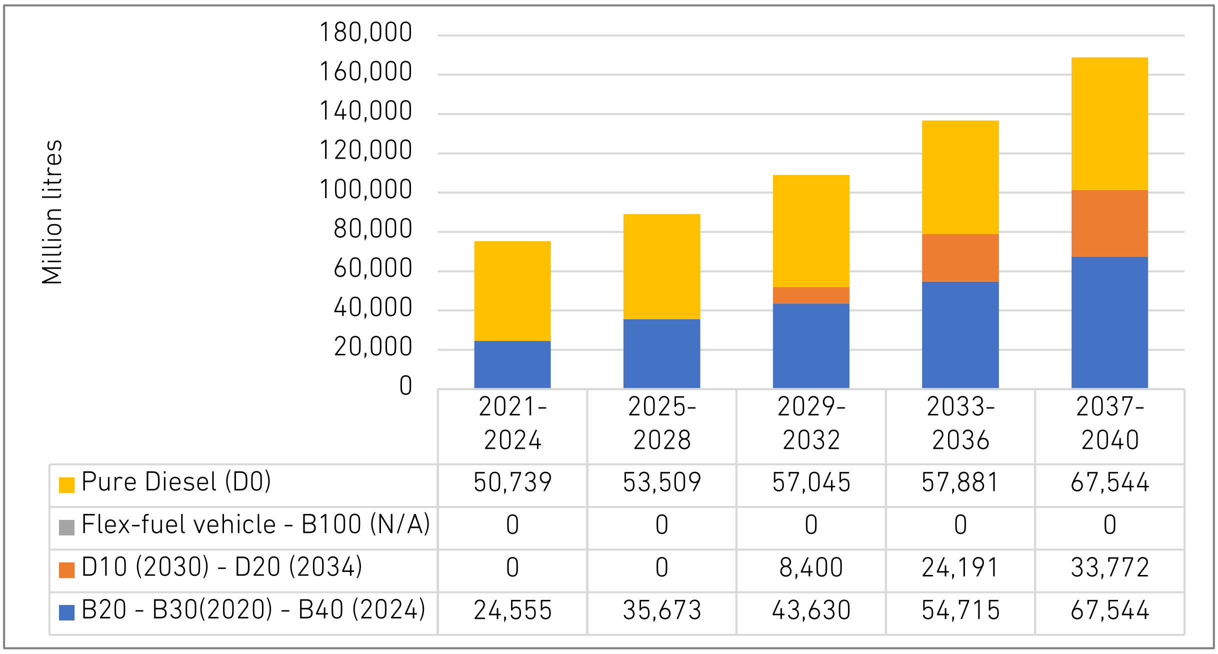
	2018	2020	2025	2030	2035	2040
🟦 CON	26,861	22,678	20,665	26,345	34,895	45,221
🟧 MOD	26,861	22,678	24,182	30,776	42,460	57,511
⬜ OPT	26,861	22,677	26,903	34,124	47,309	63,832

Source: Model results.

5.3.4. Biofuel consumption

In the CON scenario, we assume that the mandatory biodiesel programme would shift from B30 to B40 in 2024, whilst the mandatory 10% green diesel (D10) programme would be implemented in 2030, followed by D20 in 2034. Total biofuel blending in the CON scenario would increase from the current 30% to 40% in 2024, 50% in 2030, and 60% by 2034 (Figure 5.14). In this scenario, we could expect a diesel-related biofuel yearly need of around 6,400 million litres in 2021–2024 that would increase to 16,900 million litres in 2037–2040. The current biodiesel production capacity of around 12 million litres per year should be expanded before 2028. Green diesel refinery capacity should reach at least 3,000 million litres per year before its introduction in 2030.

Figure 5.14. Four-Year Consumption of Diesel-Related Biofuels – CON Scenario

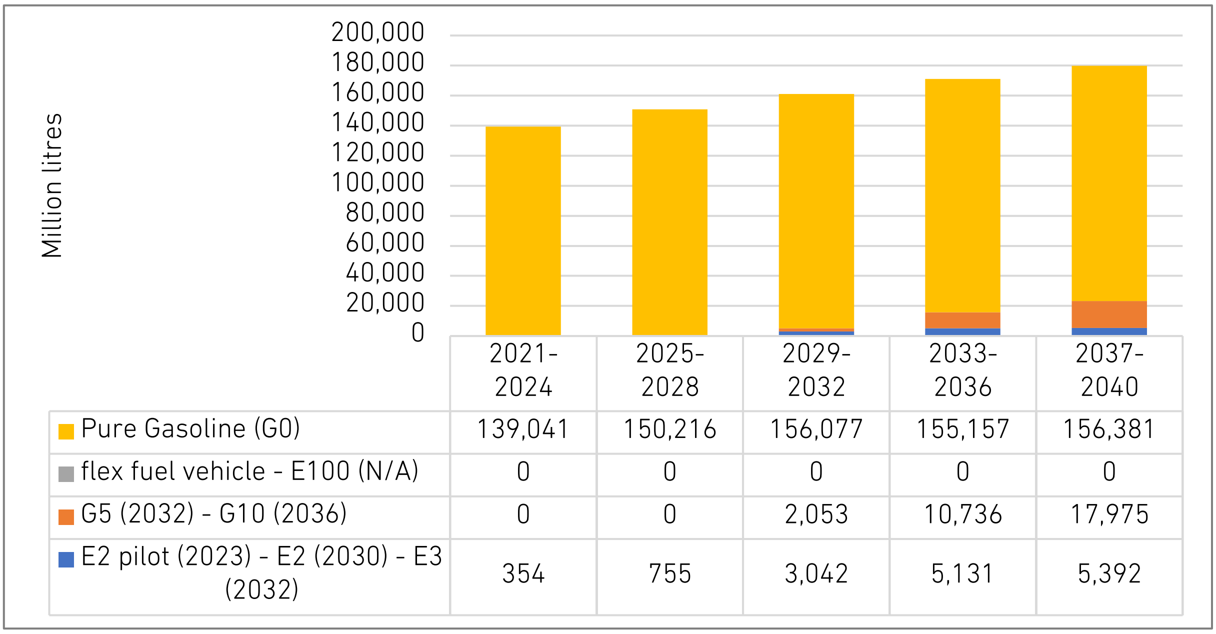


	2021-2024	2025-2028	2029-2032	2033-2036	2037-2040
🟨 Pure Diesel (D0)	50,739	53,509	57,045	57,881	67,544
⬜ Flex-fuel vehicle - B100 (N/A)	0	0	0	0	0
🟧 D10 (2030) - D20 (2034)	0	0	8,400	24,191	33,772
🟦 B20 - B30(2020) - B40 (2024)	24,555	35,673	43,630	54,715	67,544

Source: Model results.

In the CON scenario, we assumed that pilot projects of mandatory bioethanol programme would start at 2% rate in 2023 in East Java and DKI Jakarta. In this scenario, this 2% blend bioethanol programme would become a national mandatory E2 programme in 2030 and E3 programme in 2032. The mandatory 5% green gasoline (G5) programme would be implemented in 2032, followed by G10 in 2036. Total biofuel blend in the CON scenario would increase from about 0.5% in 2023 to 2% in 2030, 8% in 2032, and 18% by 2036 (Figure 5.15). In this scenario, we could expect a yearly need of around 70 million litres of bioethanol in 2021–2024, increasing to 1,100 million litres in 2037–2040. The current bioethanol production capacity of about 45 million litres per year needs to be upgraded before the pilot project implementation. Finally, green gasoline's yearly consumption should increase from 400 million litres in 2029–2032 to 3,600 million litres in 2037–2040.

Figure 5.15. Four-Year Consumption of Gasoline-Related Biofuels – CON Scenario

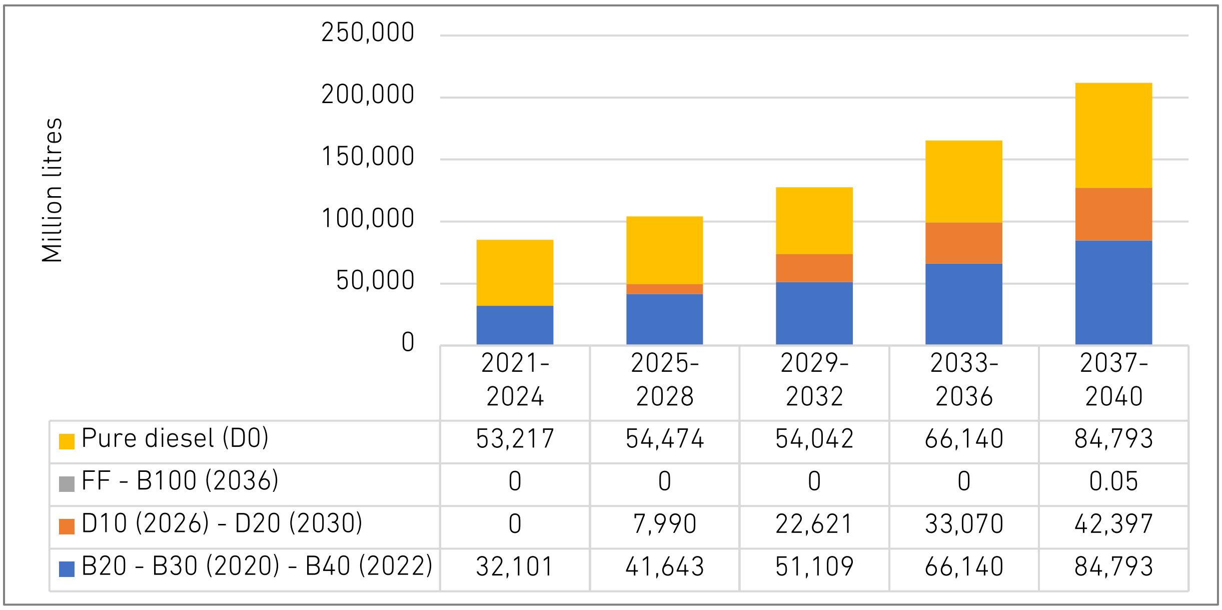


	2021-2024	2025-2028	2029-2032	2033-2036	2037-2040
🟨 Pure Gasoline (G0)	139,041	150,216	156,077	155,157	156,381
■ flex fuel vehicle - E100 (N/A)	0	0	0	0	0
🟧 G5 (2032) - G10 (2036)	0	0	2,053	10,736	17,975
🟦 E2 pilot (2023) - E2 (2030) - E3 (2032)	354	755	3,042	5,131	5,392

Source: Model results.

In the MOD scenario, we assumed that the mandatory biofuel programme would shift from B20 to B40 in 2022, whilst the mandatory 10% green diesel (D10) programme would be implemented in 2026, followed by D20 in 2030. The green diesel refinery capacity should reach around 2,500 million litres per year before 2026. Total biofuel blend in the CON scenario would increase from the current 30% to 40% in 2022, 50% in 2026, and 60% by 2030 (Figure 5.16). In this scenario, we could expect diesel-related biofuel needs of about 8,000 million litres in 2021–2024 to increase to 31,800 million litres in 2037–2040. Biodiesel-based FFVs are assumed to enter the market only in 2036. This non-mandatory technology and fuel would consume around 50 kilolitres of biofuel in 2037–2040.

Figure 5.16. Four-Year Consumption of Diesel-Related Biofuels – MOD Scenario

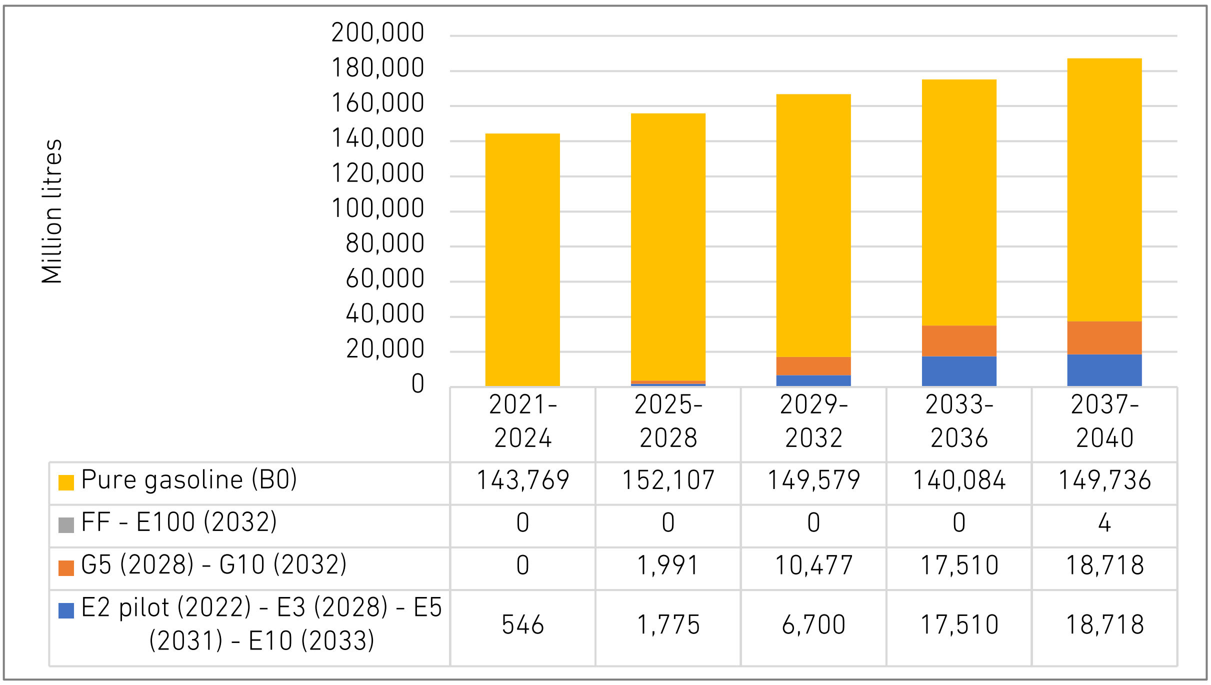


	2021-2024	2025-2028	2029-2032	2033-2036	2037-2040
🟨 Pure diesel (D0)	53,217	54,474	54,042	66,140	84,793
■ FF - B100 (2036)	0	0	0	0	0.05
🟧 D10 (2026) - D20 (2030)	0	7,990	22,621	33,070	42,397
🟦 B20 - B30 (2020) - B40 (2022)	32,101	41,643	51,109	66,140	84,793

Source: Model results.

In the MOD scenario, we assumed that pilot projects of mandatory bioethanol programme would start at a 2% rate in 2022 in East Java and DKI Jakarta, which is a year earlier than in the CON scenario. In this scenario, this 2% blend bioethanol programme would become a national mandatory E2 programme in 2028, E3 programme in 2031, and E10 in 2033. The mandatory 5% green gasoline (G5) programme would be implemented in 2028, followed by G10 in 2032. Total biofuel blend in the CON scenario would increase from around 0.5% in 2022 to 8% in 2028, 10% in 2031, and 20% by 2032 (Figure 5.17). In this scenario, we could expect a yearly need of about 109 million litres of bioethanol in 2021–2024, increasing to 3,750 million litres in 2037–2040. The annual consumption of green gasoline should increase from 400 million litres in 2029–2032 to 3,750 million litres in 2037–2040. The bioethanol-based FFVs assumed to enter the market in 2032 should consume about 4 million litres of bioethanol in 2037–2040.

Figure 5.17. Four-Year Consumption of Gasoline-Related Biofuels – MOD Scenario

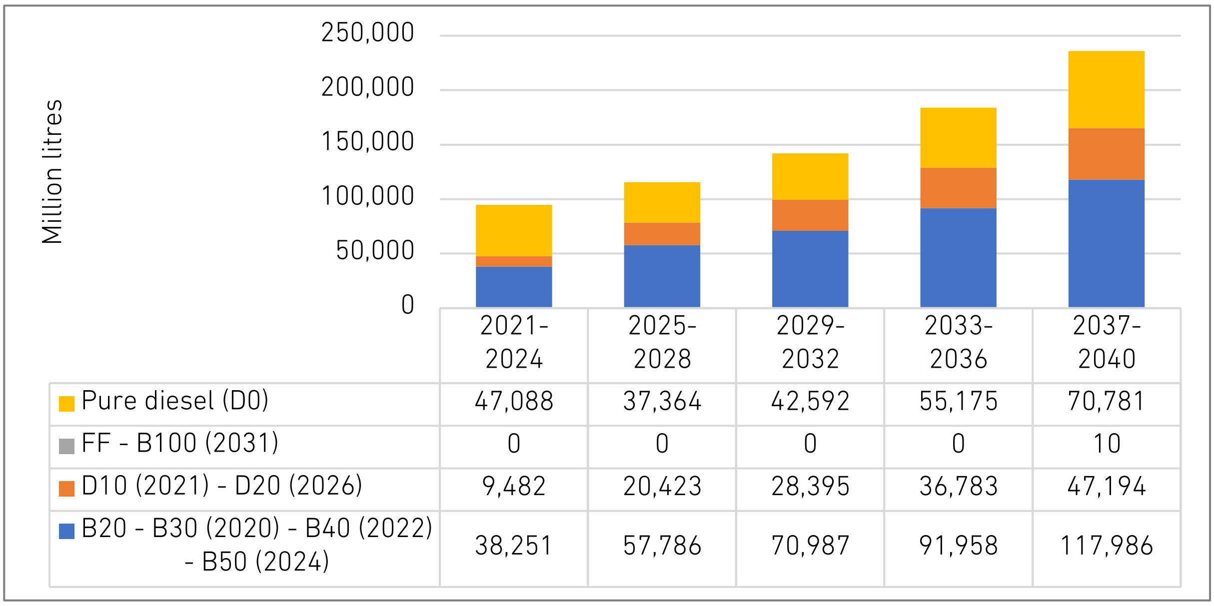


	2021-2024	2025-2028	2029-2032	2033-2036	2037-2040
🟨 Pure gasoline (B0)	143,769	152,107	149,579	140,084	149,736
⬜ FF - E100 (2032)	0	0	0	0	4
🟧 G5 (2028) - G10 (2032)	0	1,991	10,477	17,510	18,718
🟦 E2 pilot (2022) - E3 (2028) - E5 (2031) - E10 (2033)	546	1,775	6,700	17,510	18,718

Source: Model results.

Finally, in the OPT scenario, we assumed the mandatory biofuel programme to shift from B30 to B40 in 2022, followed by a shift from B40 to B50 in 2024, assuming that the biodiesel blend could be increased to that level without any problems in vehicle engine performance. The mandatory 10% green diesel (D10) programme would be implemented in 2021, followed by D20 in 2026. The green diesel refinery capacity should reach about 2,500 million litres per year before its introduction in 2021 and further to 7,000 million litres per year before 2026 to prepare for D2. The total biofuel blend in OPT would increase from the current 30% to 40% in 2021, 50% in 2022, 60% in 2024, and 70% by 2026 (Figure 5.18). In this scenario, we could expect a diesel-related biofuel need of nearly 11,934 million litres in 2021–2024 that would increase to 41,300 million litres in 2037–2040. The diesel-based FFVs should consume about 10 million litres during 2037–2040.

Figure 5.18. Four-Year Consumption of Diesel-Related Biofuels – OPT Scenario

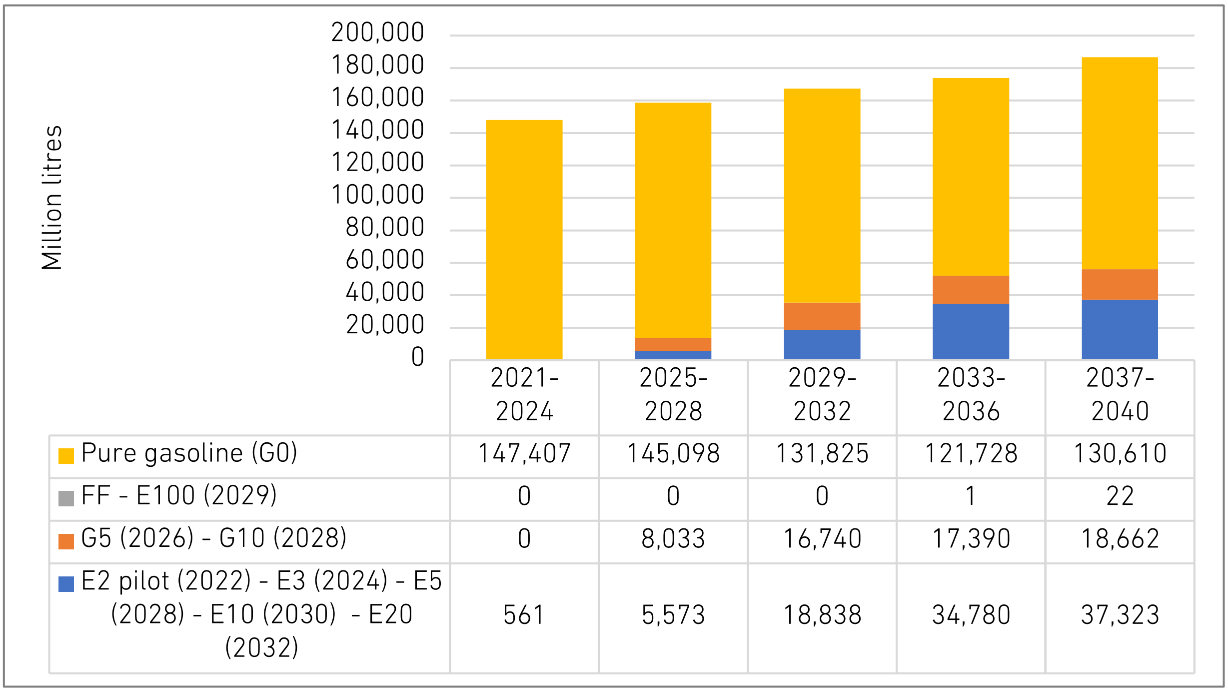


	2021-2024	2025-2028	2029-2032	2033-2036	2037-2040
🟨 Pure diesel (D0)	47,088	37,364	42,592	55,175	70,781
■ FF - B100 (2031)	0	0	0	0	10
🟧 D10 (2021) - D20 (2026)	9,482	20,423	28,395	36,783	47,194
🟦 B20 - B30 (2020) - B40 (2022) - B50 (2024)	38,251	57,786	70,987	91,958	117,986

Source: Model results.

In the OPT scenario, we assumed pilot projects of the mandatory bioethanol programme to start at a 2% rate in 2022 in East Java and DKI Jakarta. In this scenario, this pilot 2% blend bioethanol programme would directly become a national mandatory E3 programme in 2024, E5 in 2028, E10 by 2030, and E20 by 2032. The mandatory 5% green gasoline (G5) programme would be implemented in 2026, followed by G10 in 2028. This should make the percentage of gasoline-related biofuel of 3% in 2024, 8% in 2026, 15% in 2028, 20% by 2030, and 30% by 2032 and beyond (Figure 5.19). In this scenario, we could expect a yearly need of around 110 million litres of bioethanol in 2021–2024, increasing to 7,500 million litres in 2037–2040. The annual consumption of green gasoline should increase from 1,600 million litres in 2025–2028 to 3,700 million litres in 2037–2040. The bioethanol-based flex-fuel would consume about 1 million litres of bioethanol during 2033–2036 and approximately 22 million litres of bioethanol in 2037–2040.

Figure 5.19. Four-Year Consumption of Gasoline-Related Biofuels – OPT Scenario

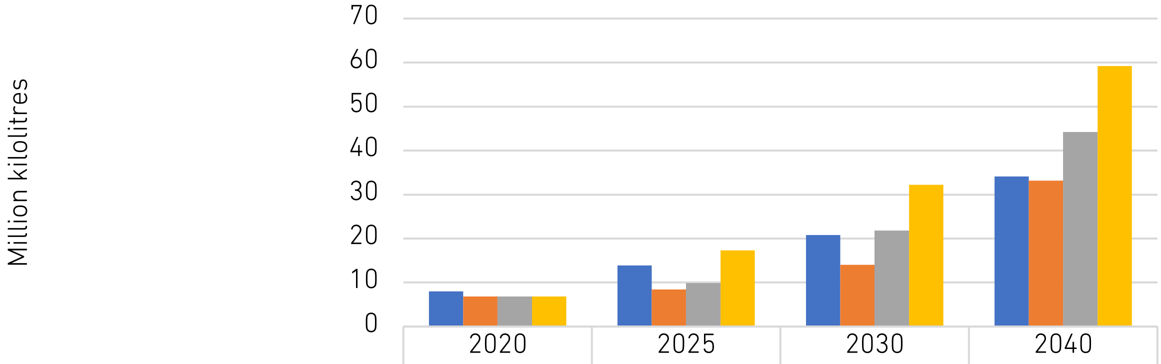


	2021-2024	2025-2028	2029-2032	2033-2036	2037-2040
🟨 Pure gasoline (G0)	147,407	145,098	131,825	121,728	130,610
⬜ FF - E100 (2029)	0	0	0	1	22
🟧 G5 (2026) - G10 (2028)	0	8,033	16,740	17,390	18,662
🟦 E2 pilot (2022) - E3 (2024) - E5 (2028) - E10 (2030) - E20 (2032)	561	5,573	18,838	34,780	37,323

Source: Model results.

Finally, we can see that at least only a 'moderate' level of biofuel policy measures in the MOD scenario would allow to catch up with the biofuel consumption target mentioned in Presidential Regulation no 22 no 17 (RUEN 2017) in the short term after the decrease, due to the pandemic in 2020 (Figure 5.20). Staying at the 'conservative' level of biofuel policy measures would allow nearly catching up with the RUEN 2017 biofuel target by 2040.

Figure 5.20. Total Biofuel Consumptions in RUEN (2017) and Scenarios



	2020	2025	2030	2040
🟦 Biofuel use target as in RUEN 2017	8	13.9	20.8	34.1
🟧 CON	6.8	8.5	14.0	33.2
⬜ MOD	6.8	9.9	21.8	44.2
🟨 OPT	6.8	17.3	32.2	59.2

Source: Authors' elaboration.

5.3.5. Needed biofuel subsidy

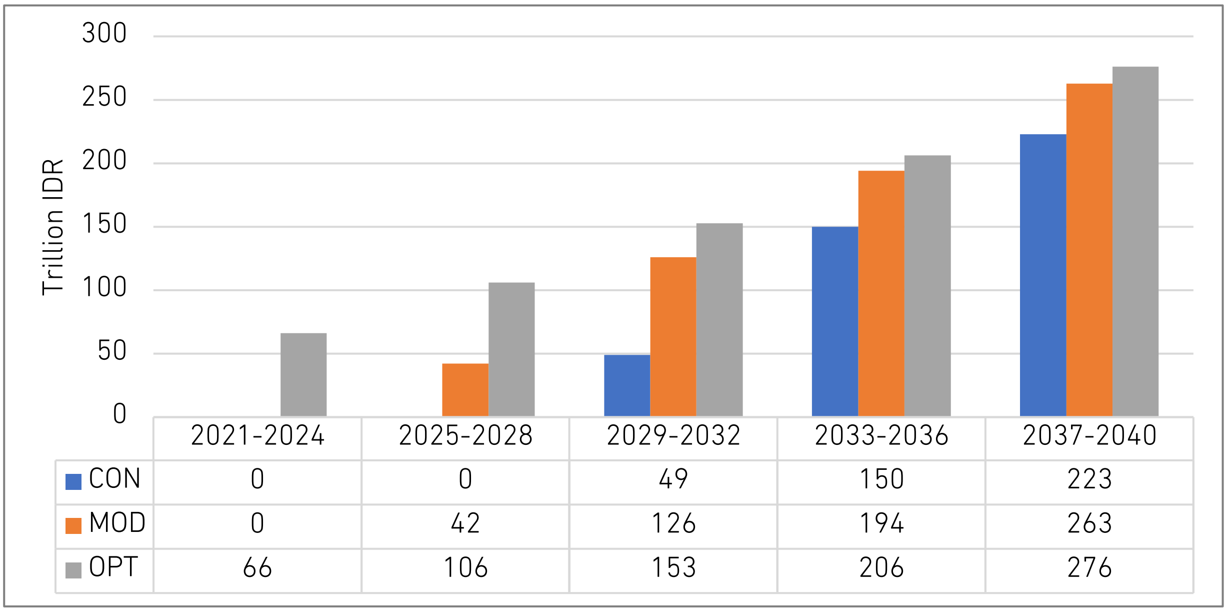
Like the current and the past biodiesel mandatory programmes, we assumed that the government would also subsidise all the mandatory biofuel blending programmes by paying the price difference or price gap. In this study, this price gap subsidy would occur in all biodiesel (Bxx), bioethanol (Exx), green diesel (Dxx), and green gasoline (Gxx) programmes.

The non-subsidised programme would be the bioethanol-based and the biodiesel-based FFV programmes. In these programmes, the vehicles and the high-blended biofuels would be launched to the market as new vehicles and alternatives.

As explained in section 5.2.3, the assumed disappearance of diesel with cetane number 48 in 2025 should increase the diesel fuel prices above the forecasted price of biodiesel. Thus, the biodiesel subsidy would become 0 (zero) starting in 2025 if the pure diesel price increases due to the removal of cetane number 48-diesel from the market.

The green diesel programme is assumed to start as a D10 programme in 2021 in the OPT scenario and later in the CON (2030) and MOD (2026) scenarios. With the assumed fuel prices, the green diesel programme can be considered expensive. For example, in 2021–2024, a mandatory 10% green diesel blend or D10 programme implementation in OPT would cost IDR66 trillion, or around IDR16.5 trillion per year (Figure 5.21).

Figure 5.21. Four-Year Subsidy of the Mandatory D100 (Green Diesel) Programmes

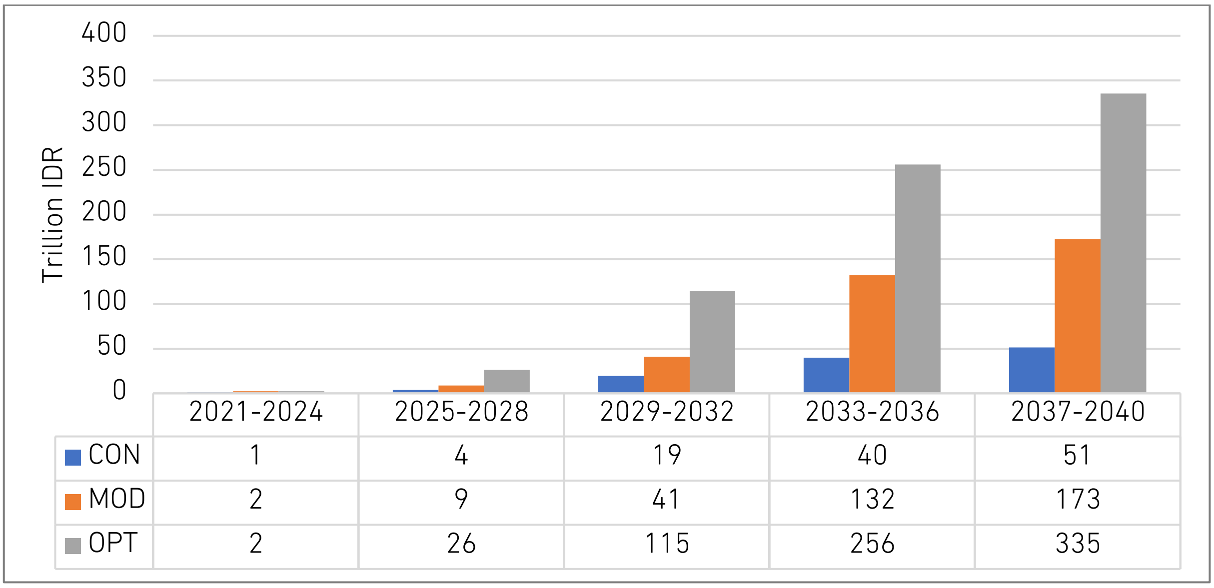


	2021-2024	2025-2028	2029-2032	2033-2036	2037-2040
🟦 CON	0	0	49	150	223
🟧 MOD	0	42	126	194	263
⬜ OPT	66	106	153	206	276

Source: Model results.

The bioethanol programmes in our study start with pilot E2 programmes in two provinces, East Java and DKI Jakarta. Having different starting years, in 2021–2024, this programme would need a subsidy of about IDR1 trillion to 2 trillion (IDR0.25 trillion to 0.5 trillion yearly). We assume that the maximum mandatory bioethanol blend would reach 10% (E10) in the CON and MOD scenarios and 20% in the OPT scenario. In 2037–2040, the needed bioethanol subsidy would reach IPR51 million in the CON scenario and IDR335 trillion in the OPT scenario (Figure 5.22).

Figure 5.22. Four-Year Mandatory Exx (Bioethanol) Programme Subsidy

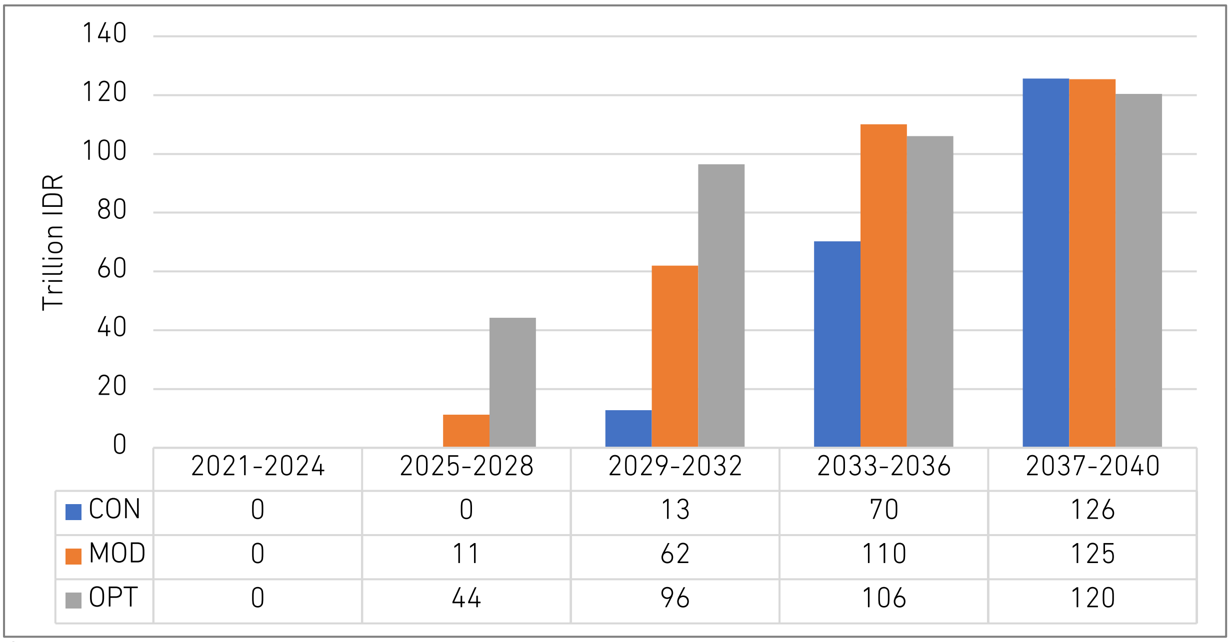


	2021-2024	2025-2028	2029-2032	2033-2036	2037-2040
🟦 CON	1	4	19	40	51
🟧 MOD	2	9	41	132	173
⬜ OPT	2	26	115	256	335

Source: Model results.

Finally, we assumed that green gasoline (Gxx) blending programmes would enter later than the green diesel programmes in the CON, MOD, and OPT scenarios, respectively, in 2032, 2028, and 2026. Figure 5.23 shows that the OPT scenario starting in 2033 to 2036 no longer has the highest needed subsidy for the green gasoline programmes. The volume of gasoline consumption between the OPT and MOD scenarios gets narrower, whilst the price difference between gasoline and green gasoline in the OPT scenario is smaller than the MOD scenario. This makes the total subsidy for green gasoline of the MOD scenario higher than OPT during that period. In 2037–2040, the gap between gasoline demand of the three scenarios and the price becomes smaller, resulting in the almost-similar needed subsidy in the three scenarios.

Figure 5.23. Four-Year Mandatory Gxx (Green Gasoline) Programmes Subsidy



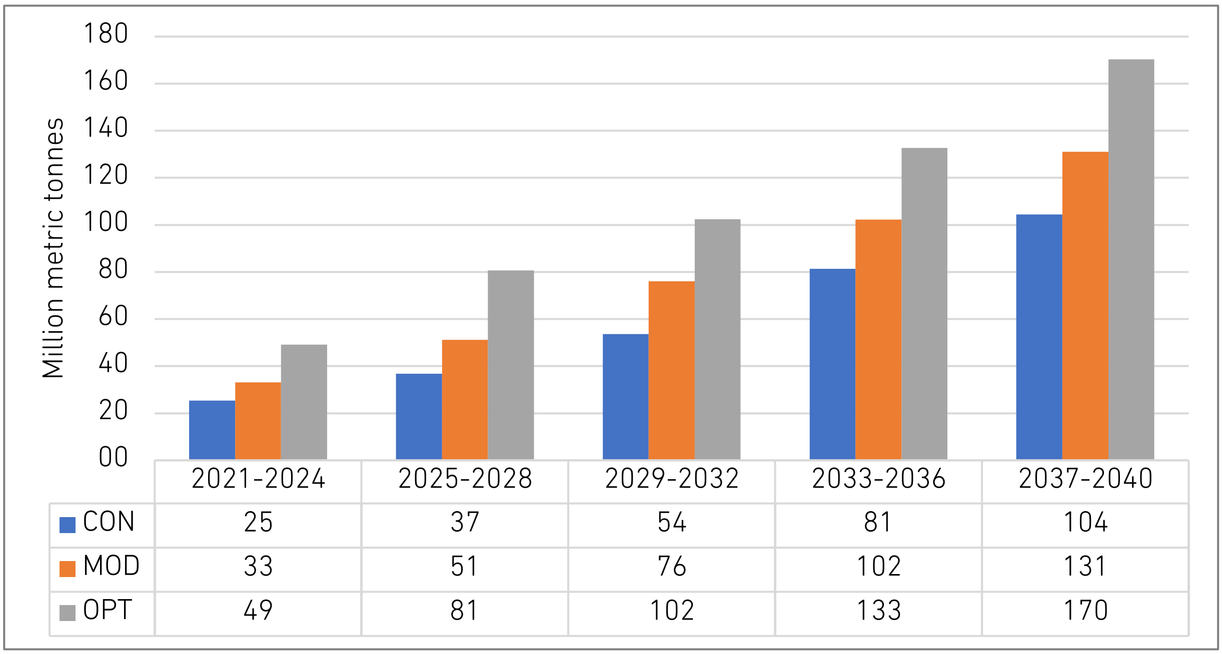
	2021-2024	2025-2028	2029-2032	2033-2036	2037-2040
🟦 CON	0	0	13	70	126
🟧 MOD	0	11	62	110	125
⬜ OPT	0	44	96	106	120

Source: Model results.

5.3.6. Needed biofuel feedstock

We used the conversion of 1,031 metric-tonne/million-litre and 4,125 metric-tonne/million-litre, respectively, for CPO to biodiesel/green diesel and for sugarcane to bioethanol/green gasoline to calculate the needed biofuel feedstock. The results are given in Figure 5.24 and Figure 5.25.

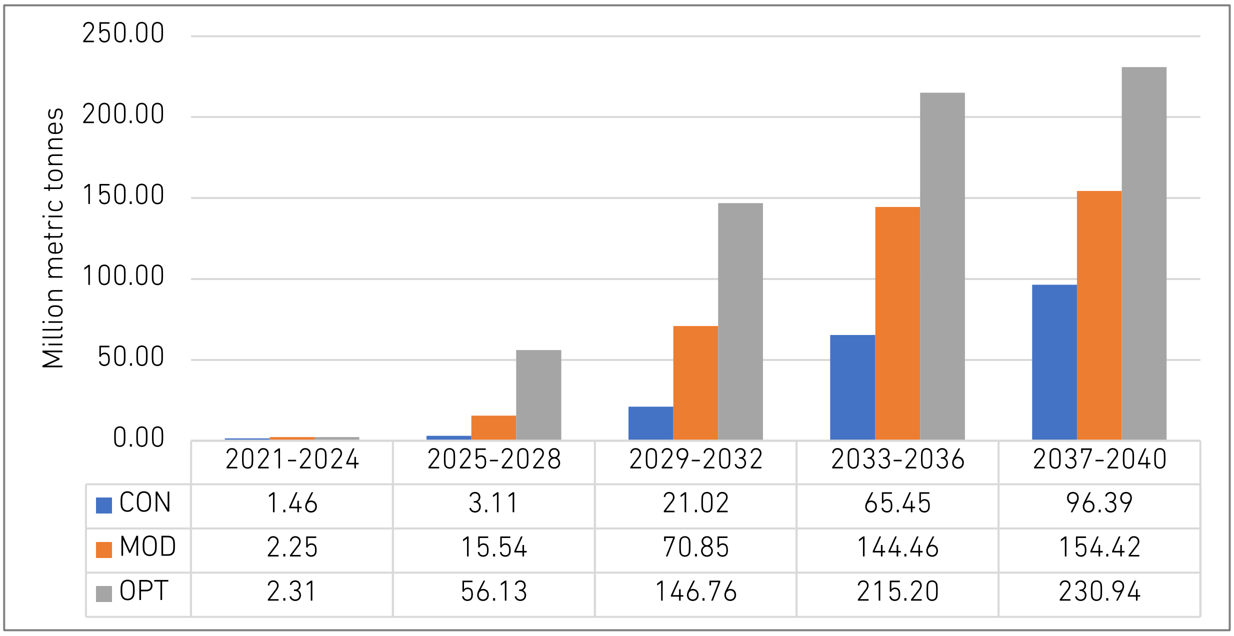
Figure 5.24. Four-Year Crude Palm Oil (CPO) Feedstock Need for Diesel-Related Biofuel Programmes



	2021-2024	2025-2028	2029-2032	2033-2036	2037-2040
🟦 CON	25	37	54	81	104
🟧 MOD	33	51	76	102	131
▩ OPT	49	81	102	133	170

Source: Model results.

Figure 5.25. Four-Year Crude Sugarcane Feedstock Need for Gasoline-Related Biofuel Programmes



	2021-2024	2025-2028	2029-2032	2033-2036	2037-2040
🟦 CON	1.46	3.11	21.02	65.45	96.39
🟧 MOD	2.25	15.54	70.85	144.46	154.42
▩ OPT	2.31	56.13	146.76	215.20	230.94

Source: Model results.

5.3.7. Greenhouse gas emissions

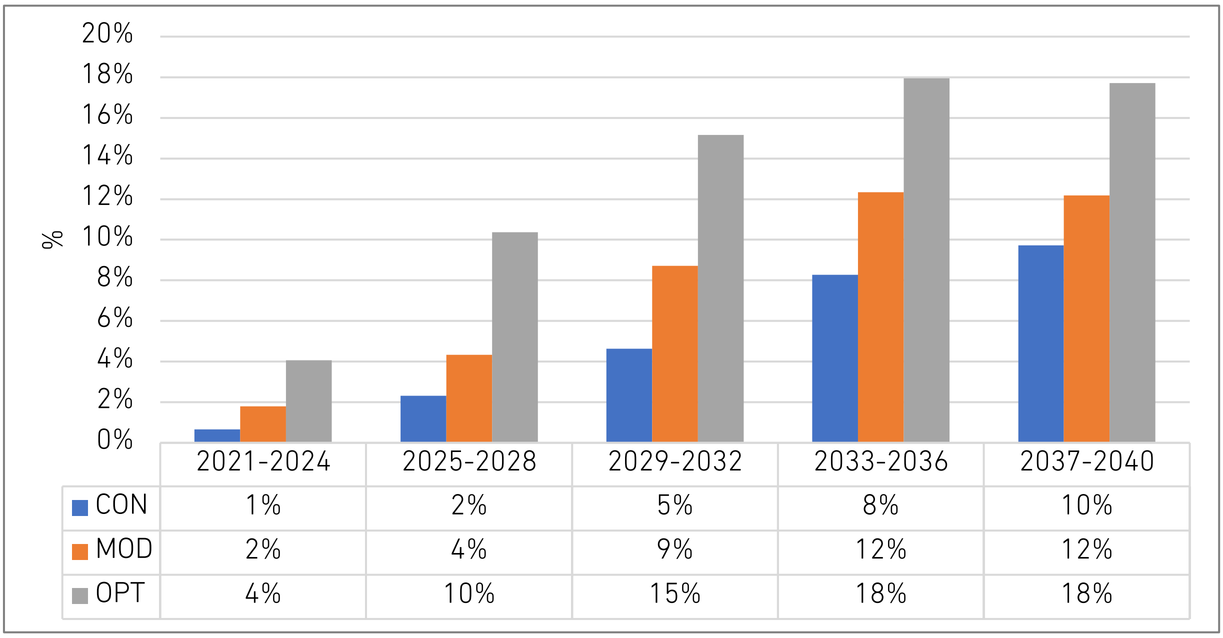
We used direct life cycle analysis (LCA) CO_2 emission factors from Posada et al. (2012) and Maga et al. (2019), respectively, for CPO-based biodiesel (0.6051 tonne-carbon/tonne of oil equivalent [toe]) and sugarcane-based bioethanol (0.2245 tonne-carbon/toe). These emissions factors mean that the B100 fuel contains 30% less carbon than pure diesel fuel and that E100 fuel contains around 72% less carbon than pure gasoline fuel.

These direct emission intensities assume no carbon loss from the field in which biofuels are grown or planted. Direct LCA emission factors from biofuel production concern agriculture and processing and are dependable on the pathways. The emission factors vary in the carbon intensity of electricity used and factors, such as fertiliser application rate.

To analyse the impact of scenarios, we assumed a 'frozen biofuel policy' scenario as a benchmark where the current mandatory B30 policy is the only biofuel policy implemented during the whole period of analysis.

Figure 5.26 shows that relative to the frozen biofuel policy scenario, the OPT scenario reduced most CO_2 emissions, followed by MOD and CON. This signifies that more aggressive biofuel policies should reduce the direct CO_2 emissions more in all economic situations. In absolute terms, during 2037–2040, regarding the frozen biofuel policy scenario, all other scenarios should reduce direct CO_2 emissions by 164, 104, and 70 million tonnes of CO_2, respectively.

Figure 5.26. Four-Year Direct CO_2 Savings of the Three Biofuel Scenarios Relative to a ‘Frozen Biofuel Policy’ Scenario

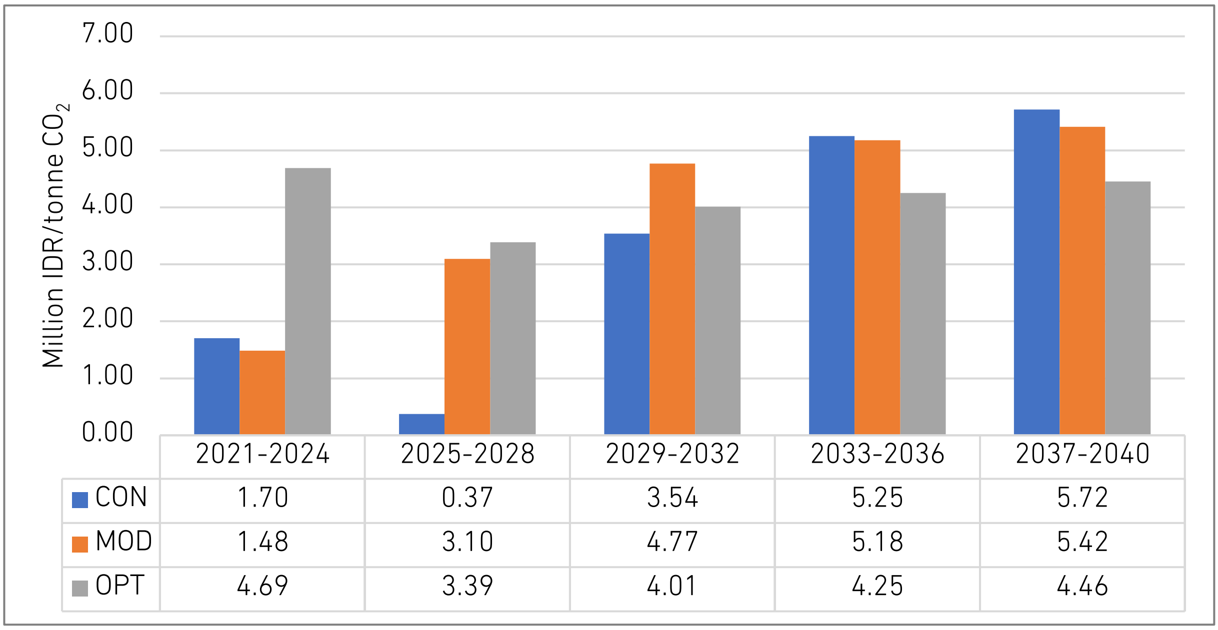


	2021-2024	2025-2028	2029-2032	2033-2036	2037-2040
🟦 CON	1%	2%	5%	8%	10%
🟧 MOD	2%	4%	9%	12%	12%
⬜ OPT	4%	10%	15%	18%	18%

Source: Model results.

Figure 5.27 shows the 4-year direct CO_2 emission average abatement cost. At the beginning of the period of analysis, aggressive policies, such as those assumed in OPT where the green diesel (D-10) programme enters the market in 2021 would result in high abatement costs as the economic situations assumed in the scenarios do not differ much. Towards the end of the period, the differences in the economic situation, especially accentuated by the narrowing price gap between biofuels and fossil fuels assumed in the scenarios, more aggressive biofuel policies’ cost is lower and so is the CO_2 emission abatement cost. This finding stresses the importance of balancing the aggressivity of the biofuel policies and the economic situation.

Figure 5.27. Four-Year Direct CO_2 Emission Average Abatement Costs



	2021-2024	2025-2028	2029-2032	2033-2036	2037-2040
CON	1.70	0.37	3.54	5.25	5.72
MOD	1.48	3.10	4.77	5.18	5.42
OPT	4.69	3.39	4.01	4.25	4.46

Source: Model results.

5.3.8. Impact of flex-fuel vehicles

Government Regulation (*Peraturan Pemerintah*) PP number 73 Year 2019 set the luxury tax (PPnBM) percentage for FFVs at 15%, with a base of the taxable selling price at 53.33%. Therefore, the effective luxury tax for FFVs is about 8% of its selling price, i.e. the result of multiplying the two previous values. In this luxury tax framework, only low-cost green cars, full-battery electric cars, and several fully hybrid electric vehicles are taxed effectively less than FFVs. The effective luxury taxes for passenger cars with fewer than 10 passengers range from 15.5% to 70%. This reduced luxury tax for FFVs aims to stimulate the purchase of FFVs when they are available in the market.

To know how the FFVs would penetrate the market, we need to properly conduct a market survey with potential purchasers as the sampling population. Various methods can be used, especially stated preference analysis. This kind of survey is not amongst the methodology used in this study. However, a preliminary analysis – by reducing the price that corresponds to the luxury tax reduction scheme for FFVs in the VEIA model – provides some findings.

Our study assumed different initial years for the FFVs' introduction to the automotive market. The CON scenario has no FFVs whilst in the OPT, they would penetrate the market earlier than the MOD scenario. We assumed that those FFVs' engines would be bigger than 1500 cc, and have the characteristics and average price corresponding to vehicle classes and their specific fuel types in Indonesia. The utilisation ratio of biofuel to conventional fuel is assumed to be 70:30.

In all cases, bioethanol FFVs are assumed to start first as the car technology is more mature. This type of vehicle is available in the car market, at least in Brazil, the US, and Thailand.

Table 5.9. Assumed Initial Year of Flex-Fuel Vehicles Introduction to the Market

PM No.	Policy Measures (PM)	Short Description	Conservative	Moderate	Optimistic
DSL5	Non-mandatory biodiesel: B100 + DSL flex-fuel vehicles (FFVs)	Non-mandatory introduction of B100 in gas stations accompanied by the introduction of diesel FFVs and high-blended biodiesel	N/A	2035	2030
GSL7	Non-mandatory bioethanol: E85/E100 + FFVs	Non-mandatory introduction of E85 in gas stations accompanied by the introduction of gasoline FFVs and high-blended bioethanol	N/A	2031	2028

Source: Authors' assumption.

This policy is not mandatory, which means that users can or cannot buy this type of vehicle. In the model, the total generalised car utilisation costs (given in rupiah per vehicle-km), including the discounted fixed and variables costs, determine users' vehicle purchase choice. Herewith, users' choice is affected by the car's purchase price and the fuel price at gas stations, amongst others.

Section 5.3.4 shows that FFV fuel consumption would be almost negligible as FFV stock would also be low. Even in the OPT scenario where bioethanol FFVs would enter the market in 2028 and biodiesel FFVs in 2030, the number of bioethanol and biodiesel FFVs in 2040 would be around 9,300 and 4,600 units, respectively. Table 5.10 shows the model results of FFV stock and fuel consumption in 2040.

Table 5.10. Flex-Fuel Vehicle (FFV) Units in Operation and Fuel Consumption in 2040

Flex-Fuel Type Scenario	Vehicle Units in Operation	Fuel Consumption (kilolitres)
Biodiesel FFV – MOD	27	31
Biodiesel FFV – OPT	4,600	5,500
Bioethanol FFV – MOD	2,538	2,526
Bioethanol FFV – OPT	9,355	9,067

Source: Model results.

This preliminary assessment shows that fiscal measures of luxury tax reduction would probably not be enough to stimulate strong penetration of FFVs when available in the market, i.e. 2028 and 2030 in the OPT scenario and 2031 and 2035 in the MOD scenario. The total generalised costs are affected by the purchase price and the car utilisation or operational costs. High-blended biodiesel and bioethanol have less energy density than conventional fuels. FFV users spend more money than conventional car users for the same travelled distance, making FFVs less competitive.

Other fiscal measures are needed to compensate for FFVs' lower energy efficiency, such as reduced biofuel prices.

Chapter 6

Conclusions and Way Forward

A biofuel roadmap for Indonesia's road transport sector should consider long-term purposes, targets, and economic and energy situations that impact the country's economic activities.

Nowadays, the world is experiencing an unprecedented period of uncertainty related to the severe drop in oil price and the COVID-19 pandemic that affect economic growth. Experts are still debating the depth and the concerned time horizon these two incidents impact the economy in general and the mobility of people and goods.

This study provides a framework to build a roadmap towards a biofuel-based transport sector of the country. The framework includes alternative economic situations related to the pandemic and the oil price drop as well as sets of possible policy measure packages considered adequate to be implemented in each economic situation.

The study brought three scenarios. Two scenarios represent two extreme situations. On one end, the CON scenario portrays slow economic growth and low oil price, resulting in a case where demand for transport fuel is low, and biofuel prices are not competitive. On the other end, the OPT scenario represents a situation where transport demand is high and biofuel prices are competitive. The policy packages are defined based on the biofuel sector's readiness and the automotive industry, respectively, to supply biofuels and the needed vehicle technologies in each economic situation. A third scenario, MOD, is elaborated and simulated to represent a rather 'neutral' economic situation and biofuel policy packages.

Below are several principles to be used in developing a roadmap:

- The consideration of the economic and energy sectors as a key – Economic growth determines economic activities that induce the movement of people and goods and the demand for transport fuels. In the meantime, fossil fuel prices would develop following a fluctuation in world oil market prices, which determines the competitiveness of biofuels produced domestically.
- Cost-effectiveness to consider – Biofuel policy measures would always reduce the country's dependency on fossil fuels and direct CO_2 emissions. Nevertheless, policymakers should consider cost-effectiveness in reaching the determined targets. The study simulation results show that the more optimistic the economic and energy market situation is, the more aggressive biofuel policies can be taken at lower costs.

- Uncertainty is a major difficulty in planning a long-term biofuel roadmap – We can only assume that policies are consistent with objectives, such as reaching Euro IV standards in fuels and reducing subsidies, especially in fossil fuels. Sticking to these objectives, we observed that diesel prices would significantly increase. This results from eliminating cetane 48 diesel fuel by 2025, which should raise the average diesel price higher than biodiesel. There should be no need to subsidise biodiesel starting in 2025. However, the increase in the prices of diesel and gasoline fuels to comply with the Euro IV standard – i.e. transport fuels with a sulphur limit below 50 ppm – needs analysis and solutions, which are beyond the scope of this study.
- Synchronising biofuel and Euro IV objectives means that Indonesia needs a policy roadmap based most probably on the blend mandate of CPO-based biodiesel during the transition period to Euro IV diesel fuel, and the blend mandate of green diesel in the Euro IV diesel fuel period and beyond. The roadmap should be based on three principles.
    - First, 'the government should gradually shift to Euro IV diesel fuel without subsiding diesel fuel price'. Phasing out the currently dominant 2,500 ppm diesel fuel (not yet a complete shift to Euro IV standards) would trigger more than a 28% increase in the average diesel fuel price. Should the government refrain from subsidising diesel fuel, the price of CPO-based biodiesel would be lower than diesel fuel. Looking at the historical price data from the MEMR, the future price of CPO-based biodiesel would unlikely increase faster than diesel fuel, in which case biodiesel subsidies would no longer be needed. The collected revenues from Indonesia's CPO export levy can then be fully used to build up the oil palm agroindustry as mandated by Presidential Decree No. 61/2015. The main challenge with this policy would be helping consumers afford the more expensive Euro IV diesel fuel. To avoid an economic shock, the government must prepare an effective subsidy scheme that avoids a sharp increase in production costs and, therefore, inflation rate. In all cases, Indonesia should not create any new diesel fuel subsidies.
    - Second, the biodiesel blending mandate policy should be maintained during the transition to Euro IV. The existing CPO-based biodiesel blend with high-sulphur diesel fuel is good in direct emissions, as previously mentioned, and decreasing diesel fuel imports. Once the Euro IV diesel fuel is available, high-blended CPO-based biodiesels, possibly as high as a 50% blend rate and over, can be sold as alternative (non-mandatory) fuels at gas stations. At the same time, FFVs or vehicles powered with low and very high-blended biodiesel will become available in the market.
    - Lastly, former MEMR Minister Ignatius Jonan once explained that green diesel should enter the market at Rp14,000/litre. Therefore, economies of scale for

green diesel should be created as soon as possible to decrease its price by introducing a very low percentage blend mandate. Simultaneously, a high percentage or pure 100% green diesel can be sold as an alternative (non-mandatory) fuel at gas stations. A study from the IEA Bioenergy in 2020 suggested that feedstock costs can make up to 65%–80% of the production costs. Should CPO prices be controllable following the development of the oil palm agroindustry, green diesel prices could also be reduced so that a higher blend mandate can be reached once Euro IV diesel fuel is fully available.

- The importance of financing strategies – Reaching determined targets would need some financing. In the current mandatory biofuel policies, the Indonesian government collects a crude palm oil export fee to pay the differences between pure diesel and biodiesel prices. This strategy would face difficulty when the demand for export CPO is low whilst the gap between high biodiesel price and low diesel price is getting large, which can happen in the future. A set of financing strategies should support the roadmap. Amongst the strategies that can be adopted is feebate or a reduction of biofuel prices at stations to compensate for the reduced fuel economy of high biofuel-blended fuels. The decrease is obtained by a government subsidy from a government fund collected by taxing conventional fuels. This scheme is implemented in Thailand,[22] whose government subsidises reduced bioethanol high-blended (E85) fuel prices by taxing gasoline fuel prices.
- Coordinated policy measures across the different sectors – energy, industry, and agriculture – need to be developed and included in the biofuel roadmap. Whilst the economic situation and energy market condition can be considered exogenous, biofuel prices are key elements in the roadmap that can be affected by policy measures. The CPO-based biodiesel industry is well developed, but the bioethanol industry capacity is currently too low to meet demand from a national mandatory bioethanol blend programme. Innovative policy measures are needed to de-block the capacity bottlenecks in bioethanol production to make its price competitive without jeopardising farmers' and producers' welfare. The development of such policy measures requires inter-ministerial cooperation.
- In the road transport sector, gasoline consumption is still higher than diesel, with an estimated ratio of 55:45. The gasoline–diesel fuel import ratio is about 70:30. Clearly, the focus must be on biofuels that can substitute gasoline. Apart from the problematic bioethanol, CPO-based green gasoline can play a more critical role in replacing pure gasoline. The CPO is domestically produced, and if it makes the most of the green

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[22] https://www.fuelsandlubes.com/knowledge-base/fuel-consumption-in-thailand-in-uptrend/

gasoline (and green diesel) cost component, the prices of those green fuels would be more controllable.

- In all situations, in 20 years, Indonesia should replace at least 60% of diesel fuel consumption with diesel-based biofuels, most likely with a combination of FAME-based-biodiesel and green diesel mandates.
- The non-mandatory flex-fuel and high-blend biofuel should enter in the later stage. Whilst gasoline-bioethanol FFVs are available globally, Indonesia would need to deal with bioethanol production. High-blend biodiesel fuel with biodiesel FFVs is an option that will also enter later, as the automotive industry needs around 5 to 10 years to prepare to produce this type of FFVs. Nevertheless, only luxury tax (PPnbM) reduction would not be enough to stimulate the strong sales of FFVs as their fuel economy are, on average, less than conventional vehicles. Fiscal policy measures, such as feebate that give more advantage to biofuels, should boost FFV penetration in the automotive market.
- Setting policy measures is arbitrary, but impacts should always be assessed. Policy measures incorporated in a roadmap are results of consultation and discussion involving stakeholders. This study proposed a set of policy measures adapted to the different economic and energy situations where the biofuel and automotive industries' readiness was considered. The proposed policy measures and their corresponding timeline are debatable. The discussion should include an assessment of policy measure impacts whose results should be used to input to the discussion that creates an iterative process.

The conducted study is limited in at least three aspects. First, the study is not able to give the most reliable roadmap for a biofuel-based transport sector in Indonesia. The main reasons are the current high uncertainty in the economic and energy price situation facing the country and the world and the lack of a long-term biofuel policy measure package that can be used as a benchmark. Second, biofuel prices have been assumed to grow at constant rates. In theory, the price should develop in a dynamic way resulting from interaction between the industry's supply and demand. Third, the study cannot assess the impact of the biofuel policies on fossil fuel imports.

As a way forward, there are three main directions to follow. First, for economic experts to agree on how the economic situation and energy market would likely develop by 2040 and have (a) set(s) of long-term biofuel policy package to be assessed that should include financing strategies and policy measures in the biofuel industries. One emphasis should be on the short-term plan to comply with the EURO IV fuel standard, i.e. how to provide the fuel at economical but affordable prices without increasing the fossil fuel subsidy. Second, to develop a model of simplified biofuel sectors that allows estimating biofuel prices by 2040. Third, to create a simplified model of refinery product exports and imports that allows assessing the impacts of biofuel policy measures on transport fuel imports.

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Appendix 1

Current Fuel Pricing Structure in Indonesia

The Ministry of Energy and Mineral Resources' regulation Kepmen ESDM 62.K/12/MEM/2020 is the latest regulation on transport fuel retail prices in Indonesia. Effective since 1 January 2020, it set the retail price formulation (rupiah per litre) as follows.

$$Retailed\ Fuel\ Price = MOPS + constant + Profit\ Margin + VAT + PBBKB$$

Where:

- MOP[23]: *Means of Platts Singapore* is the fuel production cost, i.e., the total cost of procuring gasoline and diesel fuel purchased from domestic refineries or from import until its delivery to the fuel terminals. Conversion factors are needed to change MOPS from its initial value in US$/barrel to rupiah/litre: first, the average currency exchange rate from Bank Indonesia[24] and, second, a unit conversion where 1 barrel equals 159 litres.
- Constant: Basically the sum of three components: (i) transport, insurance, and other costs related to fuel procurement; (ii) storage costs; and (iii) all distribution costs that concern all costs used to distribute fuel until it reaches the consumers.
- Margin: profit for fuel traders[25] (BU BBM) in performing activities of supplying gasoline and diesel fuels with the intermediary of public fuel stations and fuel stations intended for fishery activities.
- VAT: value-added tax, i.e. 10%
- PBB KB: provincial transport fuel tax

Fuel prices are differentiated based on the fuel type that affects the constant value and profit margin, i.e. upper and lower.

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[23] The regulation also defines how the MOPS are calculated, i.e. fuel type and the multiplier factor. For example, RON 90 gasoline MOPS is calculated by multiplying MOPS mogas 92 by a factor of 99.21%, while CN48 diesel MOPS is calculated by multiplying MOPS mogas gasoil 25% by a factor of 100%, etc.

[24] The average exchange rate of rupiah to US dollar is calculated based on median value of the Bank Indonesia's exchange rate that includes the period between the 25th of the previous 2 months to the 24th of the previous month.

[25] BU BBM: *Badan Usaha Pemegang Isin Usaha Niaga Minyak dan Gas Bumi*

Table A.1. Fuel Price Differentiation

	RON95 gasoline, CN48 diesel and below	RON98 gasoline, CN51 diesel and beyond
Upper profit margin	$Profit\ Margin = \frac{10}{90} * (MOPS + Constant)$ Constant: Rp1,800/litre	$Profit\ Margin = \frac{10}{90} * (MOPS + Constant)$ Constant: Rp2,000/litre
Lower profit margin	$Profit\ Margin = \frac{5}{95} * (MOPS + Constant)$ *Constant*: Rp 1800/litre	$Profit\ Margin = \frac{5}{95} * (MOPS + Constant)$ Constant: Rp 2000/litre

Source: Authors' elaboration based on The Ministry of Energy and Mineral Resources' regulation Kepmen ESDM 62.K/12/MEM/2020.

Indonesia also implements subsidies for certain fuel types. Subsidy is intended to form a final retailed fuel price that is affordable. Subsidy can be calculated using the following equations.

$$Retailed\ Fuel\ Price = MOPS + constant + Profit\ Margin + VAT + PBBKB - Subsidy$$

$$Subsidy = MOPS + constant + Profit\ Margin + VAT + PBBKB - Retailed\ Fuel\ Price$$

If

$$Reference\ Fuel\ Price = MOPS + constant$$

And

$$All\ tax\ and\ profits = Profit\ Margin + VAT\ PBBKB$$

Then

$$Subsidy = Reference\ Fuel\ Price + All\ tax\ and\ profits - Retailed\ Fuel\ Price$$

Three types of fuels[26]:

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[26] https://jdih.esdm.go.id/peraturan/Perpres%20Nomor%20191%20Tahun%202014.pdf

1) BBM *tertentu* (specific fuel oil): *minyak tanah* (kerosene), *minyak solar* (Gas oil) – subsidised
2) BBM *khusus penugasan* (special fuel oil assignment): gasoline with RON of minimum 88 to be distributed in all provinces in Indonesia, except in Java and Bali – non-subsidised
3) BBM *umum* (general fuel oil): all other fuel types – non-subsidised

Appendix 2

Current Vehicle Pricing Structure in Indonesia

New motorised road vehicle purchase price in Indonesia is basically formed by the road vehicle selling value and taxes. The final purchase price often named as the on-the-road (OTR) price is calculated as follows:

$$OTR = NJKB * PKB\ weight(1 + BBNKB + PPnBM + PPN + ATPM) - Subsidy$$

Where

OTR : On-the-road Price (final motorised vehicle price paid by consumer)

NJKB : Motorised Vehicle Selling Value[27]

PKB weight : motorised vehicle tax[28] weight, e.g. 1.5% of NJKB

BBNKB : Transfer of Motor Vehicle Title Fee[29], e.g. in Jakarta it is 10% of NJKB

ATPM : exclusive sole agent fees[30] that includes promotion, insurance, road traffic incident obligatory fund[31], etc. that make up around 10% of NJKB

PPnBM : luxury sale tax[32]

Government Regulation PP No. 73/2019 regulates the PPnBM, and its values are differentiated in function of vehicle type, capacity (for passenger cars) engine type, fuel type, fuel consumption (given in km/ per litre of fuel), emission factor (given in gram of CO_2 per vehicle-km). The tax values are given in two terms, i.e. the luxury sale tax itself and the base percentage of the selling value that is taxable.

For example, a spark ignition gasoline engine passenger car with an engine size below 3,000 cc and fuel consumption between 9.3 and 11.5 km/litre that is equivalent to emission factor between 200 and 250 grams of CO_2/vehicle-km has a luxury sale tax of 25% with the base percentage of the taxable vehicle selling value of 100%. The effective imposed

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[27] *Nilai Jual Kendaraan Bermotor* in Indonesian language or NJKB.

[28] *Pajak kendaraan bermotor* in Indonesian language or PKB.

[29] *Bea balik nama kendaraan bermotor* in Indonesian language or BBNKB.

[30] *Biaya Agen Tunggal Pemegang Merek* in Indonesian language or ATPM.

[31] *Sumbangan Wajib Dana Kecelakaan Lalu Lintas Jalan* in Indonesian language or SWDKLLJ

[32] *Pajak Penjualan Atas Barang Mewah* in Indonesian language or PPnBM

luxury sale tax is then 25%. The same vehicle type that consumes more fuel, i.e. less than 9.3 km/litre would be imposed a higher tax, i.e. 40%.

The regulation issued in September 2010 already includes flex-fuel vehicles (FFVs) that shall be fed with B100 and diesel or E100 and gasoline. For both FFVs, the luxury sale tax is 15% with the base percentage of the taxable vehicle selling value of 53.33%. The effective luxury sale tax for these FFVs is then 7.99% only.