Master’s Thesis of Science in Agriculture

Future Potential and Policy Implications of Liquid Biofuel in Thailand

태국에서의 액체 바이오연료의 미래 잠재력과

정책 시사점에 관한 연구

February, 2019

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Abstract

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In this study, various incentives, national standards and strategies are described by policy instruments. Thailand has been regulated national standards of biofuel since 2003. The mandate blending rates are 12% for bioethanol and 6.1% for biodiesel in 2018. The State Oil Fund (SOF) and Clean Energy Revolving Fund (CERF) are regulated to support biofuel industry and other international donor programs have been implemented in Thailand. There is an integrated program called TIEB (Thailand Integrated Energy Blueprint) in Thailand. TIEB includes 6 programs (Alternative Energy Development Plan, Power Development Plan, Energy Efficiency Development Plan, Oil Development Plan, Gas Development Plan, Renewable Energy Development Plan) usually aims to regulate goal of renewable energy and improve the usage of biofuel.

In addition, the potential of second generation biofuel was estimated with different residue extraction of second generation biomass; scenario 1 (20%), scenario 2 (44%) and scenario 3 (66%). As a result of production potential, 1.0~2.7 billion liters per year of bioethanol and 0.7~1.8 billion liters per year of biodiesel were produced in scenario 1. 2.2~6.0 billion liters per year of bioethanol and 1.5~4.0 of billion liters per year of biodiesel were produced in scenario 2. Finally, 3.3~9.0

billion liters per year of bioethanol and 2.3~6.0 billion liters per year of biodiesel were produced in scenario 3. As a result, it decreased 1.3~3.5 mega tons of CO_2 in gasoline sector and 1.4~3.8 mega tons of CO_2 in diesel sector under scenario 1. In scenario 2, it was expected 2.8~7.7 mega tons of CO_2 and 3.2~8.4 mega tons of CO_2 for gasoline and diesel sector, respectively**.** Finally, it was expected to reduce 4.2~11.6 mega tons of CO_2 in gasoline sector and 4.7~12.6 mega tons of CO_2 in diesel sector in scenario 3. In the economic potential of second generation biofuel, it is estimated with the view of emission trading. It could be gained 27~74 million USD and 30~81 million USD for each bioethanol and biodiesel sector in scenario 1, 60~163 million USD and 67~178 million USD in scenario 2, and 90~244 million USD and 100~267 million USD both bioethanol and biodiesel sector in scenario 3. It concludes the future potential of second generation biofuel in Thailand has the optimistic result and it could be contribute to bring both the environmental and the economic benefits to the country.

Key words: Biofuel, bioethanol, biodiesel, policy instruments, production potential, environmental potential, economic potential, Thailand.

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Contents

List of Table

List of Figures

List of Abbreviations

AEDP	Alternative Energy Development Plan
APEC	Asia-Pacific Economic Cooperation
AGEP	ASEAN-German Energy Programme
CERF	Clean Energy Revolving Fund
COP	Conference of the Parties
CPO	Crude Palm Oil
CU	Chulalongkorn University
EE	Energy Efficiency
EEDP	Energy Efficiency Development Plan
ESP	Energy Support Programme
FAOSTAT	FAO Statistical Database (United Nations)
FFA	Free Fatty Acid
FFV	Flexible Fuel Vehicle
GDP	Gas Development Plan
GGGI	Global Green Growth Institute
GHG	Green House Gases
GIZ	Gesellschaft für Internationale Zusammenarbeit (Society for International Cooperation)
IEA	International Energy Agency
IRENA	The International Renewable Energy Agency
KMUTNB	King Mongkut's University of Technology North Bangkok
MTEC	National Metal and Materials Technology Center
NSTDA	National Science and Technology Development Agency
ODP	Oil Development Plan
ONEP	Office of Natural Resource and Environmental Policy and

	Planning
PDP	Power Development Plan
RBDPO	Refined Bleached Deodorized Palm Oil
REDP	Renewable Energy Development Plan
RES	Renewable Energy Scheme
TIEB	Thailand Integrated Energy Blueprint
TISTR	Thailand Institute of Scientific and Technological Research

1. Introduction

1.1. Background

Greenhouse gases (GHG) emissions from fossil fuels such as oil, coal and natural gas tempt to cause air pollution and harmful to the environment (A. Lappas and Heracleous. E., 2016). According to International Energy Agency (IEA) (2013), transportation sector was responsible for 23% of CO_2 emissions energy-related globally. Currently, the energy fuel resources mainly based on the non-renewable fuels and it faces the gradual depletion. On the other hand, renewable sources derived directly or indirectly from the sun and from other natural mechanisms, can be supplemented within a short time scale (Elum, 2017).

Liquid biofuel, one of renewable energy, has been investigated globally to mitigate CO_2 emissions from transportation sector. As demand of clean energy increases, biofuel is becoming more attractive since past decades. Biofuel contributes to reduce CO_2 emissions from vehicles on the grounds that the life cycle CO_2 emissions are generally lower than conventional fuels, gasoline and diesel (Cécile et al., 2011). According to Balat (2011), cellulosic bioethanol can be reduced 90% of GHG emissions to be compared with gasoline. In addition, cellulosic diesel can be reduced about 60~90% of GHG emissions to be compared with diesel based on the research (Pål Börjesson, 2013). Furthermore, it can be improved human health with reduced air pollution, and economic growth for rural area (Ben-Iwo et al., 2016).

Most of biofuel production currently, however, is based on the first generation biomass such as corn, sugarcane and cassava, palm oil and soybean, etc. It can be caused to increase the price of grain which is food resource. First generation biomass, in terms of food depletion in the future, it is inevitably lowered as a source of energy. Considering the amount of GHG emitted from the production of raw materials for biofuel, it can be found that has a negative effect on the environment. Furthermore, there are also challenges to overcome in this sector such as oil price fluctuation with different stakeholders, various risks, related government policy, infrastructure development and cooperation of private agencies and institutions (Ministry of Energy, 2016).

To overcome the drawbacks of first generation biofuels, non-food crops such as cellulosic biomass (second generation biomass) should be utilized as energy crops. It will be an effective way to use agricultural residues such as straws, bagasse from various fruits and grains. There is a need for estimating potential regarding the barriers to increased biofuel production from second generation biomass. To support this industry, the investment about tax incentives, national target, promotion and R&D should be needed to convert to second generation-based system from first generation-based system.

1.2. Purpose of Study

Thailand is a major biofuel producer country in Asia and have high potential of both bioethanol and biodiesel. Thailand was the first country in Asia to regulate national policies. In 2000 and 2001, the Thai government signed cabinet resolutions (An official decision made by the group of government ministers who make and approve government policy) to promote biofuel industry. The government set the goal for renewable energy to be at least 8% of the total energy consumption by 2011, of which 1.9% was targeted to be the contribution from biofuel (Bloyd, 2017). Furthermore, Thailand has well-organized funding (subsidies) programs that can be provide lessons to learn for other biofuel producer countries. It is necessary to focus on renewable energy for economic growth since Thailand heavily relies on energy import. As a biggest biofuel producer in Southeast Asia, Thai government actively promotes domestic production of biofuels (Metthew and Aung, 2018). As a result, it is increased farmers' income by producing biofuels of higher market value than conventional agricultural products.

The technology improvements and market status changes, however, are occurred many new opportunities and challenges over recent years. It is needed to be updated of the feasibility of commercializing biofuel in Thailand. This is important to look over various programs in biofuel sector to analyze overall status of planning instruments before estimating biofuel potential in Thailand. It helps to found the result more comprehensive and informative.

Previous researches are usually used same extraction rate (20%) to calculate biofuel potentially produced. However, since the extraction rate depends on the status of resource utilization by countries, it will be a feasible research if the same value is applied. Therefore, in this paper, three scenarios had been selected to measure the future potential of biofuels by applying various extraction rates. This assessment is crucial for the following reasons: 1) it can be expected the amount of GHG reduction and the economic benefits to be achieved by calculating the actual production of second generation biofuel; 2) it would motivated Thai government and biofuel suppliers to develop second generation biofuel; 3) it helps to utilize the use of the residues (second generation biomass) from first generation biomass more efficiently.

This study aims to reduce such a gap between past and current status, and provide a comprehensive view on biofuel development in Thailand. The aspects of policy instruments (economic instruments, regulatory instruments, planning instruments) are covered to understand overall status of biofuel industry in Thailand. It will assist in the development of relevant policy incentives and regulations for this country as they can expect the second generation biofuel production at any extraction rates. In addition, this paper investigates and quantifies the potential availability of agricultural residues in Thailand. It is measured the cellulosic ethanol technical process and Fishcer-Tropsch diesel from those residues. Cellulosic ethanol technical process requires pretreatment step to break down the cellulosic material into sugars which is an additional step compared to typical ethanol process. Fischer-Tropsch (BTL process, Biomass-to-Liquids is a multi-step process to produce liquid biofuels from biomass) which is a chemical reactions that converts a mixture of carbon monoxide and hydrogen into liquid hydrocarbons. It comprises gasification of biomass feedstock, cleaning and conditioning of the produced synthesis gas, and subsequent synthesis to liquid biodiesel (Lappas and Heracleous, 2016). For the potential, it is divided to two categories as the environmental view and the economical view based on the production potential.

This paper describes the current status of biofuel production and consumption in Thailand and research design for this study in the following two sections. Subsequently, the policy instruments and future potential of second generation biofuel production are estimated and it is concluded in the section 6.

2. Contextual Background

2.1. Biofuel Classification

Biofuel can be classified into primary resources and secondary resources (Vaibhav, 2015). Such as wood chips, pellets and fire wood are belongs to Primary resources. In addition, secondary resources are categorized into first generation, second generation and third generation.

Figure 1 presents biofuel classification and pros and cons of secondary resources. First generation biofuel is called as food crops or food sources based biofuel. Fermenting sugars extracted starch from those crops and produced ethanol the most well-known first generation biofuel. It is typically derived from sources such as starch, sugar, vegetative oil and animal fats, etc. It is measured lower CO_2 equivalents compared to conventional gasoline and diesel because of the characteristic of carbon neutral (Cécile et al., 2011). In addition, it has a wide range of materials and less harmful carbon such as carbon monoxide, tetrahydrocannabinol and significant reduction of Particulate Matter (PM) emissions which affects the air pollution. First generation biofuel has cost competitive to fossil fuels and used familiar feedstock, however, can be controversial because it is made from food source and caused to increase the cost of feedstock price. Furthermore, first generation biomass is extremely linked to the efficient cultivation of the feedstocks as they require land, water, fertilizer, and other materials which may eventually affects environmental pollution (Keat and Ofori- Boateng, 2013).

On the other hand, second generation biomass which includes cellulosic biomass and agricultural residues among others is less controversial. It can be also utilized for the surplus feedstock supply and has less dependence on land use. In contrast, second generation biomass has disadvantages that it has high cost to take a pretreatment process which is not included on first generation biomass feedstock process. Also, it is still in the pilot stage in the most of countries in the world.

Finally, oleaginous microbes, microalgae, bacterium, yeast and fungi are belong to third generation biomass. It has no conflict with food or land usage and higher growth rate tendencies. In addition, it has high cell lipid accumulation and can be needed for inputs carbon dioxide (CO_2) for growing (Wai-Hong Leong, et al., 2018). However, it has not only the high capital cost but limitations on technology.

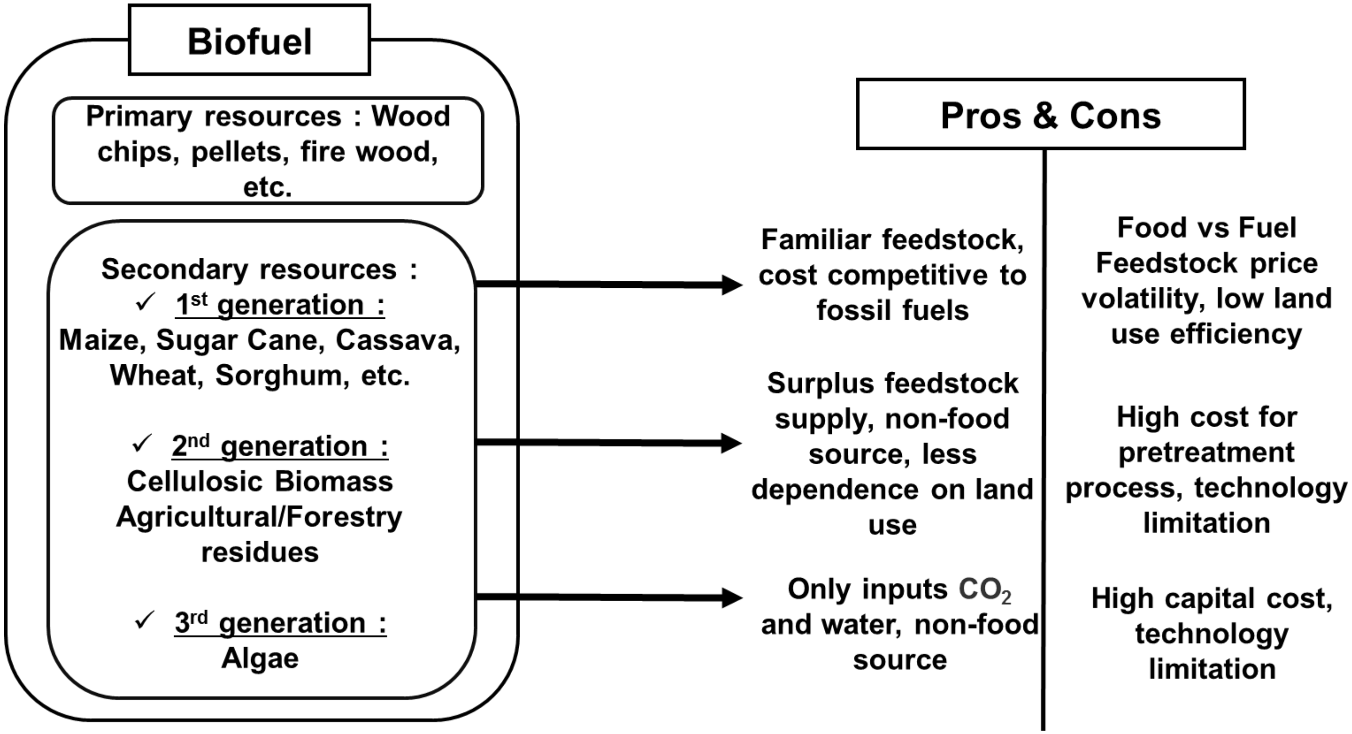


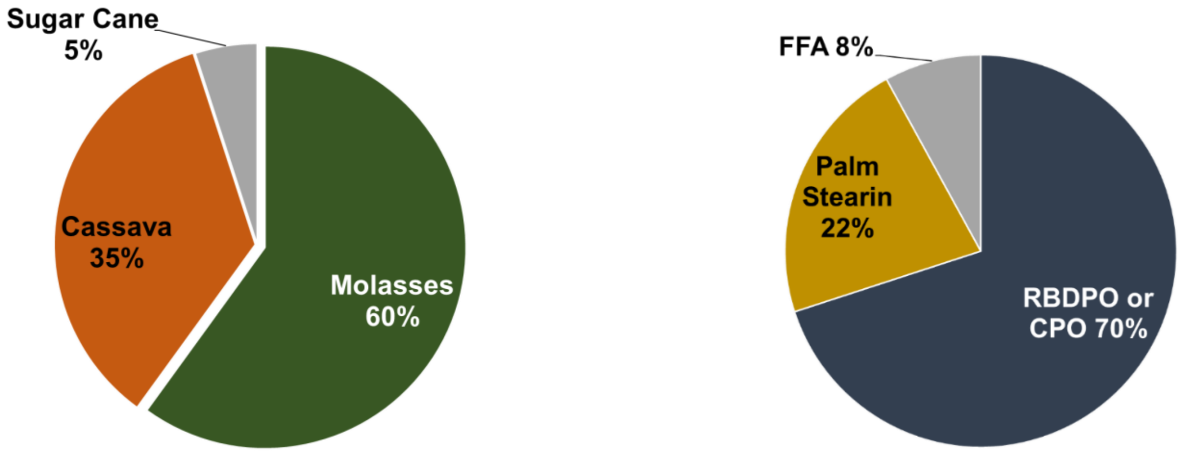
Figure 1. Biofuel classification and its pros and cons

2.1.1. First and second generation biomass price and feedstocks in Thailand

Thailand began bioethanol production since 2003 using sugarcane molasses and cassava starch as feedstock. Figure 2 shows the percentage of feedstock use for bioethanol and biodiesel. Molasses which is a product from refining sugarcane take the largest part (60%) among other feedstock and followed by cassava (35%) and sugarcane (5%). In the case of biodiesel feedstock, CPO or RBDPO (70%) take the largest using rate and followed by Palm stearin (22%) and FFA (8%). For the feedstocks of bioethanol production in Thailand, there are sugar cane, molasses (viscous product resulting from refining sugar cane or sugar beets into sugar. It varies by amount of sugar, method of extraction, and age of plant. Sugar cane molasses is primarily used for sweetening and flavoring foods in the United States, Canada, and elsewhere. Also, molasses is defining component of fine commercial brown sugar) and cassava, whereas RBDPO (Refined Bleached Deodorized Palm Oil), CPO (Crude Palm Oil), Palm stearin and FFA (Free Fatty Acids of Palm Oil) are used for biodiesel production. FFA is produced by the hydrolysis of oils and fats. Since FFA is less stable than neutral oil, they are more prone to oxidation and to turning rancid. Thus, FFA is a key feature linked with the quality and commercial value of oils and fats.

The production cost of biofuel mainly consists of feedstock cost, facility depreciation cost, operation cost and labor cost, etc (Hao, 2018). It is hard to expect the fluctuation of price each year because of some problem such as nature factor, weather, supply and demand problem, energy security issues. These are the reason why second generation biofuel should be developed and gradually substituted from first generation biofuel. The production of bioethanol in Thailand increased steadily over the past decade and the actual scale, however, is far lower than previously expected. This can be mostly due to the price variability of feedstock for producing biofuel. In addition, first generation biomass biofuel is more expensive to produce than fossil fuel (Dainis, 2014) and it conflicts with food supply and less suitable for use in low temperatures (ex. palm oil solidifies when the conditions below 24 Celsius degree).

On the other hand, second generation biomass has low fluctuation of its price to compare with first generation biomass. Figure 3 describes the price variation of rice (first generation biomass) and rice straw (second generation biomass) at maximum and minimum cost during 2011 and 2016. Maximum price of rice in 2011 was at 335 USD and lowest price was at 228 USD in 2016. On the other hand, rice straw has low fluctuation of its price to compare with rice. The maximum price of rice straw is about 35 USD/tonne and minimum price is about 20 USD/tonne. Unlike rice prices which differ by a difference of about 110 USD/tonne from the highest price and lowest price, about 20 USD/tonne differences of rice straw. It is also much less expensive in the case of rice straw than rice crops.



(a) **(b)**

Figure 2. Percentage of feedstock use for bioethanol (a) and biodiesel (b) in Thailand

Source : GAIN, 2017

Note : RBDPO - Refined Bleached Deodorized Palm Oil, CPO – Crude Palm Oil,

FFA – Free Fatty Acid.

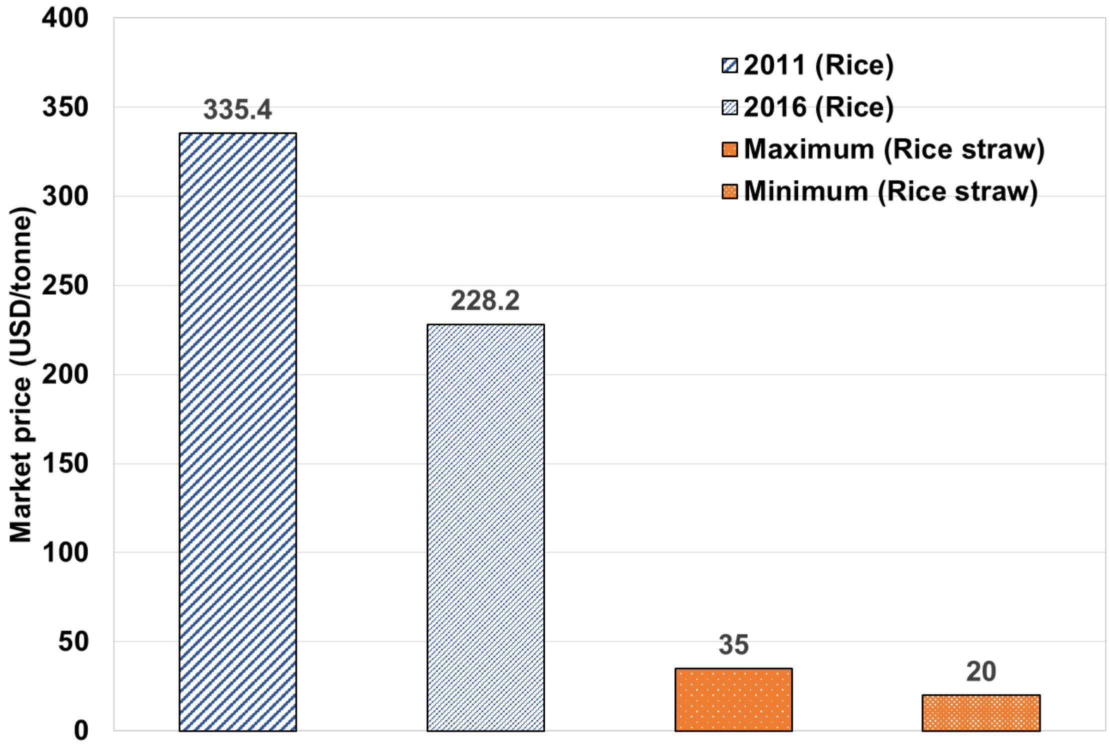


Figure 3. Producer price of rice and rice straw in Thailand

(Source : FAOSTAT)

2.2. Biofuel production trend in Thailand

Thailand consists of part of North and Northeast, Central and South (Figure 4). The north of the country is a mountainous area of the Thai highlands, and northeast part consists of the Khorat Plateau, bordered to the east by the Mekong River. In addition, the center of the country is dominated by the predominantly flat Chao Phraya river valley, which runs into gulf of Thailand. The most of regions excluding South part, have tropical savanna climate. On the other hand, the monsoon climate is dominant in South part, while some region in South part has equatorial climate.

Table 1 lists the number of bio-refineries and the nameplate capacity of both bioethanol and biodiesel. The number of bioethanol plants have been more than doubled in 2018 since 2009. The number of biodiesel plants, however, remained almost same refineries in 2018 compared to 2009. The location of these bio-refineries in Thailand is described on Figure 4. The number of bio-refineries for bioethanol has increased while that of biodiesel has remained constantly. The nameplate capacity of bioethanol is increased to 1,815 million liters in 2018 from 581 million liters in 2009 (Table 1). There was a sharp increase since 2013 to 1,307 million liters from 977 million liters in 2012. However, it has not been changed with great value in that case of biodiesel. The name plate capacity of biodiesel was reduced and 570 million liters for three years between 2012~2014, but increased again in 2015.

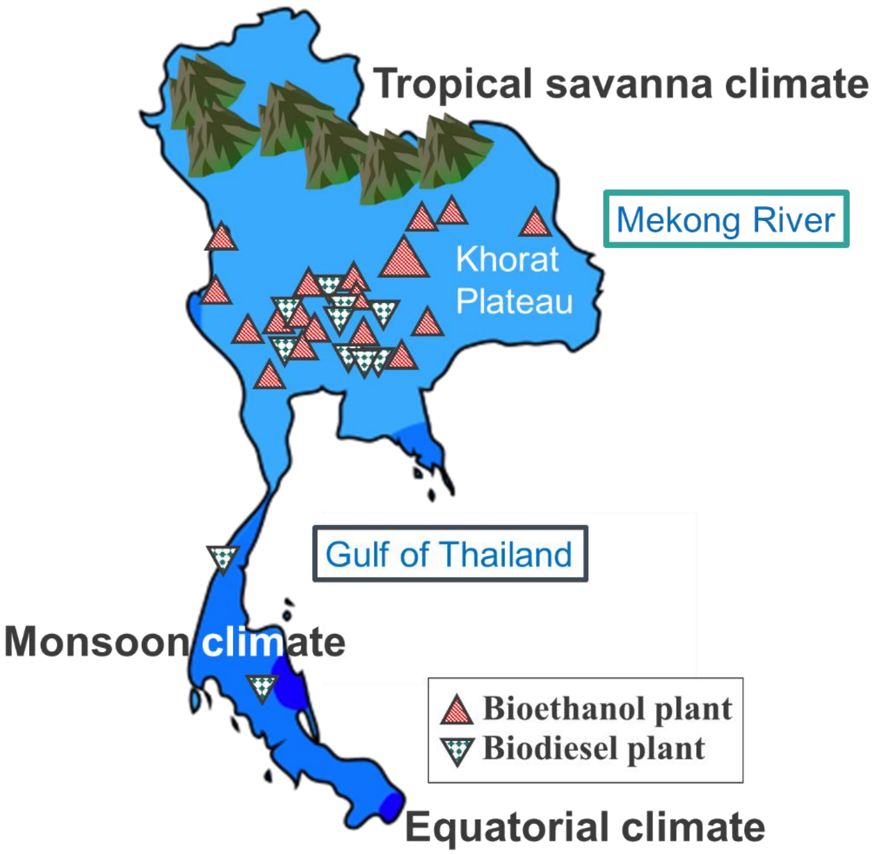


Figure 4. The location of biofuel plants in Thailand

Source: Ministry of Energy, 2015; Wikipedia, 2018

Table 1. Number of registered biofuel plants and nameplate capacity of biofuel in Thailand

Year	Bioethanol plants		Biodiesel plants	
	No. of bio-refineries	Nameplate Capacity (million liters/year)	No. of bio-refineries	Nameplate Capacity (million liters/year)
2009	11	581	13	2,170
2010	19	977	13	2,170
2011	19	977	13	2,170
2012	19	977	10	1,600
2013	21	1,307	10	1,600
2014	21	1,472	10	1,600
2015	21	1,472	12	2,060
2016	21	1,472	12	2,060
2017	23	1,815	12	2,060
2018	23	1,815	14	2,290

Source: GAIN, 2017

The case of biodiesel production, however, is based on trans-esterification of vegetable oils and fats including the addition of methanol and a catalyst, and it provides glycerol as a by-product. As a feedstock, palm oil, rapeseeds, sunflower seeds and soy beans are usually used. These oil seeds are extracted from chemical or mechanical process (OECD/IEA, 2007).

Figure 5 shows biofuel production and market penetration over the past decade in Thailand. It has been increased over the years except in 2012 for bioethanol and in 2011 for biodiesel, respectively. The production of bioethanol in 2013, however, rapidly increased to 1,048 million liters from 790 million liters. In the case of biodiesel, the production also sharply increased to 910 million liters in 2012 from 630 million liters in 2011. Biodiesel production was lower than that of bioethanol until 2012, whereas the production of bioethanol and biodiesel have been increased since 2013 and estimated at almost the same amount in 2018 as 1,500 million liters for bioethanol and 1,480 million liters for biodiesel. On the status of market penetration, biofuel used almost all the amount of produced while biodiesel used only half or less than that used. For example, bioethanol has been used almost all the production to the on-road transportation, on the other hand, biodiesel used only 60% out of total quantity. The other 20% for agriculture, 17% for industry, and the rest of 3% for the inland shipping. This is because the dominant vehicle in Thailand is motorcycle which use gasoline as fuel, not a car including Sport Utility Vehicle (SUV) which use diesel as fuel (ASEAN UP, 2019).

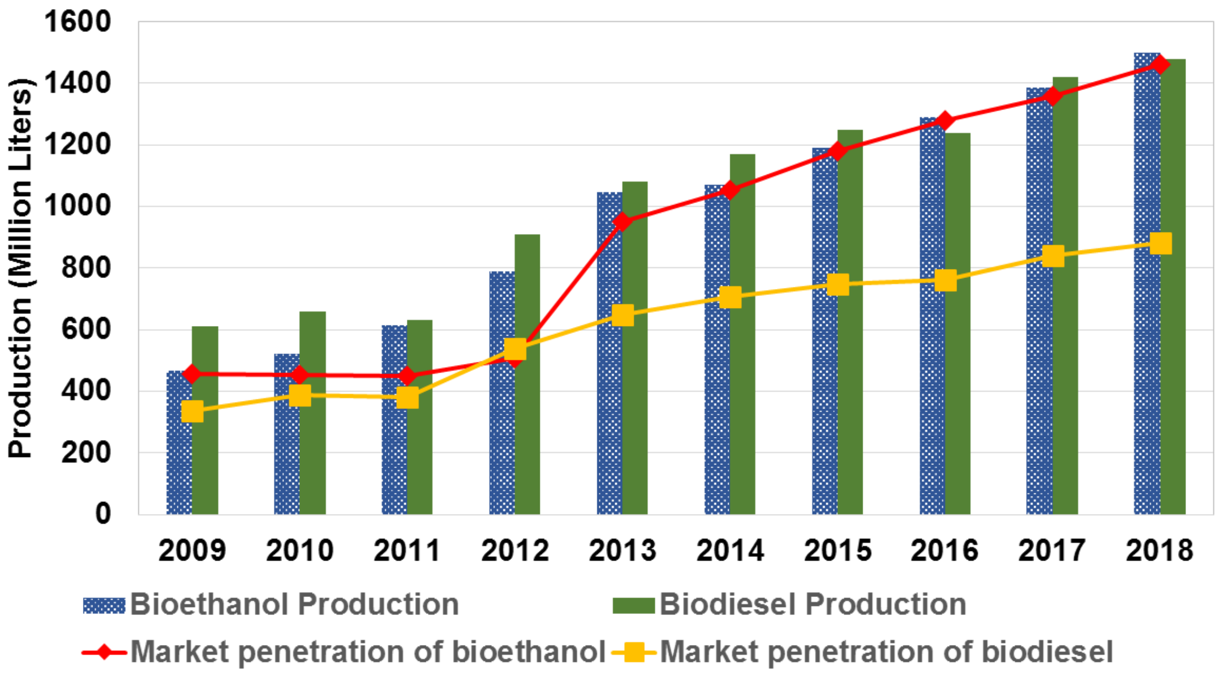


Figure 5. Biofuel production since past decade in Thailand

Source: GAIN, Department of Alternative Energy Development and Efficiency, Ministry of Energy

Note: The data for 2017, 2018 is an estimate

2.3. Biofuel consumption in Thailand

The demand of bioethanol and biodiesel is increased after the energy crisis which crude oil price rose above 140 USD/barrel (One of units of volume. 1 barrel (oil) = 42 US gallons = 159 liters) in 2008 in Thailand to replace oil imports. Subsequently, it was raised usage of ethanol from 1.3 million liters/day in 2012 to 2 million liters/day in 2013 (Ministry of Energy, 2016).

Table 2 presents biofuel consumption from 2009 to 2018. Both consumption of bioethanol and biodiesel have been increased in Thailand. The consumption of bioethanol, however, has a sharp increase between 2012 and 2013. Finally, it has increased 3.19% from 2.41% in 2018 compared to 2009 for the consumption of bioethanol and biodiesel, respectively.

Through these data, it can be seen that Thailand has a great market potential for biofuel industry. The discussion on the potential of biofuel supply in this country is of vital importance for planning biofuel industry.

Table 2. Biofuel consumption in Thailand

Year	Bioethanol (million liters)	Biodiesel (million liters)
2009	457	609
2010	453	646
2011	450	640
2012	509	890
2013	949	1,050
2014	1,053	1,180
2015	1,179	1,243
2016	1,280	1,233
2017	1,360	1,400
2018	1,460	1,470

Source: GAIN, 2017.

3. Research Design

In this section, policy instruments and three scenarios are collected and analyzed about biofuel status and future potential in Thailand.

Figure 6 illustrates the relations between policy instruments and estimation of potential in biofuel sector. Estimation of potential could be the one part of policy instruments. In other words, well-organized policy instruments will be supported biofuel development. Using the policy instruments, the biofuel industry could be investigated from various aspects (Economic, Regulation, Plans). These instruments make the result of potential estimation more informative and predictable of overall biofuel status in Thailand.

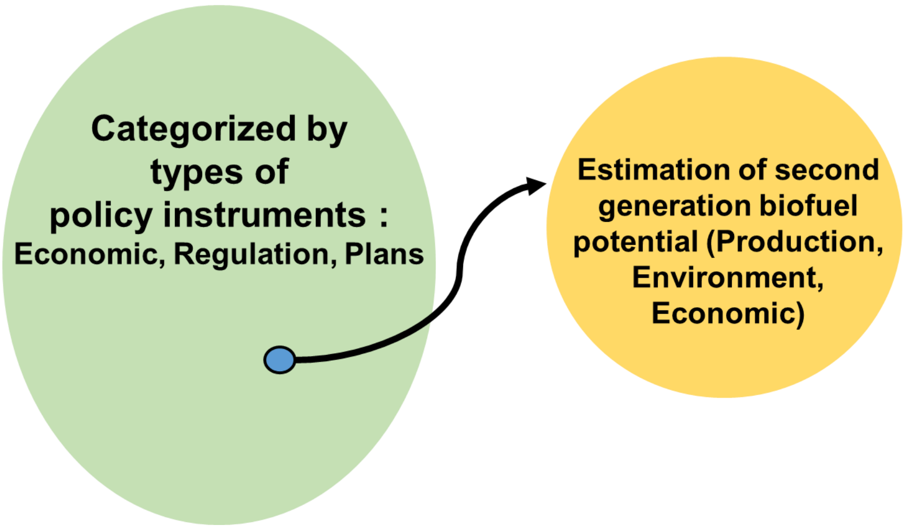


Figure 6. Relations between policy instruments and potential of the biofuel sector

3.1. Policy instruments

There are 4 types of policy instruments: 1) Economic instruments; 2) Regulatory instruments; 3) Planning instruments; 4) Informational instruments (Table 3). Economic instruments include subsidies, funds, taxes and grants. Regulatory instruments include regulations, decisions, laws and orders. Planning instruments include national plans, programs, actions, strategies and roadmaps. Last but not least, Informational instruments include forums, training, conferences, workshops and exhibitions. In this study, however, only 3 policy instruments are analyzed except Informational instruments.

Table 3 describes type of policy instruments on biofuel sector in Thailand. In this study, economic instruments, regulatory instruments and planning instruments had been selected to be analyzed Thai biofuel policy. Economic instrument includes grants and taxes and funding programs and regulatory instruments includes the laws and regulations, decisions, etc. Finally, planning instruments includes the contents of strategies, programs and actions. It is described precisely in the following parts (4.1., 4.2., 4.3.) about the details of each instruments.

This tool will make more effective to evaluate policies related biofuel industry in Thailand. Prior to identifying the potential of second generation biofuel in the next chapter, it is crucial to organize policy instruments by types. It can be found policy implication from the new point of view is taken into account in relation to the calculated biofuel potential.

Table 3. Types of policy instrument on biofuel sector in Thailand

Title of instruments	Contents
Economic instruments	Grants, taxes, and subsidies
Regulatory instruments	Laws, regulations, orders and decisions
Planning instruments	Strategies, programs, actions, and roadmaps
Informational instruments	National plans, programs, strategies, actions and roadmaps

Note : Informational instruments are excluded in this research.

3.2. Scenario construction

In this study, three scenarios to investigate the potential of second generation biofuel had been assumed (Figure 7). These scenarios are based on different rate of residue extraction. Herein, the extraction rate refers to the remaining percentage excluding the portion, for example, considering the possibility of being used for other purposes such as ecosystem function, nutrient recycling and animal feed, because it is practically impossible to utilize 100% of the predicted production (Ackom et al, 2013).

Scenario 1 and Scenario 2 are estimated with 20% of extraction rate, 44% of extraction rate, respectively. Last but not least, scenario 3 is measured at 66% of extraction rate for its residue. First scenario follows the other previous researches (Ackom et al, 2013; Kumar et al, 2013) set at 20% of extraction rate which reported in OECD/IEA (2010) for the extraction sustainably. According to Helwig (2002) and Lal (2008) the sustainable extraction rates from those residues, however, are affected by factors such as the type of soil and fertility, land slope, tillage, crop yield. In addition, the studies in Quebec, Canada showed the sustainable extraction rates had been applied between 44 to 64% (Ackom, 2013; Helwig et al., 2002). These rates are applied to scenario 2 and 3, respectively. Each extraction rate from agricultural residues, however, is reasonable average for bioenergy application (Ackom, 2013; Wood and Layzell, 2003).

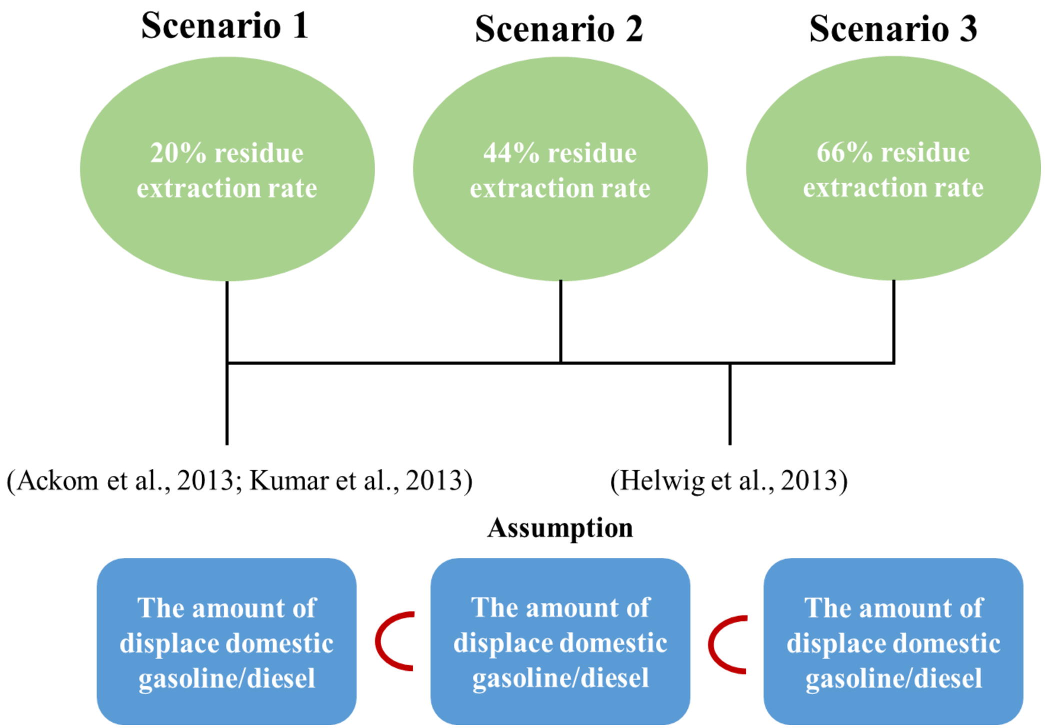


Figure 7. Summary of scenario 1, 2 and 3

4. Policy Instruments

4.1. Economic instruments

Thai government has been developed the bioethanol industry since 2000 after signed up for cabinet resolution, they started to develop biodiesel industry in 2001. They support for not only the tax exemption but price incentives for Flexible Fuel Vehicle (FFV, dual fuel vehicle that can use both bioethanol and gasoline) which compatible for E20 and E85 to promote biofuel industry. As a result, these subsidies have led to an increase in biofuel consumption in Thailand and make mandate 10 percent of ethanol mix with gasoline (get profit the gasohol sold per liter). In the case of biodiesel industry, the producers have received the subsidy of tax incentives for machinery from import duties and corporate income tax (Bloyd, 2017).

The State Oil Fund (SOF), the price subsidy, supports the gasohol price E10 and E20~E85 for 20~40 percent and 30~40 percent less expensive than premium gasoline. In addition, it supports the excise tax rate reduction for 3 percent of manufacturing of FFV which uses E85 gasohol. Through the SOF, the consumption of gasohol accounts for 95 percent of total gasoline consumption, especially for E20 and E85. Furthermore, it is increased the number of gasohol stations increased up to 3,396 stations for E20 and 1,000 stations for E85 in 2017 which accounts for 10 percent and 20 percent from the same period in 2016, respectively. It is expected that the consumption of bioethanol would be increased to 1.6 billion (7 percent increase from 2017) liters under this condition (GAIN, 2017). Furthermore, SOF promoted to continue to impose the mandate blending rate of biodiesel production to increase its consumption.

Table 4 (IRENA, 2018) describes donor programs about renewable energy in Thailand. Currently, there are seven programs as follow: 1) ASEAN – German Energy Programme (AGEP) – ASEAN Centre for Energyand GIZ, 2) The Energy and EnvironmentPartnership Mekong (EEP Mekong), Finland, 3) Energy Support Programme (ESP) – The Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ), 4) Country programs – Global Green Growth Institute (GGGI), 5) Office of Natural Resource and Environmental Policy and Planning (ONEP), 6) Berkeley Energy – Renewable Energy Asia Fund I (USD 112 million) and closing of the Renewable Energy Asia Fund II (REAF II) is pending, and 7) Nexus for Development and Pioneer Facility – Clean Energy Revolving Fund (CERF).

The donor programs, however, do not describe the information about detail of liquid biofuel. Those programs are usually about wide range of renewable energy section; hydro, wind, geothermal, solar, landfill gas and bioenergy. It can be expected that the new funding programs in the biofuel industry should be progressed in the future. It could be pursue biofuel suppliers to produce more by obtaining benefits from them. For example, according to Bloyd (2017), the sales of gasohol have continued to increase in 2017 compared to 2016 with the price incentives in this industry. Average sales of gasohol was 28.8 million liters per day as compared to 27.7 million liters per day in 2016. It is about 1.1 million liters increased per day.

Table 4. Donor programs about renewable energy in Thailand

Program	Major contents
ASEAN – German Energy Programme (AGEP) – ASEAN Centre for Energy and GIZ	In contribution to the ASEAN Plan of Action for Energy Cooperation 2016 – 2025, the overall objective of AGEP is the improvement of regional coordination for the promotion of renewable energy and energy efficiency towards sustainable energy for all ASEAN Member States.
The Energy and Environment Partnership Mekong (EEP Mekong), Finland	39 projects have been supported by providing partial grant-based funding to project developers for feasibility studies and pilot and demonstration projects in Cambodia, Lao PDR, Myanmar, Thailand and Viet Nam.
Energy Support Programme (ESP) – The Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ)	The ESP is supporting the Vietnamese government with a total budget of EUR 6,900,000 in the period 2014~2018. One aim is to encourage the development of wind energy in Viet Nam through technical assistance (in policy and regulation, capacity development, data collection, etc.). The GIZ also has renewable energy programs in Thailand and Indonesia.

Source: IRENA, 2018

(Continued-)

Program	Major contents
Country programs – Global Green Growth Institute (GGGI)	GGGI supports countries in developing their green growth plans. It also develops finance mechanisms and investment instruments in its member countries. It has active renewable energy programs in Indonesia, Viet Nam, Cambodia, Thailand, Lao PDR and Myanmar.
Office of Natural Resource and Environmental Policy and Planning (ONEP)	Renewable energy national financing agency
Berkeley Energy – Renewable Energy Asia Fund I (USD 112 million) and closing of the Renewable Energy Asia Fund II (REAF II) is pending	Invests in small hydro, wind, geothermal, solar, landfill gas and biomass projects in Asian markets, with a primary focus on the Southeast Asia region.
Nexus for Development and Pioneer Facility – Clean Energy Revolving Fund (CERF)	Funds renewable energy, and encourages an early shift away from fossil-fuel-based energy sources.

Source: IRENA, 2018

4.2. Regulatory instruments

Thailand has established blending mandate rate of biofuel since 2003 and 2007 for bioethanol and biodiesel, respectively. Some factors such as the trend of financial incentives and a shift of emphasis from first generation biomass to second generation biomass and also enduring plan affects when making the regulation. Above all, Thai government seems put a lot of efforts in promoting biofuel commercialization. The overall trend is a phasing out of demonstration program, cooperation with other agencies/institutions and financial incentives. Additionally, it is crucial that industry leaders and policy makers understand supportive small (infant) producers to support developing on a regional basis. It is unlikely that these regional markets would take advanced technology and get ready for the production globally.

The established biofuel national standard over the long term help to reduce capital cost for large and small plants (refiners) and benefit new suppliers in the biofuel industry (Pierre et al., 2010). Furthermore, it helps to develop products more specifically for the budget preparation for biofuel refining from a national perspective.

According to World Energy Council (Pierre et al., 2010), the national standard should fully be considered with sustainability of factors such as present local and regional specification and biodiversity losses in poor social condition. There are some factors as driver to pursuing use renewable energy instead of conventional energy in Thailand; 1) energy security, 2) energy diversification, 3) rural economic development, 4) GHG mitigation (Sims, 2010). Furthermore, sustainability is one of drivers based on the economic, social and environmental sustainability. For the development of biofuel industry (including entire bioenergy sector), sustainability criteria is the complex task which may have crucial implications. Both stakeholder involvement and broad-gauged consultation are essential for coherent and achievable outcome of the process. It can be found four criteria of sustainability on the Table 5: 1) Energy sustainability, 2) Social sustainability, 3) Economic sustainability, 4) Environmental sustainability. The energy sustainability is the provision of energy which fulfill the needs of the present without adjustment the ability of future generations to meet their needs. The social sustainability reflects how the production and use of biofuels in the transportation sector, including impacts of local development. It also includes land use rights and labor standards and safety issues. For the economic sustainability, it has a wide range of local, national and international level through different inputs and outputs. Finally, the environmental sustainability is related to various sectors including biodiversity, land conservation and water/soil preservation.

Table 5. Criteria of sustainability

Criteria	Contents
Energy sustainability	Provision of energy
Social sustainability	Reflection of production use of biofuel
Economic sustainability	Local, national and international level through different inputs and outputs
Environmental sustainability	Biodiversity, land conservation and water/soil preservation, etc.

Source: Pierre et al., 2010

Table 6 describes the mandate rate of biofuel in Thailand, Malaysia and Indonesia since 2009. It can be found Thailand has positive potential both bioethanol and biodiesel to compare with Malaysia and Indonesia. There is no blending rate of bioethanol in Malaysia and Indonesia because the lack of the bioethanol infrastructure and low motivation to utilize it (GAIN, 2017). However, the mandate rate of biodiesel is higher than Thailand since 2015 in Malaysia and 2016 in Indonesia. To be considered Malaysia and Indonesia are the biggest producer of palm oil (consist more than 90% of the world production), it is not a high blending mandate rate. Generally, the mandate rate of bioethanol is higher than that of biodiesel in Thailand. It was 6 percent blending (E6, 6% bioethanol and 94% gasoline. ex. - E00: 00% of bioethanol plus the other % of gasoline) in 2009 and end to 12 percent blending in 2018. There was a sharp increase between 2012 and 2013. The mandate rate of biodiesel steadily increased from 3.3 percent in 2009 to 6.1 percent in 2018. Biodiesel is mainly used in the form of B5 (B00: 00% of biodiesel plus the other % of diesel), a blending consisting 5 percent biodiesel in total diesel quantity. Biodiesel rate has steadily increased (except 2011, 2016), in the meanwhile that of bioethanol has no changed between 2009~2011 and 2013~2018. In addition, it was rapidly increased in 2013, compared to that of last year. According to Energy Efficiency Development Plan (EEDP) which derived demand for biodiesel use, is estimated to sustain annual growth of 2.5~2.7 percent from 2018~2022, and is then forecasted to slow to 1.5~2.0 percent after 2022. Thai government set B7 mandate blending, currently it has not reached due to the inadequate palm oil feed stock and import control. As get recovered in Crude Palm Oil (CPO) in Thailand, it will increased the mandate blend rate as 6.0 in 2017 (GAIN, 2017).

Thai government has been raised the domestic palm oil production and set the target to 1.63 million hectares by 2036 from 0.70 million hectares in 2015 to meet the demand goal. For the second generation biomass and third generation biofuel, TIEB 2015 set the biofuel target to meet 10 ktoe (kiloton of oil equivalent) by 2036 (GAIN, 2017). These related research is supported by Thai Universities (related contents are described in the section 4.3.). National standards are very important element for biofuel development. Goal development only occurs at the highest levels of planning. These goals may be national, state/territory and/or regional goals. Identifying goals is crucial step in guiding the development of transportation planning and initiatives.

In the transportation sector, it is crucial that identifying and select goals to develop for potential to contribute in the future. Because a lot of factors are affecting in this area. Some factors such as people are using different time at different places with different purpose, etc. are included. Thus, when the government set the goal, they have to take related factors such as the current status of economic and social and the environmental aspiration and the flow of global issues and risks into consideration when making regulations (Australian Transport, 2018). In addition, new regulations based on strong but sustainable standards to be built upon in the future (Ministry of Energy, 2016).

Table 6. Mandate blend rate of biofuel in Thailand, Malaysia and Indonesia

		2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Bioethanol	Thailand	6	6	6	7	12	12	12	12	12	12
(Unit: %)	Malaysia	0	0	0	0	0	0	0	0	0	0
	Indonesia	0	0	0	0	0	0	0	0	0	0
Biodiesel	Thailand	3.3	3.5	3.4	4.4	5.2	5.6	5.7	5.6	6.0	6.1
(Unit: %)	Malaysia	0	1	4.5	4.5	5	5	7	7	7	7
	Indonesia	0.2	0.8	1.1	2.2	3.5	5.6	3.2	10.2	9.2	8.7

Note: The data for 2017 and 2018 is an estimate

Source: GAIN, 2017 - Thailand, Malaysia, Indonesia

4.3. Planning instruments

The Ministry of Energy in Thailand is focusing on the development of alternative energy and renewable energy sources to secure new energy resources and provide inexpensive energy to citizens of Thailand (Heo and Choi, 2018).

Current national energy plan consists of TIEB (Thailand Integrated Energy Blueprint). It reflects the goals to be achieved in line with the National Economic and Social Development Plan between 2015 and 2036 (Ministry of Energy, 2016). The goals are administered based on the challenges of Energy Efficiency (EE) development and production capacity in practice. It is focused on that yield have economic benefit from commercialized technology development. This scenario is included with following six master plans (Table 7); 1) The Alternative Energy Development Plan (AEDP), 2) The Power Development Plan (PDP), 3) Energy Efficiency Development Plan (EEDP), 4) Oil Development Plan (ODP), 5) Gas Development Plan (GDP) and 6) REDP (Renewable Energy Development Plan). For the direction of the TIEB, it considers both domestic and international situations. In addition, the TIEB formed the basis for Thailand's commitments at the 2015 United Nations Climate Change Conference (COP 21, Conference of the Parties 21 held in Paris, France. 2015). The AEDP and REDP precisely mentioned about biofuel regulation. The contents that biofuel to increase from 7% of total fuel energy use in 2015 to 25% in 2036 is included on AEDP. Especially, REDP has detail goal of biofuel sector between these programs. It has a production goal of 9.0 million liters per day for bioethanol and 7.20 million liters per day for biodiesel by 2021.

As a result of the TIEB 2015, the AEDP (2012~2021) which is set to increase the share of renewable and alternative energy from 20 to 25% by 2021 is replaced with a new AEDP (2015~2036). While both AEDP 2012 and AEDP 2015 national target energy security and domestic economic development rather than the environmental protection, the revised AEDP 2015 is to extend plan year coverage from 10 years to 20 years and integrating all national energy plans (GAIN, 2017).

According to Ministry of Energy, the recent trend is moving to utilization of second generation biomass based energy from first generation biomass in the biofuel sector, globally. Currently, there are five institutions which taking research on second generation biofuel in Thailand (Figure 8). The National Science and Technology Development Agency (NSTDA), Thailand Institute of Scientific and Technological Research (TISTR), and King Mongkut's University of Technology North Bangkok (KMUTNB), Chulalongkorn Univiersity (CU) and the Natioanl Metal and Materials Technology Center (MTEC) had been working mainly on R&D (Ministry of Energy, 2016).

These five institutions have carried out basic research on biofuel production technology, maintaining the research environment, and supporting the development of the country's biofuels industry. These institutions play an important role on biofuel technology development in Thailand. Many of the researches, however, are in the initial stages and not ready for commercialization while first generation biofuel has been mastered for converting feedstock to liquid biofuel. Current research focuses on Cellulosic ethanol, Flexible Fuel Vehicle (vehicle which could be blended with ethanol

Table 7. Summary of TIEB's and REDP Objectives

Plans	Objectives
Alternative Energy Development Plan (AEDP)	Overall goal that 30% of total energy consumption from renewable energy by 2036. Biofuel to increase from 7% of total fuel energy use in 2015 to 25% in 2036.
Power Development Plan (PDP)	To improve electricity generation capacity to be sufficient with future consumption by taking cost, environmental impact and stability into account.
Energy Efficiency Development Plan (EEDP)	To decrease energy intensity to 30% of final energy consumption compared to 2010 by 2036.
Oil Development Plan (ODP)	Manage both petroleum consumption and provision to be at the optimal level, and hedge the external risks at the same time.
Gas Development Plan (GDP)	Natural gas usage management and provision to be sufficient with future demand.
REDP (Renewable Energy Development Plan)	- Bioethanol: 9.0 million liters per day by 2021. - Biodiesel: 7.20 million liters per day by 2021.

Source: Ministry of Energy, 2016

-and gasoline, FFV) conversion kit (It is not considered to be a type of ‘device’, as has been suggested by manufacturers. However, there is a certificate system from EPA (Environmental Protection Agency) before selling their kits) for bioethanol and Bio-hydrogenated diesel, Biomass to liquid, algae-based fuel for biodiesel. The production target for the second generation and third generation biofuels at 10 kilotonnes of oil equivalent (ktoe) is set by TIEB (2015) until 2036 (GAIN, 2017).

It is still lack of infrastructure and technology related to second generation and third generation biofuel. It is crucial to breakthrough technology process with high capability cost and less energy-efficient. To overcome this, it is needed an additional development of a new infrastructure for harvesting, transporting and storing and refining second generation and third generation biofuel for the commercialization in Thailand (Kumar et al., 2013).

The global cooperative efforts are significant for converting biofuels into the current energy system. It will proceed technology innovation of biofuel production and optimize the condition (Rodionova et al., 2017). Additionally, monitoring the large-scale demonstration program and investment in research about second generation biofuel will be needed. It could help with developing the sustainable management in the transportation sector (Patumsawad, 2011).

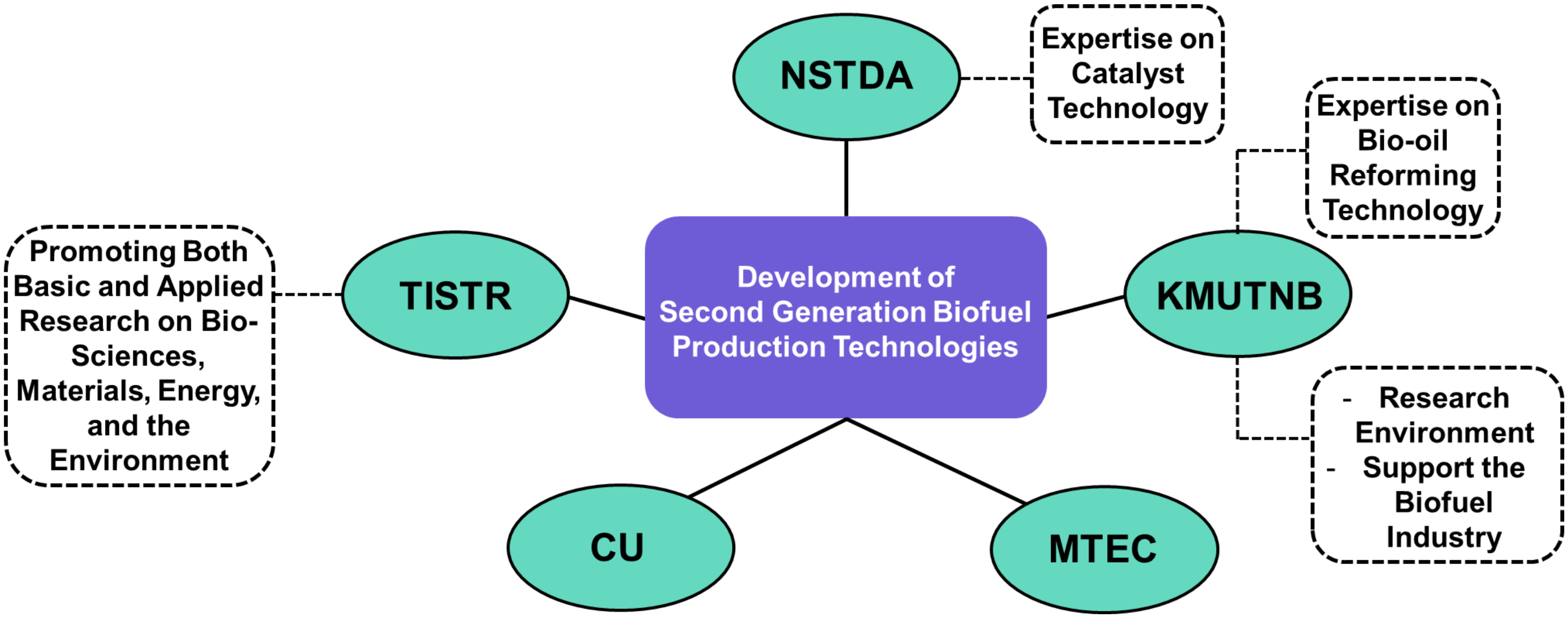


Figure 8. Summary of second generation biofuel projects and its contents in Thailand

Source: IEA 2010, Ministry of Energy 2016

5. Future Potential of Second Generation Biofuel

5.1. Production potential

Second generation biofuel technology is crucial for sustainable development for the future generations. In this study, it was assumed that bioethanol is produced through fermentation of sugars derived from the cellulose and hemicellulose fractions of lignocellulosic biomass. In the case of biodiesel, Fischer-Tropsch process is applied. It comprises gasification of biomass feedstock, cleaning and conditioning of the produced synthesis gas, and subsequent synthesis to liquid biodiesel.

The product potential of second generation biofuel in Thailand is estimated through Table 8 to Table 13. It is updated and modified of Kumar's study (2013) which the raw data of crop production based on year 2011. The raw data of crop production in this study, however, is used of year 2016 and the wheat as feedstock was not considered because of a significant low production to be compared with other crops.

It is estimated the potential following agricultural residues from agricultural crops and forestry residues; maize (*Zea mays*), rice (*Oryza sativa*), sorghum (*Sorghum biocolor*), sugarcane (*Saccharum officinarum*), coffee (*Coffea arabica*), coconut (*Cocos nucifera*) (Table 5). These crops are contributes to either bio-electricity or transport fuel. It is considered the technical potential for biofuel production of enzymatic hydrolysis and fermentation for bioethanol and thermochemical syngas to Fischer-Tropsch diesel for biodiesel (Kumar et al., 2013). The biofuel production based on three scenario is potentially available that approximately 9.08 million dry tonnes per year in scenario 1, 20.0 million dry tonnes per year in scenario 2 and 30.0 million dry tonnes per year in scenario 3 (Table 9).

The estimation is indicated that the production potential per year from agricultural residues are in the range of around 1.0~2.70 billion liters per year for bioethanol and 0.68~1.82 billion liters per year for biodiesel in scenario 1 (Table 10). In addition, it was estimated around 2.2~5.99 billion liters per year for bioethanol and 1.5~4.0 billion liters per year for biodiesel in scenario 2 (Table 11). Under scenario 3, it turns out 3.30~8.99 billion liters per year for bioethanol and 2.25~5.99 billion liters per year for biodiesel (Table 12). Herein, the conversion factors used from Sims's study (2010). In addition, this estimated values are comparable to Kumar's study with a potential of 1.14~3.12 billion liters per year (based on 20% residue extraction rate) and 0.8~2.1 billion liters per year both bioethanol and biodiesel, respectively. This is because, this study utilizes the latest data from 2017, unlike Kumar's study, which uses data from 2011 on gasoline consumption in Thailand. In addition, Kumar's study used the data only 100% of gasoline, while the rest of gasohol except ethanol proportion is applied as the amount of gasoline in this study based on the database of statistics from Ministry of Energy in Thailand. Also, the data such as heating value of each bioethanol and biodiesel and the conversion value has bit changed to toe unit from J (Joule) unit.

Table 13 describes the estimated biofuel potential in relation to Thailand's transport fuel consumption. The result shows that the estimated production of second generation bioethanol (by scenarios) can be possibly displace 7.19~19.62% of Thai national gasoline in scenario 1. It was compared with the year 2017 domestic gasoline consumption and the estimated 1.0~2.7

billion liters of ethanol per year is tantamount to 0.51×10^6~1.38×10^6 toe. For scenario 2, 15.83~43.17% of Thai national gasoline could be displace and is tantamount to 1.11×10^6~3.03×10^6 toe. In addition, it was estimated 23.74~64.75% could be displaced Thai national gasoline consumption. It is tantamount to 1.67×10^6~4.55×10^6 toe. The gasoline includes the consumption of 100% of gasoline and also including gasoline proportion only in total gasohol. For example, if the gasohol has 10% of ethanol mixing, the other 90% of gasoline for the calculation (currently, it has consumed 10, 20, 85% of ethanol blended with gasoline in Thailand).

It turns out, it can be potentially offset 4.07~10.86% of domestic diesel consumption in Thailand in scenario 1. This was estimated biodiesel per year is equivalent to 0.56×10^6–1.50×10^6 toe, and compared with the year 2017 national diesel consumption. Under scenario 2, it was estimated 1.23×10^6~3.29×10^6 toe and it possibly offset national diesel consumption about 8.96~23.89%. Also, it was estimated 1.85×10^6~4.94×10^6 toe and it could potentially displace the national diesel consumption around 13.44~35.84% in scenario 3. As a result, it can be found as extraction rate is higher, the reduction ratio of GHG emission will be decreased as estimated production of biofuel increased as it was assumed.

In the next section, the environmental potential and the economic potential in Thailand will be analyzed based on the production potential of second generation biofuel which is discussed.

Table 8. Estimated production by types of residues in Thailand

Agricultural Residues	Production (tonnes/ year)[a]	Residue Type	Residue to Product Ratio (RPR)[b]	Moisture Content (%)[b]	Residue (wet tonnes/ year)	Residue (dry tonnes/ year)
Maize	4.81×10^6	Stalk	1.5	15	7.22×10^6	6.14×10^6
Rice, paddy	2.52×10^7	Straw	1.5	15	3.78×10^7	3.21×10^7
Sugar cane	8.74×10^7	Bagasse	0.3	75	2.62×10^7	6.55×10^6
Sorghum	3.71×10^4	Stalk	2.62	15	9.72×10^4	8.26×10^4
Coffee	3.28×10^4	Husk	2.1	15	6.89×10^4	5.86×10^4
Coconut	8.15×10^5	Shell	0.6	10	4.89×10^5	4.40×10^5

[a] agricultural crop production based on year 2016 statistics information (FAOSTAT); [b] RPR and moisture content based on information in (IEA, 2010)

Table 9. Estimated extraction residues production by scenarios

Agricultural Residues	Residue, 20% Extraction (dry tonnes/year) (Scenario 1)	Residue, 44% Extraction (dry tonnes/year) (Scenario 2)	Residue, 66% Extraction (dry tonnes/year) (Scenario 3)
Maize	1.23×10^6	2.70×10^6	4.05×10^6
Rice, paddy	6.43×10^6	1.41×10^7	2.12×10^7
Sugar cane	1.31×10^6	2.88×10^6	4.33×10^6
Sorghum	1.65×10^4	3.64×10^4	5.45×10^4
Coffee	1.17×10^4	2.58×10^4	3.86×10^4
Coconut	8.80×10^4	1.94×10^5	2.91×10^5
Total	9.08×10^6	1.20×10^7	3.0×10^7

Table 10. Estimated potential of second generation biofuel in Thailand (Scenario 1)

Agricultural Residues	Cellulosic Bioethanol[a] (million liters/year)		Fischer-Tropsch Diesel[b] (million liters/year)	
	Low	**High**	**Low**	**High**
Maize	135	368	92.0	245
Rice, paddy	707	1,928	482	1,285
Sugar cane	144	393	98.3	262
Sorghum	1.82	4.96	1.24	3.31
Coffee	1.29	3.51	0.88	2.34
Coconut	9.68	26.4	6.60	17.6
Total	999	2,724	681	1,816

[a] low conversion factor of 110 1/dry t for biochemical enzymatic hydrolysis ethanol; high conversion factor of 300 l/dry t for biochemical enzymatic hydrolysis ethanol (Sims, 2010)

[b] low conversion factor of 75 l/dry t for thermochemical syngas-to-diesel (Fischer-Tropsch process) was applied. For high conversion factor, 200 l/dry t was applied (Sims, 2010).

Table 11. Estimated potential of second generation biofuel in Thailand (Scenario 2)

Agricultural Residues	Cellulosic Bioethanol (million liters/year)		Fischer-Tropsch Diesel (million liters/year)	
	Low	**High**	**Low**	**High**
Maize	297	810	202	540
Rice, paddy	1,555	4,241	1,060	2,827
Sugar cane	317	865	216	577
Sorghum	4.0	10.9	2.73	7.27
Coffee	2.83	7.73	1.93	5.15
Coconut	21.3	58.1	14.5	38.7
Total	2,197	5,993	1,498	3,995

Note : Biochemical ethanol and biomass to Fischer-Tropsch diesel are converted with the even calculation with scenario 1, 3.

Table 12. Estimated potential of second generation biofuel in Thailand (Scenario 3)

Agricultural Residues	Cellulosic Bioethanol (million liters/year)		Fischer-Tropsch Diesel (million liters/year)	
	Low	**High**	**Low**	**High**
Maize	445	1,214	304	810
Rice, paddy	2,333	6,362	1,590	4,241
Sugar cane	476	1,298	325	865
Sorghum	6.0	16.4	4.09	11.0
Coffee	4.25	11.6	2.90	7.73
Coconut	32.0	87.1	21.8	58.1
Total	3,296	8,989	2,247	5,993

Note : Biochemical ethanol and biomass to Fischer-Tropsch diesel are converted with the even calculation with scenario 1, 2.

Table 13. Estimated biofuel potential in relation to Thai transport fuel consumption

	Potential feedstock sustainably extracted (dry million tonnes/year)	Estimated bioethanol production (billion liters/year)	National gasoline consumption[a] (year 2017) (Mtoe)	Percentage of national gasoline consumption it could potentially offset[b]	Estimated biomass to F-T diesel production (billion liters/year)	National diesel consumption (year 2017) (Mtoe)	Percentage of national diesel consumption it could potentially offset[c]
Scenario 1	9.1	1.0~2.7	7.0	7.2~19.6%	0.7~1.8	13.8	4.1~10.9%
Scenario 2	20.0	2.2~6.0		15.8~43.2%	1.5~4.0		9.0 ~23.9%
Scenario 3	30.0	3.3~9.0		23.7~64.8%	2.3~6.0		13.4 ~35.8%

Note : the data used from FAOSTAT, Ministry of Energy (Thailand), [a] Total gasoline consumption excluding ethanol based on first generation biomass mixed with gasoline in the transportation sector. There are 10%, 20% and 85% of gasohol used in Thailand. Data from 2017 national gasoline/gasohol consumption in the transportation sector (Ministry of Energy). [b] It was calculated with the factors of average heating value of ethanol as 21.2 MJ/l. [c] The calculation was applied with the average heating value of biodiesel as 34.5 MJ/l. Plus, $1J = 23.88 \times 10^{-12}$

5.2. Environmental potential

The result of production potential in the previous section (5.1.), scenario 1 turns out about 7.2~19.6% (based on biochemical process) and 4.1~10.9% (based on Fischer-Tropsch process) can be possibly offset of national gasoline and diesel consumption in Thailand, respectively. In addition, it can be offset around 15.8~43.2%, 9.0~23.9% for gasoline and diesel in scenario 2, and 23.7~64.8%, 13.4~35.8% can be displaced in scenario 3. In this section, GHG emission of each scenario is estimated based on the production potential estimated.

According to Balat (2011), GHG emissions from second generation bioethanol is about one tenth (1/10) of gasoline (Figure 9). Also, it is about 60~90% of GHG reduction of second generation biodiesel compared to first generation biodiesel (Pål Börjesson, et al., 2013). So, the average value of 75% was applied in this study (Figure 10). Table 14 describes the expected quantity of decreased GHG emission each sector. As a result, 1.3~3.5 (a-c~b-d) mega tons of CO_2 in gasoline sector and around 1.4~3.8 (a'-c'~b'-d') mega tons of CO_2 in diesel sector were estimated to decreased in scenario 1. In scenario 2, it was expected 2.8~7.7 (a-c~b-d) mega tons of CO_2 and 3.2~8.4 (a'-c'~b'-d') mega tons of CO_2 for gasoline and diesel sector, respectively**.** Finally, it was expected to reduce 4.2~11.6 (a-c~b-d) mega tons of CO_2 in gasoline sector and 4.7~12.6 (a'-c'~b'-d') mega tons of CO_2 in diesel sector in scenario 3.

Table 14. Expected quantity of decreased GHG emissions in Thailand

	Gasoline sector (metric tons of CO_2)	Diesel sector (metric tons of CO_2)
Scenario 1	1,285,097~3,504,809	1,430,867~3,815,067
Scenario 2	2,827,212~7,710,576	3,146,867~8,392,800
Scenario 3	4,240,818~11,565,866	4,720,733~12,589,200

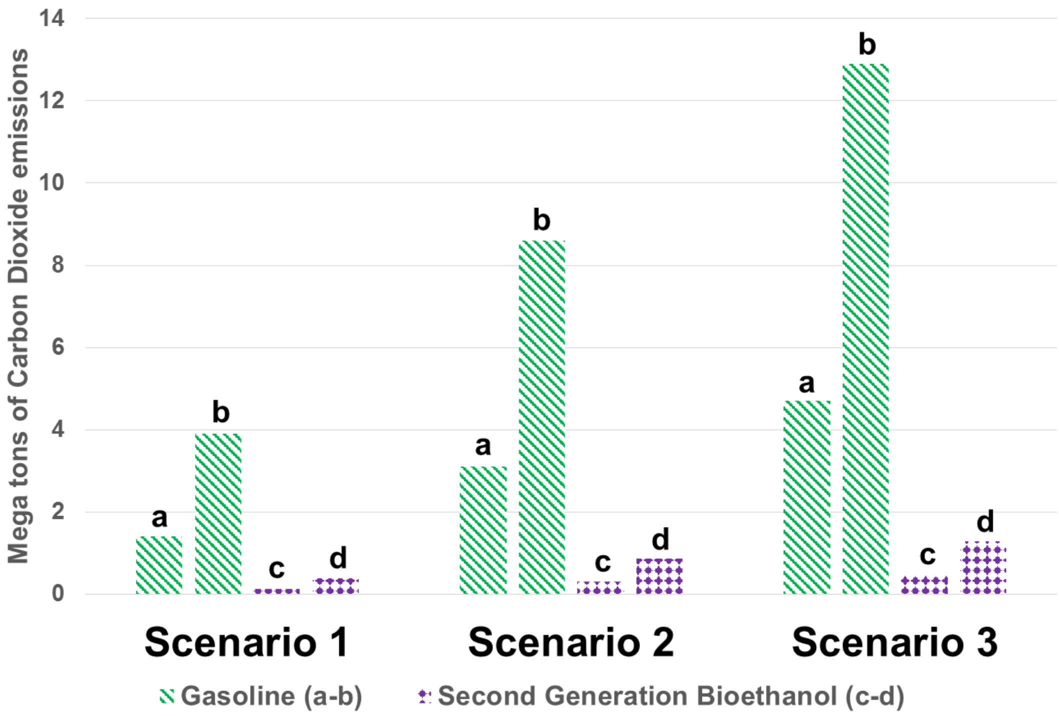


Figure 9. Comparison of scenario 1, 2 and 3 reduced amount CO_2 emissions (gasoline and bioethanol)

Note : (a, b) – Possible amount could be offset with bioethanol, original gasoline emission; (c, d) – Second Generation Bioethanol emission displaced by gasoline (Table 12); Carbon dioxide emission calculator – United States Environmental Protection Agency (EPA)

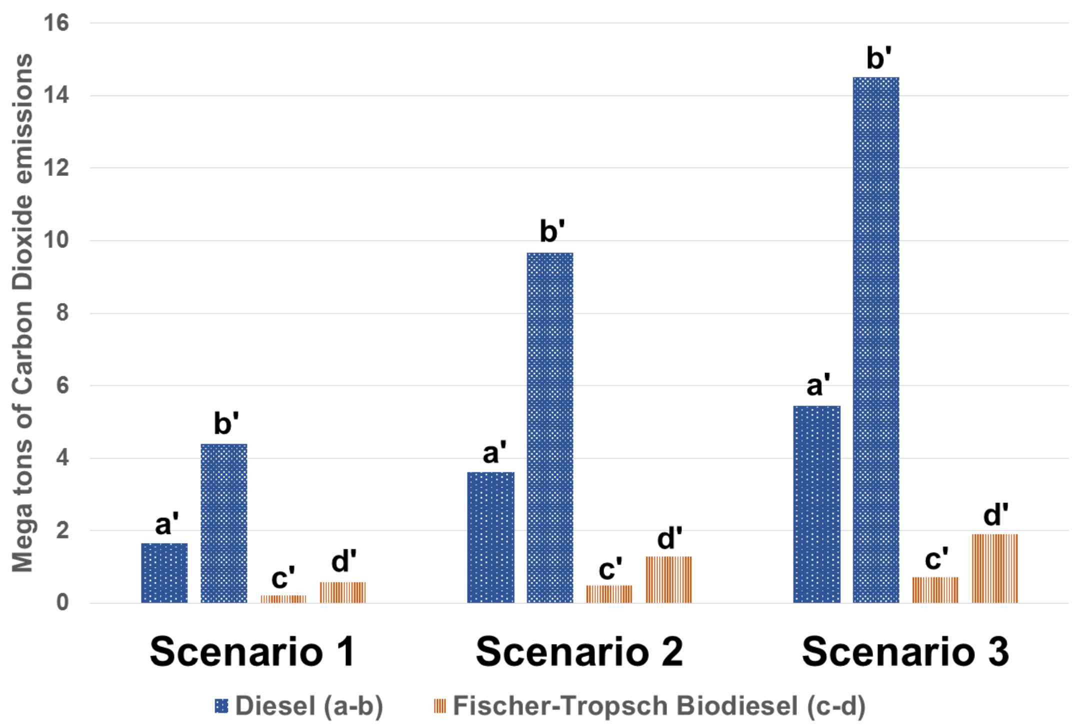


Figure 10. Comparison of scenario 1, 2 and 3 reduced amount CO_2 emissions (diesel and biodiesel)

Note : (a’, b’) – Possible amount could be offset with biodiesel, original diesel emission; (c’, d’) – Fischer-Tropsch Biodiesel emission displaced by diesel (Table 12); Carbon dioxide emission calculator – New Zealand Energy Efficiency and Conservation Authority (EECA)

5.3. Economical potential

In this section, economic profit will be estimated based on the decreased quantity of CO_2 emissions based on the previous section (5.2.). If these result can be seen the view of emission trading which is market-based approach to controlling pollution by providing economic incentives for achieving reductions in the emissions of pollution. For instance, companies can sell and buy from another company for the permits if there are unused permits. One company which excesses the CO_2 emissions buy permits from another company which have still leftover of the right of CO_2 emission allowances for the sale (Figure 11).

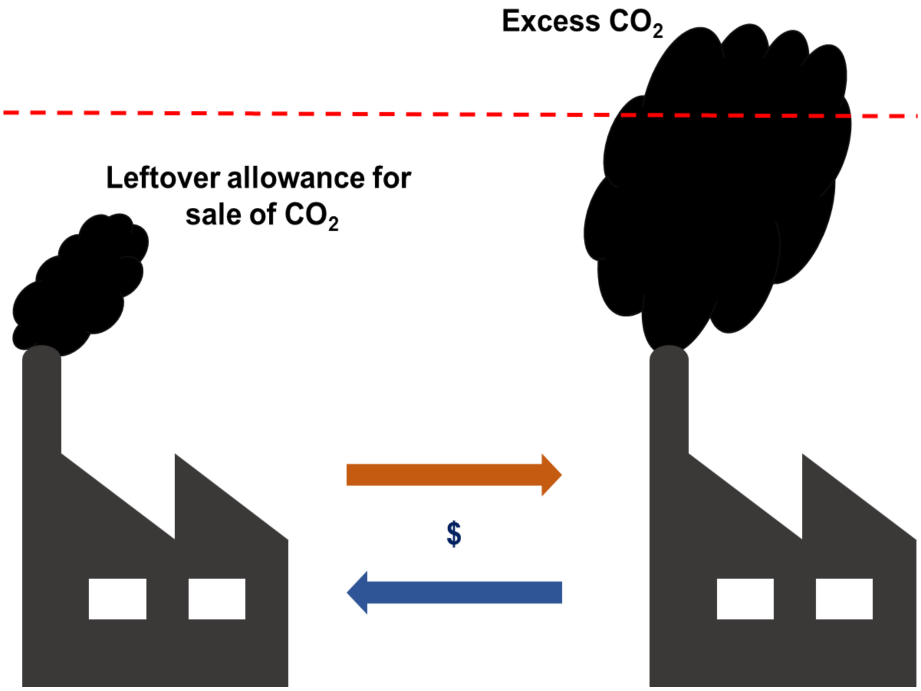


Figure 11. Emission trading scheme

It is expected to gain profits as follows (Table 15): 27~74 million USD for bioethanol sector, 30~81 million USD for biodiesel sector in scenario 1; 60~163 million USD for bioethanol sector, 67~178 million USD for biodiesel sector in scenario 2; 90~244 million USD for bioethanol sector, 100~267 million USD for biodiesel sector on scenario 3. It will be huge contribution to Thai economic, considered that GDP per capita in Thailand is about 6,593 USD (based on 2017).

Table 15. Economic effect on emission trading by scenarios

	Economical profits by sector (USD)	
	Gasoline	Diesel
Scenario 1	27,105,660~73,924,479	30,310,305~80,815,241
Scenario 2	59,632,410~162,633,790	66,660,641~177,786,185
Scenario 3	89,448,607~243,950,714	100,000,139 ~266,679,278

Note : CO_2 European Emission Allowances – 18.55 EUR per tonne of CO_2, 1 EUR = 1.14 USD (based on Dec.12.2018)

6. Discussion

Currently, the dependence on energy import is a serious issue in Thailand. Especially the pollution from transportation sector is a huge contributor. In this case, biofuel one of renewable energy will bring positive effect to substitute fossil fuels. It has not high fluctuation of price as typical gasoline and diesel have, so it can be found it has more stability even when the price spike of oil globally. If the feedstock is based on second generation biomass, that will make more stable of the raw material prices than that of first generation biomass (Section 2.1.1.).

Under current technology status, without financial incentives (Economic instruments), biofuel is less market-competitive than conventional feedstock (food crops) based biofuel products. The existing financial incentives have already investigated positive impacts on biofuel utilization, it can be expected optimized in the future. For example, with the current funding programs related to renewable energy, especially CERF encourages an early shift away from fossil fuel-based energy sources. It can be seen many funding programs are play an important role for developing biofuel industry in Thailand. In the long-run view, it should be supported continued for subsidy policies, even though the benefit is sometimes lower than expected. This is because, the optimal tax incentives should be more alternatives be offered to solve the energy problem.

Thai government should regulate the national standard with feasible blending mandate of biofuel (Regulatory instruments). The right regulation and policy system related to biofuel will give motivations to stakeholders, especially the biofuel producer company. In addition, that will be the way of promoting biofuel use for public. This regulation helps the policy makers have better control the total scale of biofuel consumption. Although, high blending rate seemed good, however, is more important to set the feasible rate of it. To be better, it should be expected with the enduring view from biofuel industry before set the plans. Also, it is crucial to regulate related policies such as energy standards plan and incentives for both producer and consumer.

On the planning instruments, TIEB and REDP are important to be set the enduring regulation and the target. It is not desirable to stick to one regulation even when it is not reasonable to fulfill. As mentioned in the section 4, AEDP has changed few times. Cooperating with private sectors and other agencies would affect positive impact. In Thailand, many institutions including universities are taking research about it with the available feedstock. However, those are still in the initial stage and not enough for commercialization. In this case, Thai government should supply incentives about research and development for second generation biofuel and also provide benefits of tax exemption when supplier produce biofuel or consumers use biofuel for their vehicles. The current market competiveness of second generation biofuels is relatively lower than that of first generation biofuel. However, it is expected that second generation biofuel will be gradually improved through technology innovation and production optimization.

For the second generation biofuel production potential, it was estimated at 1.0~2.7, 2.2~5.99, 3.30~8.99 billion liters per year for bioethanol and 0.68~1.82, 1.50~4.0, 2.25~5.99 billion liters per year for biodiesel each scenarios 1, 2 and 3. These possibly displaces conventional fuel at 7.19~19.62, 15.83~43.17, 23.74~64.75 percent for bioethanol sector and 4.07~10.86, 8.96~23.89, 13.44~35.84 percent for biodiesel sector in each scenarios 1, 2 and 3.

The environmental potential and economic potential are estimated based on production potential of second generation biofuel. For the environmental potential, it turns out scenario 1 would be reduced about 1.3~3.5 mega tonnes of CO_2 for gasoline sector and 1.4~3.8 mega tonnes of CO_2 for diesel sector. Also, it was measured about 2.8~7.7, 3.2~8.4 mega tonnes of CO_2 for gasoline and diesel sector in scenario 2 and 4.2~11.6, 4.7~12.6 mega tonnes of CO_2 for gasoline and diesel sector in scenario 3.

In the case of the economic potential, it was expected to get profits through emission trading about 27~74 and 30~81 million USD in scenario 1, 60~163, 67~178 million USD in scenario 2 and 90~244, 100~267 million USD in scenario 3 for gasoline and diesel sector, respectively.

7. Conclusion

Biofuels are not something that only exists in laboratories, but they are alternative fuels used in reality. Thailand is a country with great potential to grow biofuel industry.

In this study, the policy initiatives had been categorized by instrument types and future potential of second generation biofuel was measured by different extraction rates. It is crucial to have strong motivation, public awareness towards utilizing biofuel to larger groups of the population for conserving environment and developing new energy.

According to the economic instruments, it can be found Thailand has SOF and international donor programs to support biofuel industry. On the regulatory instruments, it turns out national standards are 12% for bioethanol and 6.1% for biodiesel in 2018. There are various programs to develop biofuel in Thailand has been invested to copy with the environmental issues. Integrated program TIEB includes AEDP, PDP, EEDP, ODP, GDP and REDP. Those programs are usually aims to regulate goal of renewable energy sector, gas and oil, etc. Especially REDP set a goal for biofuel production which based on first generation biomass. For the second generation biofuel development, five institutions are taking researches; 1) NSTDA, 2) KMUTNB, 3) MTEC, 4) CU and 5) TISTR. Second generation biofuel in Thailand is still at the pilot plant and it is expected to needed the cooperation with other agencies and subsidies from Thai government. In addition, the global cooperative efforts are significant to continue technology innovation of biofuel production and improve its quality. It was expected that monitoring for the large-scale demonstration program and investment would be needed. It could help to be achieved the goal with sustainable management on the transportation sector.

Future potential of second generation biofuel was measured by different extraction rates. It is crucial to have strong motivation, public awareness towards utilizing biofuel to larger groups of the population for conserving environment and developing new energy. Therefore, biofuel from agricultural residues are vital factor to meet such a goal. In addition, this study is distinguished with those previous studies; Ackom et al., 2013; Kumar et al., 2013 with three scenarios related to the potential use of agricultural residues for biofuel production in Thailand. As considered second generation biomass potential under three scenarios with different extraction rates - scenario 1 (20%), scenario 2 (44%) and scenario 3 (66%), could possibly offset national consumption of gasoline and diesel. It is estimated that as much amount of residues are extracted, it could be contribute with higher rate of biofuel production and it makes reduce GHG emissions get more economical profits. To summarize, this energy diversification such as fuel production from agricultural residues, will continue to bring both the environmental and the economic benefits to the country.

This study has filled some data gaps with the current plans and strategies for biofuel utilization by types of programs and the potential availability of agricultural residues for liquid biofuel applications in Thailand. Through these efforts, the goal of sustainability in transportation sector would be achieved with the diversification of agricultural residue. It should be required to carry out to break down existing barriers of second generation biofuel and considerably more investment in R&D in this sector.

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Abstract (Korean)

국 문 초 록

태국에서의 액체 바이오연료의 미래 잠재력과 정책 시사점에 관한 연구

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허수정

본 연구는 바이오연료 관련 정책 수단을 통하여 태국에서의 보조금 정책, 다양한 국가 기준 및 전략을 파악하고자 하였으며, 농업과 임업부산물을 원료로 사용하는 2세대 바이오연료 개발을 위한 R&D 현황에 대해 분석하였다. 이러한 분석을 바탕으로 환경적, 경제적 관점에서의 2세대 바이오연료 잠재력을 측정하고자 하였다.

태국은 2003년부터 바이오연료 의무 혼합률을 제정한 국가로써, 그 비율은 2018년에 바이오에탄올 12%, 바이오디젤 6.1%를 기준으로 하고 있다. 태국의 State Oil Fund (SOF)와 Clean Energy Revolving Fund (CERF)는 대표적인 국가 펀드로서, 수년 간 바이오 연료 산업에 긍정적인 영향을 미쳤다. Thailand Integrated Energy Blueprint (TIEB)

라는 통합 프로그램은 Alternative Energy Development Plan (AEDP), Power Development Plan (PDP), Energy Efficiency Development Plan (EEDP), Oil Development Plan (ODP), Gas Development Plan (GDP), Renewable Energy Development Plan (REDP)의 6가지를 포함하고 있다. 이러한 프로그램에서는 대체로 재생에너지 활용 목표를 설정하고 바이오연료의 사용을 증가시키기 위한 구체적인 계획을 확인 할 수 있었다.

잠재력 파악을 위한 시나리오는 각각 잔여물의 추출률을 다르게 설정하여 비교되었다- 시나리오 1 (추출률 20%), 시나리오 2 (추출률 44%), 시나리오 3 (추출률 66%). 결과로써 시나리오 1은 바이오에탄올 10~27억 리터/일과 바이오디젤 7~18억 리터/일을 생산하는 것으로 계산되었으며, 시나리오 2는 22~60억 리터/일의 바이오에탄올과 15~40억 리터/일의 바이오디젤을, 시나리오 3에서는 33~90억 리터/일의 바이오에탄올과 23~60억 리터/일의 바이오디젤을 생산하는 것으로 나타났다. 이는, 환경적 측면으로 보았을 때, 시나리오 1은 태국 내 가솔린 및 디젤 소비량의 각각 7.2~19.6% 및 4.1~10.9% 상쇄할 수 있는 것으로 판단되었다. 또한, 시나리오 2에서는 가솔린과 디젤 부문에서 각각 15.8~43.2% 및 9.0~23.9%의 비율로 추정되었으며, 시나리오 3에서는 각각 23.7~64.8% 및 13.4~35.8%로 측정하였다.

탄소배출권을 통해 얻을 수 있는 경제적인 잠재력을 계산해 보았을 때 시나리오 1에서는 바이오에탄올 영역에서 2,700~7,400만 달러(미국 달러)와 바이오디젤 영역에서 3,000~8,100만 달러의 이익을 창출 할 수 있는 것으로 나타났다. 또한, 시나리오 2의 경우 바이오에탄올 영역에서

6,000~16,300 만 달러, 바이오디젤 영역에서 6,700~17,800 만 달러를, 시나리오 3의 경우 바이오에탄올 영역에서 9,000~24,400만 달러와 바이오디젤 영역에서 10,000~26,700만 달러의 이익을 창출하게 되는 것으로 판단하였다.

결과적으로, 태국에서 2세대 바이오매스를 활용한 바이오연료 생산은 환경적인 잠재력과 경제적인 잠재력 모두에서 긍정적인 영향을 미칠 것으로 판단하였다.

주요어: 바이오연료, 바이오에탄올, 바이오디젤, 정책 수단, 생산량 잠재력, 환경적 잠재력, 경제적 잠재력, 태국.

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