Chapter 3

Supply Potential of Next Generation Biofuels from Non-Conventional Resources

November 2020

This chapter should be cited as

ERIA (2020), ‘Supply Potential of Next Generation Biofuels from Non-Conventional Resources’, in Toba et al. (eds.), *Evaluation of CO2 Emissions Reduction by Mobility Electrification and Alternative Biofuel Introduction in East Asia Summit Countries.* ERIA Research Project Report FY2020 no. 15, Jakarta: ERIA, pp.86-114.

Chapter 3

Supply Potential of Next-Generation Biofuels from Non-Conventional Resources

1. Non-Conventional Biomass as Feedstock for Transportation Fuel Potential for Indonesia

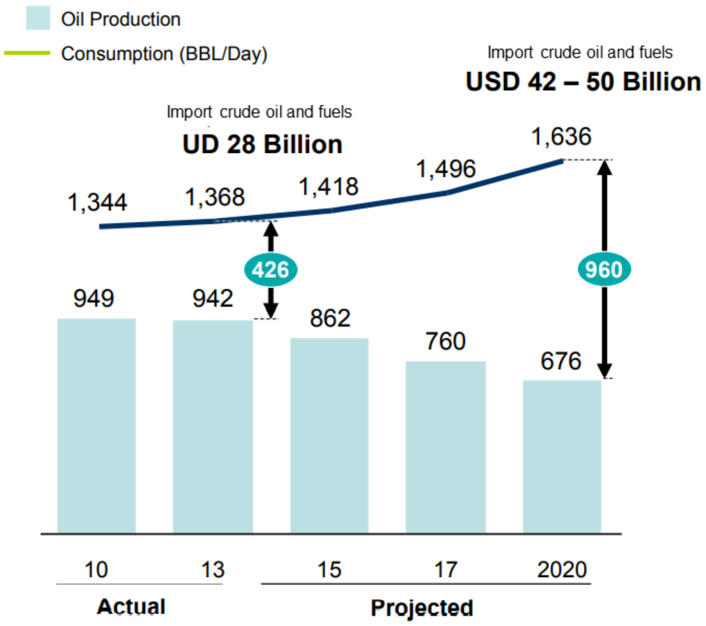
Background of Renewable Energy Sector of Indonesia

Being a densely populated country (237.4 million people) with an annual gross domestic product of US$878.3 billion in 2014 (BPS, 2015). Indonesia is set to be the largest consumer market in Southeast Asia, a member of the Group of 20, and has a growing and solid industry. Its sustained economic growth of 5–6% for the past 10 years has put pressure on the energy offer and environmental issues. Implementing sustainable bioenergy solutions, particularly from biomass, can overcome bottlenecks to economic growth whilst mitigating climate change impacts.

In addition to being rich in fossil energy, Indonesia's renewable energy sources are also considerable. Overall energy consumption in 2017 including biomass, was 1.23 billion barrels of oil equivalent (Boe), whilst the final commercial energy consumption was 927 million Boe (Center for Data and Information Technology, 2017). The use of traditional biomass, however, is prevalent for basic cooking and thermal purposes amongst millions of rural households in Indonesia. The share of final commercial energy consumption is divided into the sectors of industry (29.86%), households (15.45%), transport (46.58%), commercial use (5.43 %), and other sectors (2.68%). Although the industry sector previously was a major energy-consuming sector, the transport sector has overtaken to be the largest energy consumer since 2012.

The national fossil-fuel balance, however, does not fare well as fuel products and crude oil are imported (Figure 3.1). Oil production will reduce significantly, whilst product demand is increasing at 4–5% per year. Indonesia's fuel import could reach 1 million barrels/day in 2020. The inadequate oil refinery capacity has exacerbated the situation. These have contributed to the rapid increase of the national current account deficit. It is important, therefore, to explore other means to facilitate mobility for the people or alternative renewable fuel to substitute fossil fuel. Several alternatives are readily available including the use of electric mobility and utilising biofuels, particularly from non-conventional biomass.

Figure 3.1. Actual and Projected Domestic Crude Oil Production and Fuel Products Consumption

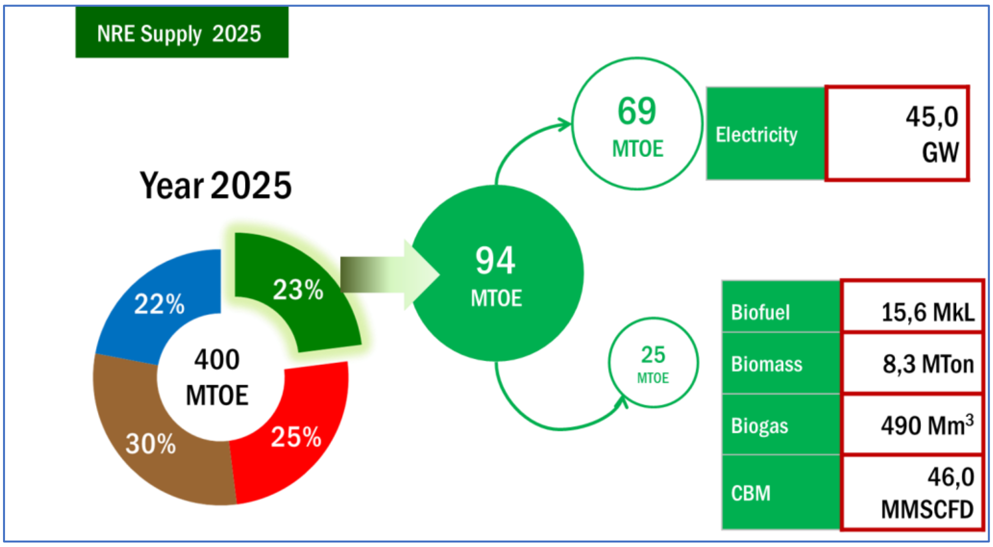


Source: Pertamina.

Presidential Decree No. 5/2006 on National Energy Policy (Kebijakan Energi Nasional, or KEN) is the Indonesian government's strategy on the energy sector. KEN was revised in 2014 by Regulation No. 74/2014, setting a larger target for new and renewable energy at 23% of the energy mix, with oil at 25%, gas 22%, and coal 30%, for a total of 400 million tons of oil equivalent (Mtoe) by 2025 (Government of Indonesia, 2014). To meet the target of renewable energy, the National Energy Council set that biofuel is projected to contribute 15.6 million kilo litres, biomass as a solid fuel would be 8.3 million tons, and biogas to be 490 million cubic metres. The biofuel is mainly for the transport sector, whilst biomass solid fuel and biogas are intended for electricity production. Figure 3.2 presents a visual presentation of renewable energies to meet the new and renewable energy target in 2025.

There is an untapped potential for bioenergy, about 246 million tons per year (Conrad and Prasetyaning, 2014), using dedicated crops and residual flows such as forestry and agricultural residues, organic municipal solid organic waste, offal, sewage sludge, and landfill gas. In the meantime, the total biomass consumption in 2017 is 306 million Boe or 18.6% of the total energy mix (Center for Data and Information Technology, 2017). The majority is used in the household sector followed by the industry sector. The use of biomass is also an attractive option for the electricity generation, particularly biomass derived from waste and oil palms.

Figure 3.2. Forms of Renewable Energies to Meet the New and Renewable Energy Target in 2025



CBM = coalbed methane GW = gigawatt, MkL = metric kilo litre, Mm^3 = metric cubic metre, MMSCFD = million standard cubic feet per day, Mtoe = million ton of oil equivalent, Mton = million ton.
Source: Dewan Energi Nasional (2017).

To speed up the development of biomass-based power plants, the government has issued Presidential Regulation No. 18/2016 to build waste to energy (WTE) plants for seven major cities including Jakarta, Bandung, and Surabaya. Given the significant share of biomass-derived renewable energy, it is also equally important to explore the source of biomass, whether they are in the form of conventional biomass such as vegetable oil or non-conventional biomass including forest residue, agricultural and municipal solid waste, and novel biomass feedstock such as algae.

Non-Conventional Biomass Supply

(1) Forest Residue

An analysis of the 2012's forest cover status showed about 128.4 million hectares (ha) or 68% of Indonesia's land area were state-owned forest areas (Ministry of Forestry of Indonesia, 2014). Of this forest area, limited and permanent production forests were about 58.1 million ha, which consists of a primary forest of 14.5 million ha, a secondary forest of 23.2 million ha, plantations of 2.5 million ha, and area without forest cover of 17.8 million ha. The primary forest here is a virgin forest or an old-growth forest – an untouched forest within the context of logging activities, whereas a secondary forest is a forest that has already been logged and must be left idle for 35 years for regrowth before a second cut is allowed. Most primary forests were located in Papua and Kalimantan, whilst secondary forests include the one in Sumatra.

Forest harvest residues come primarily from the harvesting of natural production forests and industrial forest plantations. About 50.4% resulted from harvesting residues and 49.6% from wood processing residues. The estimated total potential forest biomass in Indonesia for bioenergy in the year 2013 was 7.26 million tons or 132.16 PJ (Simangunsong et al., 2017). Riau province has the largest potential bioenergy followed by Central Kalimantan, East Kalimantan, East Java, South Sumatera, Central Java, and Jambi, which altogether accounted for 87% of total potential bioenergy. Table 3.1 shows the Indonesia's estimated total potential bioenergy (GJ) from harvesting and wood processing residues in the year 2013.

Table 3.1. Estimated Total Potential Bioenergy (GJ) from Harvesting and Wood Processing Residues, 2013, by Province

No.	**Province**	**Harvesting residues from**		**Total**	**Wood processing residues from production of**				**Total**
		Natural production forest	**Industrial Forest Plantations**		**Sawnwood**	**Plywood**	**Veneer**	**Chipwood**	
1	N. Aceh Darussalam	0	0	0	0	0	0	0	0
2	Sumatera Utara	269,992	712,043	982,035	885,892	317,677	9,615	0	1,213,184
3	Sumatera Barat	244,157	3,810	247,967	0	0	0	0	0
4	Riau	119,112	24,438,107	24,557,219	341,776	757,612	0	20,726,068	21,825,455
5	Kepulauan Riau	0	0	0	0	0	0	0	0
6	Jambi	30,850	3,666,682	3,697,532	18,042	590,710	94,180	3,515,230	4,218,162
7	Bengkulu	0	0	0	0	0	64,202	0	64,202
8	Bangka Belitung	0	1,010	1,010	0	0	0	0	0
9	Sumatera Selatan	0	8,540,742	8,540,742	87,346	0	171,999	419,188	678,533
10	Lampung	0	0	0	0	0	206,497	34,976	241,473
11	DKI Jakarta	0	0	0	11,859	0	0	0	11,859
12	Jawa Barat	0	352,759	352,759	48,014	41,932	159,878	15,470	265,295

No.	Province	Harvesting residues from		Total	Wood processing residues from production of				Total
		Natural production forest	Industrial Forest Plantations		Sawnwood	Plywood	Veneer	Chipwood	
13	Banten	0	68,590	68,590	31,929	1,549,746	1,298	0	1,582,973
14	Jawa Tengah	0	524,219	524,219	1,926,103	3,290,916	2,295,963	0	7,512,983
15	D.I. Yogyakarta	0	0	0	0	0	0	0	0
16	Jawa Timur	0	772,195	772,195	3,191,752	5,007,771	2,155,114	0	10,354,637
17	Bali	0	0	0	104,394	0	0	0	104,394
18	Nusa Tenggara Barat	0	0	0	0	0	0	0	0
19	Nusa Tenggara Timur	0	0	0	0	0	0	0	0
20	Kalimantan Barat	520,913	275,575	796,488	149,594	1,918,509	319,424	114,804	2,502,332
21	Kalimantan Tengah	7,060,304	8,019,374	15,079,678	41,724	1,091,208	212,117	418,797	1,763,846
22	Kalimantan Timur	5,224,009	3,975,322	9,199,331	807,816	3,592,638	2,611	1,809,425	6,212,490
23	Kalimantan Selatan	37,552	16,375	53,927	70,961	2,818,678	96,169	0	2,985,809
24	Sulawesi Utara	0	0	0	0	0	0	0	0

No.	Province	Harvesting residues from		Total	Wood processing residues from production of				Total
		Natural production forest	**Industrial Forest Plantations**		**Sawnwood**	**Plywood**	**Veneer**	**Chipwood**	
25	Gorontalo	0	0	0	0	0	0	0	0
26	Sulawesi Tengah	0	0	0	0	0	0	0	0
27	Sulawesi Tenggara	0	0	0	0	0	0	0	0
28	Sulawesi Selatan	0	0	0	68,225	870,077	505,001	0	1,443,303
29	Sulawesi Barat	29,793	0	29,793	0	0	0	0	0
30	Maluku	0	0	0	3,443	779	23,405	0	27,626
31	Maluku Utara	0	0	0	0	0	0	0	0
32	Papua	1,261,937	0	1,261,937	393,738	1,291,378	0	66,409	1,751,525
33	Papua Barat	439,245	0	439,245	536,224	14,612	171,003	70,197	792,036
	Indonesia	15,237,863	51,366,803	66,604,666	8,718,833	23,154,244	6,488,478	27,190,564	65,552,118

Source: Simangunsong et al. (2017).

Using a conversion return approach, the economic value of forest biomass when it was pelletised was estimated to be about US$5.60 per ton of wood residues. The economic value of forest biomass is more sensitive to changes in the price of wood pellets than to changes in the collection and hauling cost of wood residues.

(2) Agricultural Waste and Municipality Solid Waste

Indonesia is the world's largest producer of crude palm oil an important feedstock for biodiesel – and the third-largest producer of rice. Other major agricultural products are cassava (tapioca), groundnuts, cocoa, coffee, and copra. Table 3.2 outlines potential non-conventional biomass for biofuel production.

Table 3.2. Biomass Potential from Agricultural Waste

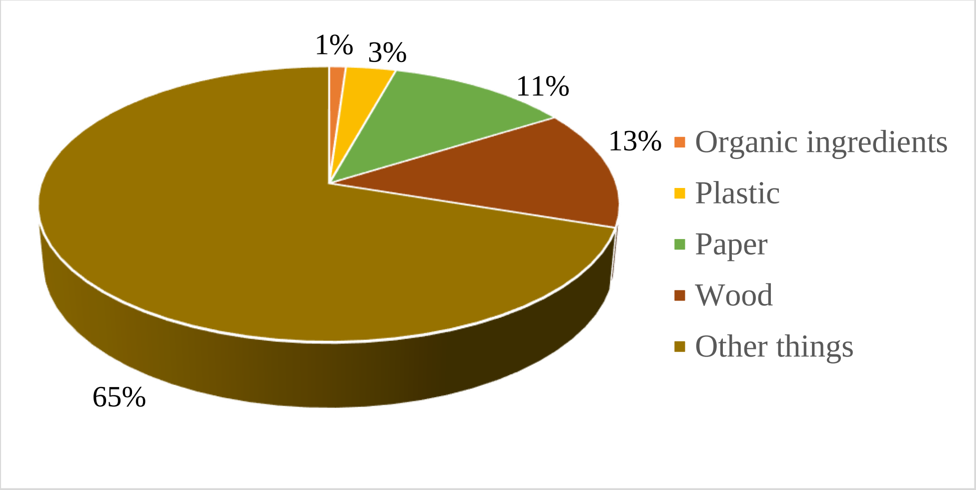
Biomass	Waste (mton)*	Biofuel from Cellulose (mton)	Biofuel from Hemicellulose (mton)	Total Biofuel (mton)
Rice Straw	6.85	0.79	0.36	1.15
Rice Husk	5.19	0.56	0.23	0.80
Corn Stalk	2.32	0.27	0.17	0.44
Bagasse	0.51	0.07	0.03	0.09
EFB Palm	7.44	0.90	0.50	1.41
Palm Frond	12.62	1.13	0.49	1.62
Total				5.55

EFB = empty fruit bunch, mton = million ton.
Source: Authors (fuel production was calculated based on Badger, 2002).

Another potential option of renewable energy in urban areas is the utilisation of biomass for electricity production. One possible source is municipal solid waste (MSW), natural and biomass waste discharged from agriculture and forestry that has little economic value. The increase in population and economic growth will put a strain on municipal waste management. Several cities are experiencing difficulties in waste management as the public tends to dispose of waste without separation. The local authorities on the other hand, only organise the collection and transportation to final waste disposal sites without further treatment. As a result, the waste is left uncollected on the street curbs, which later poses dangers to human health and the environment. The current practices of open dumping in designated final disposal sites may cause serious impacts such as methane gas explosions, landslides, and air pollution due to open burning.

A survey by the Central Bureau of Statistics , revealed that the majority of MSW is organic waste that constitutes 65%. Figure 3.3 shows the overall composition.

Figure 3.3. Typical Municipal Solid Waste Composition



Source: Central Bureau of Statistics.

The composition for urban waste is slightly different; 70% of the waste is organic, 28% is inorganic, whilst 2% is classified as dangerous waste. Of the 70% organic waste, around 54% of it (38% of the total waste) is classified as degradable, thus potentially being composted or fermented.

Waste has become a major environmental issue since it produces methane gas (CH_4) and carbon dioxide (CO_2), besides being potentially dangerous to human health. The increasing population of Indonesia means an increasing volume of waste production. On the other hand, there is a limit on the capacity and lifetime of the existing landfill sites. Meanwhile, municipal solid waste has a potential of biomass energy that can be converted to electricity and this source of biomass can be developed in all regions of the country.

Table 3.3. Biomass Distribution Potential for Electricity

No.	Potential (MWe)	Unit	Sumatra	Kalimantan	Java–Bali–Madura	Nusa Tenggara	Sulawesi	Maluku	Papua	Total
1	Oil palm	MWe	8,812	3,384	60	-	323	-	75	12,654
2	Sugar cane	MWe	399	-	854	-	42	-	-	1,295
3	Rubber	MWe	1,918	862	-	-	-	-	-	2,781
4	Coconut	MWe	53	10	37	7	38	19	14	177
5	Rice husk	MWe	2,255	642	5,353	405	1,111	22	20	9,808
6	Corn	MWe	408	30	954	85	251	4	1	1,733
7	Cassava	MWe	110	7	120	18	12	2	1	271
8	Wood	MWe	1,212	44	14	19	21	4	21	1,335
9	Cow dung	MWe	96	16	296	53	65	5	4	535
10	Municipal Solid Waste	MWe	326	66	1,527	48	74	11	14	2,066
	Total potential	MWe	15,588	5,062	9,215	636	1,937	67	151	32,654

MWe = megawatt electric.
Source: Ministry of Energy and Mineral Resources (MEMR)

Table 3.4. Total Capacity of Power Plants using Biomass Derived Fuel, 2018

No.	Type	Quantity of Power Producer		Total Capacity (MW)		Total Investment (US$ million)	
		Proposal	Appointed	Proposal	Appointed	Proposal	Appointed
1.	Biomass	29	15	246.43	130.63	434.4	171.3
2.	Biogas	29	15	48.10	25.40	101.9	49.135
3.	Municipal Solid Waste	7	2	35.5	11	136.8	53.5

MW = megawatt.

Source: Ministry of Energy and Mineral Resources (MEMR)

(3) Algae

The production of biodiesel and bioethanol from algae is the most efficient way to produce biofuel. The main advantage of this system is that it has the efficiency of conserving higher levels of the photon (the factor of an increase in biomass production per hectare), can be harvested for most of the year, produce biofuels that are non-toxic and have high biodegradable capabilities (Schenk et al., 2008). Micro algae can grow ideally in tropical condition. Microalgae can grow ideally in tropical conditions. It can produce cellulose, flour, and oil efficiently and in large quantities (Sheehan et al., 1998). Some microalgae and cyanobacteria can produce bio-hydrogen under anaerobic conditions (Melis et al., 2000) and the fermentation process can produce methane (Schenk et al., 2008). Assuming a 20,000-kilometre-long and 1 kilometre wide beach coast of Indonesia used for algae growth, the potential of algae to oil in Indonesia is about 2 million barrels of oil per day (potential production of algae oil is predicted to be 10 times of palm oil production).

Several institutions in Indonesia are actively working on microalgae for biofuel. The venture of Universitas Gadjah Mada and Pertamina has been working with microalgae since 2015. They work on algae selection, cultivation, harvest, and algae oil extraction. The Indonesian Institute of Science is also actively working in this area, particularly algae oil extraction, in addition to their activities on producing bioethanol from lignocellulose material. LEMIGAS is also actively working with microalgae since 2014 in addition to its regular activities on first-generation biofuel testing. Some researchers of the Agency for the Assessment and Application of have also been working in this field. They have also been working on second-generation biofuel research since early 2010 in cooperation with Japan. The second-generation biofuel utilises biomass through liquefaction and gasification processes. Biodiesel is derived from biomass, including palm empty fruit bunches, midribs, and other agricultural waste.

Challenges

The challenges for using non-conventional biomass is to ensure a balanced allocation of biomass for fuel and electricity. As forest residues are exported in pellet form, they fetch a price of US$135 per ton as wood pellet price in the Republic of Korea, and a range of US$57 to US$249 per ton destined for Europe. Moreover, incentives to utilise biomass for biofuel are less attractive as the announced bioenergy projects in the Republic of Korea would further attract biomass imports from 2 million oven-dry metric tons (ODMT) to up to 12 million ODMT by 2024. Meanwhile the export of palm kernel shells to Japan and Singapore could reach 47 million ODMT by 2021. This trend has a drawback as Indonesia is exporting important chemical elements such as potassium and fibres that otherwise are needed for maintaining soil nutrients.

Besides, there are also challenges in the aspects of financing and investment. This is due to high initial investment costs related to a green field of renewable energy. Other challenges to guarantee the availability of raw materials and to provide adequate infrastructure such as the construction of electricity grids, charging station installation, and rewiring low voltage distribution.

Another issue is land use and land-use change for evaluating carbon emissions. Despite promising greenhouse gas, saving, and energy security, the growth of Indonesia's biofuel that relies on the domestic palm oil industry and sugar cane plantations is presenting enormous environmental and social costs. Given the recent expansion in oil palm plantation is at the expense of tropical forest (US EPA, 2012), the expansion of dedicated plantations for biofuels will likely follow such a trend. This plantation expansion suggests that the potential impact due to land-use change may occur. Instead of being renewable and environmentally friendly, this plan would potentially contribute significantly to greenhouse gas emissions along with other potential impacts such as diverting land from food crops to energy crops, de-afforestation, and social change. Moreover, potential conflicts could arise between local people and companies seeking to build dedicated biofuel feedstock plantations over land use. This could be solved by conducting a life cycle analysis for this biomass.

2. Biofuel Production from Non-Conventional Resources

Introduction

From the viewpoint of global environmental protection, the reduction of energy consumption and greenhouse gas (GHG) emissions in the transport sector is required worldwide. To realise this proposition, electrification of vehicles is being promoted, mainly in developed countries. The electrification of vehicles has many problems such as the construction of infrastructure for charging and the development of high-performance batteries. Therefore, rapid spread is difficult. Some countries in East Asia have a high proportion of coal-fired power generation, and electrification of vehicles may not necessarily reduce GHG emissions. The energy source of battery electric vehicles (BEV) is only electricity. GHG emissions reduction from BEV depends on reducing GHG emissions in power generation. On the other hand, there are abundant biomass resources in the East Asian region, and the introduction of biofuels made from these resources has realised the reduction of GHG emissions and the suppression of crude oil imports. In this area, it is expected that the combination of biofuels and high fuel efficiency vehicles such as hybrid electric vehicles (HEV) and plug-in hybrid electric vehicles (PHEV) will further enhance the reduction effect of GHG emissions.

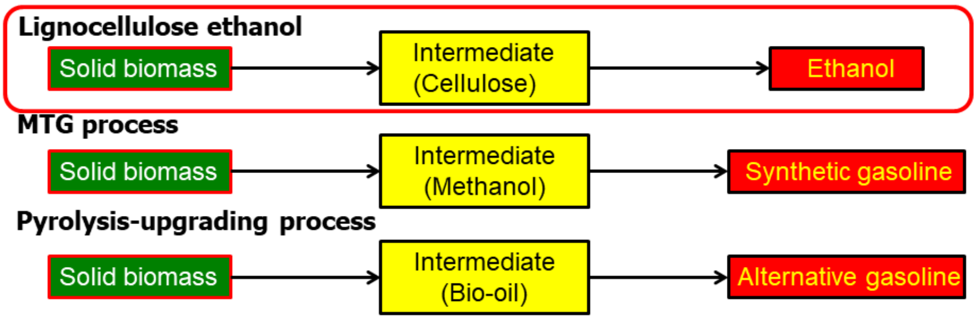
The current first-generation biofuels are limited in the species of raw materials and established manufacturing processes. Thus, it is possible to accurately estimate energy consumption and the amount of GHG emissions in fuel production. On the other hand, the species and production areas of biomass are diverse and methods for producing fuel have not established in the next-generation biofuel production using non-conventional biomass as raw materials. Therefore, it is difficult to accurately estimate energy consumption and the amount of GHG emissions. However, it is essential to use next-generation biofuels made from unconventional biomass to supply a sufficient amount of biofuels in the future.

As HEVs and PHEVs will be introduced mainly as substitutes for existing gasoline vehicles, we have considered how to reduce energy consumption and GHG emissions in the production of alternative fuels.

Biofuels as Alternative Gasoline

As a representative alternative gasoline, ethanol and hydrocarbon fuel produced by the gasification and pyrolysis of biomass and subsequent chemical synthesis and upgrading are known (Figure 3.4).

Figure 3.4. Alternative Fuels Production from Non-Conventional Resources



MTG = methanol to gasoline.
Source: Authors.

First-generation bioethanol is produced from sugar and starch crops as raw materials through the steps of saccharification and fermentation. The next generation bioethanol from non-conventional lignocellulosic biomass is produced through three steps of pre-treatment, saccharification, and fermentation. On the other hand, there are multiple methods for producing hydrocarbon-based bio-gasoline. Typical methods are the synthesis of methanol through gasification of biomass, followed by catalytic conversion to hydrocarbon (MTG process), and upgrading of bio-oil obtained by flash pyrolysis by deoxygenation to hydrocarbon. Amongst these methods, first-generation bioethanol is currently supplied commercially as a transportation fuel.

Energy consumption and GHG emissions are calculated based on first-generation bioethanol in the simulation of this project. In order to compare differences in energy consumption and GHG emissions using first-generation bioethanol with lignocellulosic ethanol as the next-generation biofuel, the estimation of energy consumption and GHG emissions associated with ethanol manufacturing was investigated.

Selection of Raw Materials

Various grass and woody biomass can be used as raw materials of lignocellulosic ethanol. This biomass can be classified into energy crops, biomass residues (agricultural wastes, forest residues, wood processing waste), and biomass waste. In producing ethanol from sugar crops and starch crops, biomass rich in sugars and starch is suitable for obtaining ethanol in high yield. In case of starch crops, crops with a starch content of 65%–75% (dry basis) are generally used for ethanol production. Table 3.5 shows the composition of biomass assumed as an ethanol source. The holocellulose content, which is the total amount of cellulose and hemicellulose, is 5%7–80%, excluding municipal solid waste. It is almost the same as the starch content of starch crops. Corn-derived residues and sugarcane bagasse are suitable as raw materials, although the composition of holocellulose is not constant. Amongst biomass obtained in large quantities in Southeast Asia, palm empty fruit bunch (EFB) is suitable as a raw material. Rice straw and wheat straw contain a large amount of hemicellulose. Ethanol can be produced with high yields if high-efficiency fermentation technology of pentoses is developed. Woody materials contain relatively large amounts of lignin. Since lignin is a substance that inhibits fermentation of sugars, it needs to be separated and removed for fermentation.

Table 3.5. Composition of Lignocellulosic Biomass

Lignocellulosic Biomass	Holocellulose (%)	Cellulose (%)	Hemicellulose (%)	Lignin (%)
Miscanthus	60.0	39.0	21.0	24.5
Silver grass	57.0	33.3	23.7	24.5
Switchgrass	57.1	31.9	25.2	18.1
Corn cob	80.5	43.5	37.0	14.5
Corn cob	72.6	39.7	32.9	12.3
Corn stover	64.0	39.0	25.0	13.0
Oil palm empty fruit bunch	83.3	54.2	29.1	15.1
Rice straw	57.5	32.0	25.5	13.0
Rice straw	56.1	32.1	24.0	18.0
Rice straw	63.0	38.0	25.0	25.0
Sugarcane bagasse	67.0	45.0	22.0	31.0
Sugarcane bagasse	80.0	45.0	35.0	15.0
Sugarcane bagasse	68.4	42.3	26.1	22.4
Sugarcane bagasse	67.3	37.5	29.8	13.2
Sweet sorghum bagasse	62.0	39.5	22.5	17.5
Wheat straw	64.5	35.5	29.0	18.0
Wheat straw	80.0	30.0	50.0	15.0
Wheat straw	63.6	33.7	29.9	23.4
Softwood	66.0	28.5	37.5	27.5
Hardwood	70.0	22.5	47.5	22.5
Municipal solid waste	53.5	41.0	12.5	12.0
Newspapers	80.0	47.5	32.5	24.0

Note: holocellulose = cellulose+ hemicellulose.
Sources: Pandiyan et al. (2019), Loh, Kassim, and Bukhari (2018), Singh and Trivedi (2014), Nakanishi et al. (2018), Zabed et al. (2017).

Estimate of Lignocellulose Ethanol Yield

With regards to the yield of lignocellulosic ethanol, there are differences in the values reported because the production technology is at the development stage. Table 3.6 shows the standard yields reported in the literature. The ethanol yield per biomass unit weight (dry basis) is estimated to be 30%–40%.

Table 3.6. Ethanol Yield from Lignocellulosic Biomass

Biomass	Ethanol Yield (wt%/wt-biomass [dry])
Corn stover	35.5
Rice straw	37.9
Sugarcane bagasse	39.5
Wheat straw	31.6
Wheat straw	38.6
Molasses	22.0
Cassava	35.8

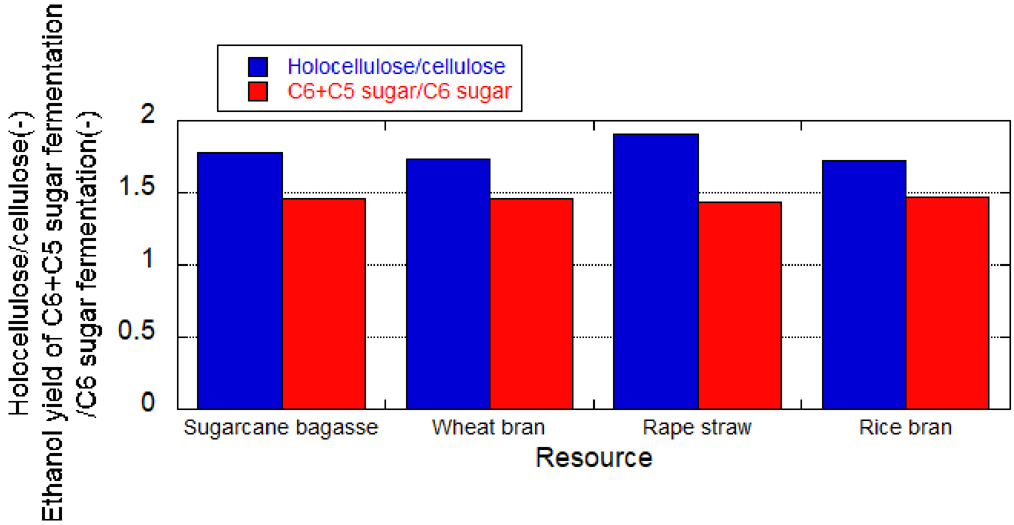
Sources: Pandiyan et al. (2019), Zabed et al. (2017).

Attempt to Improve Ethanol Yield

Research and development to improve the yield of lignocellulosic ethanol, saccharification and fermentation processes, enzymes, and removal technology of fermentation inhibitors have been investigated. Saccharification and fermentation are usually carried out following pre-treatment for the decomposition of the crystal structure of cellulose, which is performed to promote saccharification. The yield of ethanol is higher if these processes are performed simultaneously rather than in separate steps of saccharification and fermentation. It is reported that saccharification and fermentation are performed in separate steps, the ethanol yield based on sugar is 59%. On the other hand, when saccharification and fermentation are carried out simultaneously, the ethanol yield increases to 60%–72.5%. In this case, the ethanol yield increases to 75%–76% when coexisting with a pentose (C5 sugar) fermentation enzyme.

The main objective of the enzyme improvement is to improve the fermentation efficiency of pentoses. The ratio of holocellulose to cellulose contained in sugarcane bagasse, rice straw, wheat and rice husk is approximately 1.7 to 1.9. The ethanol yield improves by 1.4 to 1.5 times when the hexose (C6 sugar) and pentose are simultaneously fermented using multiple enzymes, compared to the ethanol yield when only hexose is fermented (Figure 3.5).

Figure 3.5. Effect of Pentose (C5 sugar) Utilisation on Ethanol Production

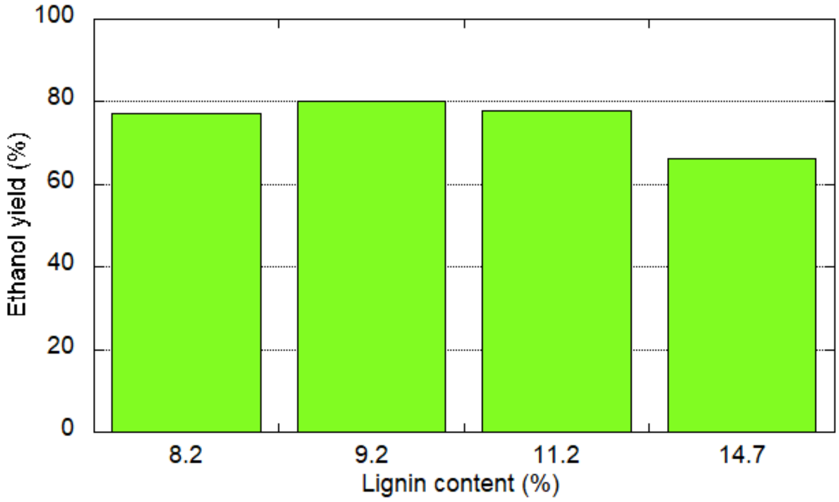


Source: Singh and Trivedi (2014).

The ratio of the hexose and the pentose simultaneous fermentation to only the hexose fermentation shows smaller than the holocellulose/cellulose ratio because the hemicellulose also contains the hexose. Fermentation of pentoses is essential to improve the yield of lignocellulosic ethanol.

The difference between sugar and starch crops and lignocellulosic biomass is that lignocellulosic biomass contains significant amounts of lignin. Because lignin has phenolic structures, it acts as an inhibitor of fermentation. Therefore, it is preferable to remove lignin in pre-treatment. The yield of ethanol obtained by saccharifying and fermenting of the delignified sugar cane bagasse which is obtained by decomposing and removing lignin with a chlorine-based oxidising agent is shown in Figure 3.6. The samples with lignin content 11.2% or less show high ethanol yield. However, it is not preferable to decompose and remove it when lignin is used as an energy source. So, it is preferable to develop lignin tolerant enzyme.

Figure 3.6. Effect of Lignin Content on Ethanol Production

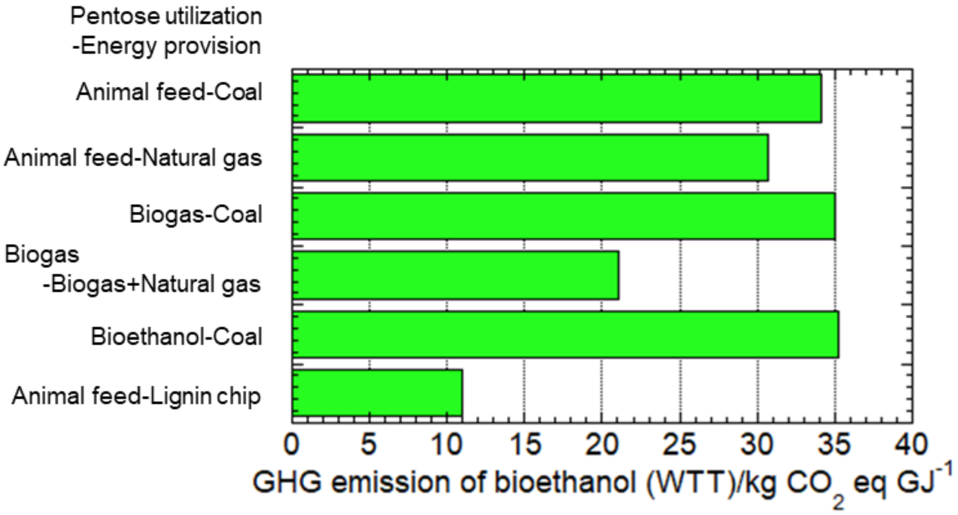


Source: Yu et al. (2018).

Reduction of Energy Consumption and Greenhouse Gas Emissions in Ethanol Production Process

In the production of ethanol from lignocellulose, the process of ethanol production is the largest energy consumption amongst crop cultivation, ethanol production, and transportation of raw materials and products. The ethanol production process requires external energy supply such as electricity and heat. If these energies can be covered by the use of by-products from ethanol production, it is possible to reduce the external energy supply. When fermentation of only hexoses is performed, hemicellulose-derived pentose can be used as an energy source. Comparing the case where pentose is used as animal feed and the case where it is converted to biogas and used as energy supply, it is possible to reduce GHG emissions by co-firing biogas (Figure 3.7). On the other hand, when lignin chips are used as energy sources such as heat (steam) or electricity generation, GHG emissions decrease significantly. When fermenting pentose to obtain ethanol, GHG emissions increase slightly compared to when it is used as animal feed. However, since the saving effect of energy supply by lignin is large, it is possible to satisfy both the improvement of ethanol yield and the reduction of GHG emissions.

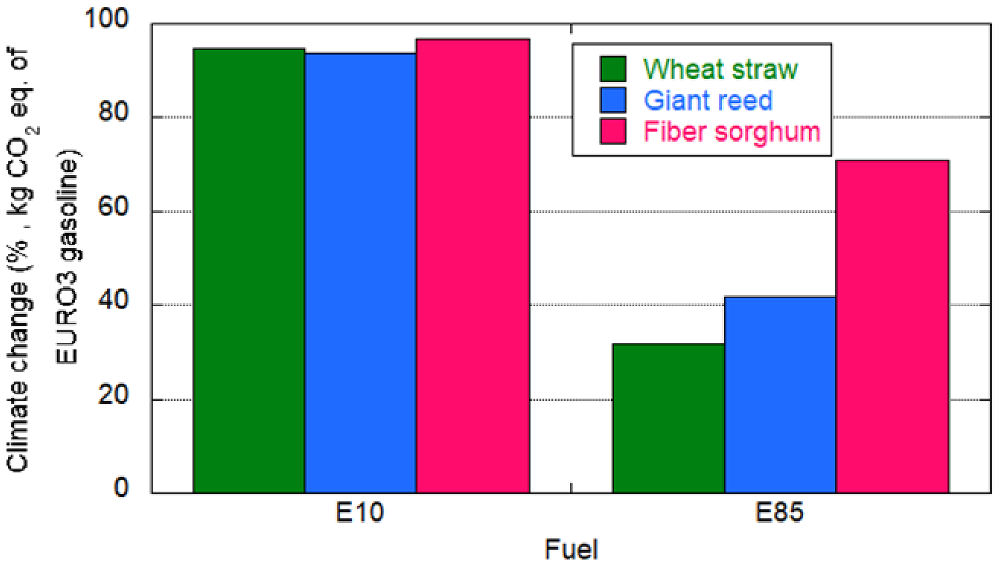
Figure 3.7. GHG Emissions from Ethanol Production



GHG = greenhouse gas. kg = kilogram, WTT = well-to-tank.
Source: Zech et al. (2016).

Differences in the energy consumption of cultivation and pre-treatment process of raw materials influence the amount of GHG emissions in ethanol production. In the case of using E10 fuel, there is no significant difference in the amount of GHG generated in well-to-wheel, (WtW) because the amount of the mixed bioethanol is small. However, when using E85, the difference in GHG emissions in ethanol production has a major impact on the amount of GHG emissions in WtW (Figure 3.8). Therefore, the selection of raw materials and the optimisation of the ethanol production process become more important.

Figure 3.8. Effect of Biomass species on GHG Emissions in WTW



GHG = greenhouse gas, WTW = well-to-wheel.
Source: Singh and Trivedi (2014).

Conclusion

There are many non-conventional biomass types that can be expected to yield ethanol comparable to starch crops. The productivity of lignocellulosic ethanol is difficult to estimate accurately because there are many development factors in the whole process. Many elemental technologies are currently under development. Estimated ethanol yield is 30%–40% of lignocellulosic biomass (dry base). By the utilisation of pentose (C5 sugar), the ethanol yield can be improved (1.4 times as compared with the case of using only hexose). In order to economically introduce lignocellulosic ethanol, it is preferable to improve the ethanol yield by a production process using conventional molasses and starch crops in the short and medium term. By utilising lignin, the environmental impact can be reduced and economics can be improved.

When lignocellulose ethanol is used at high concentrations, the effect of GHG emissions on ethanol production becomes larger. For ethanol production, it is more important to select optimal raw materials and processes with less environmental impact.

Based on the discussion, the following items are proposed as policy recommendations.

- The location of the fuel production facility should be considered in the biomass production area.
- Research and development of production technology of next-generation biofuel should be continued to provide data that can accurately estimate production efficiency, environmental compatibility, and economy.
- In the short term, energy production by sharing non-conventional biomass and fossil resources is a practical method (e.g. coprocessing in the refinery).

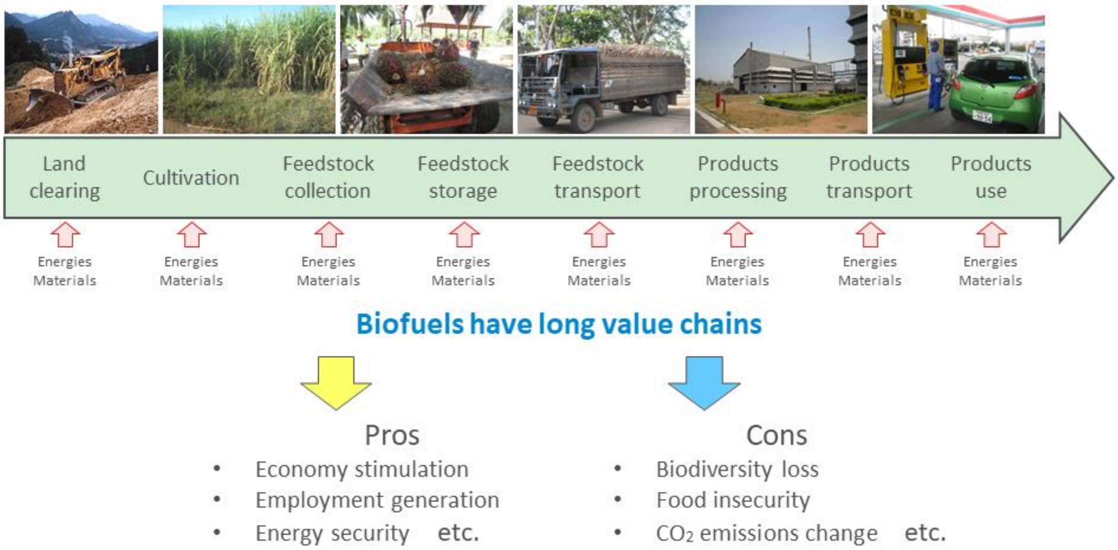
3. Life Cycle Assessment Study of Bioenergy Production

Introduction

East Asia Summit countries are abundant in biomass feedstocks and bioenergy produced from these feedstocks is expected to play important roles to diversify the current heavy energy dependence on imported oil and improve the environment in this region. One of the characteristics unique to bioenergy is that it has a long value chain (Figure 3.9) compared with other renewable energy resources and many stakeholders are involved in this value chain. This is why not only the environmental benefit (greenhouse gas [GHG] mitigation) but also economic (local economy stimulation, etc.) and social benefits (employment generation, etc.) can be expected by the deployment of bioenergy.

On the other hand, it should be noted that some negative impacts such as food insecurity and biodiversity loss may arise if the bioenergy and their feedstock production is not managed in a sustainable manner. Another negative impact that may affect the environment is the GHG/CO_2 emissions increase through the use of bioenergy. It is true that the direct CO_2 emissions from biomass combustion are counted as zero because the bioenergy is regarded as carbon neutral. However, various energy sources and materials necessary to operate the processes comprising the value chain induce indirect GHG/CO_2 emissions. It is reported that the value chain carbon footprint of biofuels sometimes becomes larger than the conventional automotive fuels (gasoline and diesel) if produced in an unsustainable manner.

Figure 3.9. Bioenergy Value Chain



Source: Authors.

Life Cycle Assessment of Bioenergy

The life cycle assessment (LCA) technique is frequently used to quantify the carbon footprint of the target bioenergy value chain. LCA is a useful tool to evaluate the environmental aspects and potential impacts associated with a product or service throughout its life span and the ISO-14040 series has been put forward as a framework of the internationally standardised LCA application method. To understand to what extent the LCA on bioenergy should cover, the 'GBEP Common Methodological Framework for GHG LCA of Bioenergy' (GBEP, 2010) that had been developed by the Global Bioenergy Partnership (GBEP) provides policymakers and bioenergy stakeholders with a harmonised methodological framework to assess the life cycle of GHG emissions of bioenergy. The methodological framework is a checklist that comprises 10 steps in the full LCA of GHG emissions from bioenergy production and use:

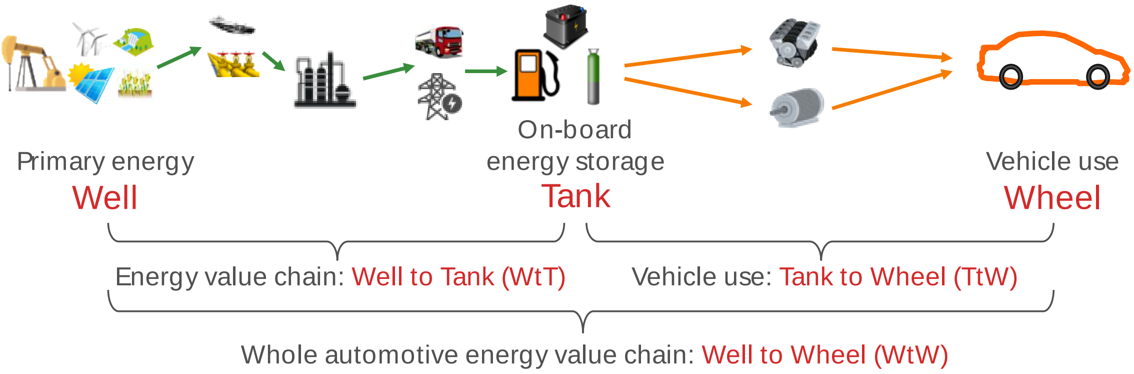
1. GHG covered
2. Source of biomass
3. Land-use changes (LUCs) due to bioenergy production
4. Biomass feedstock production
5. Transport of biomass
6. Processing into fuel
7. By-products and co-products
8. Transport of fuel
9. Fuel use
10. Comparison with replaced fuel

For each step, a set of questions was developed to ascertain which sources of emissions (or sinks) were considered and through which methods, and which assumptions were made. Since not all 10 steps will apply to all bioenergy systems, in some applications it will be necessary to skip one or more steps of the framework.

Definition of 'Well-to-Wheel'

The term 'well-to-wheel' has become well-known in the transport sector and currently various vehicle makers and automobile industry associations have set their long-term target to reduce the GHG/CO_2 emissions from well-to-wheel viewpoints. As shown in Figure 3.10, well-to-wheel is a specific LCA framework to evaluate the whole environmental emissions throughout the automotive energy value chain from extraction and collection of primary energy, energy transformation/refinery/transport, and consumption for vehicle use. The automotive energy value chain is called 'well-to-tank' and the vehicle use phase is called 'tank-to-wheel'. In other words, it can be said that well-to-wheel assesses the life cycle environmental emissions difference by the combinations of automotive energy (well -to-tank) and powertrain (tank-to-wheel).

Figure 3.10. Well-to-Wheel Analysis Outline



Source: Authors.

Examples of Bioenergy Life Cycle GHG/CO_2 Emissions

There are various studies that evaluated the life cycle of well-to-tank GHG/CO_2 emissions of bioenergy. All these cover some or most of the steps listed in the GBEP's framework (GBEP, 2010) but the results depend on the assumptions made for each study. To understand the carbon footprint profiles of both first- and second-generation bioenergy,[4] this article reviews the following four articles that are relevant to East Asia Summit countries or the emissions from non-conventional resources.

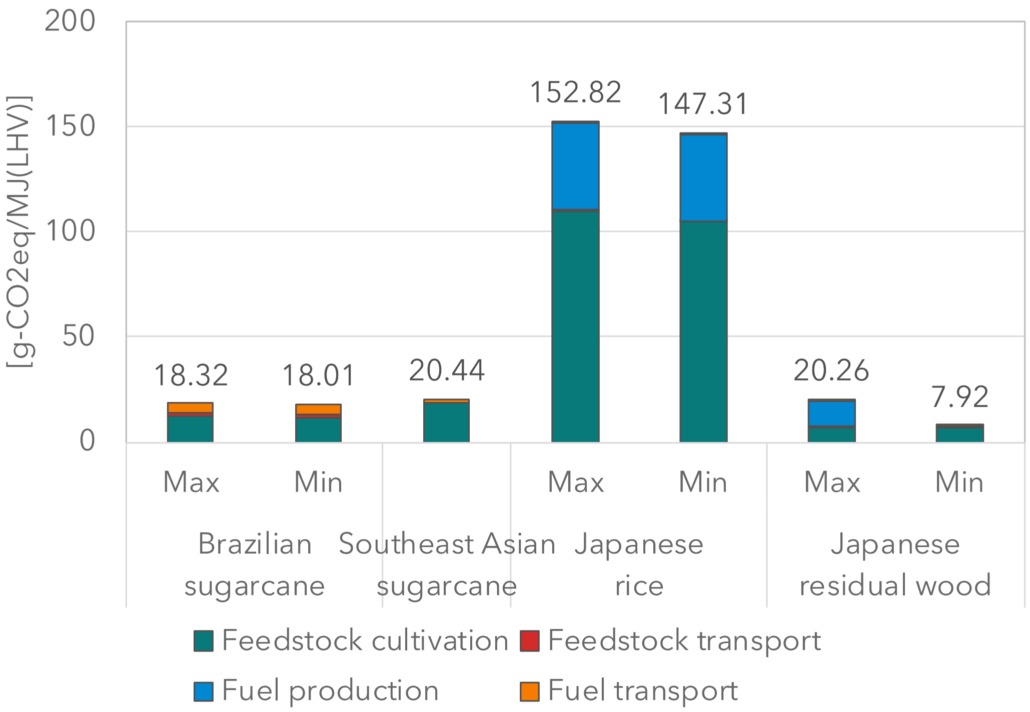
---

[4] First-generation bioenergy is the conventional and commercial bioenergy made from food crops, whereas second-generation or advanced bioenergy is produced from non-food biomass feedstock.

- Toyota and Mizuho (2008)

  In this report, Toyota Motor Corporation and Mizuho Information and Research Institute jointly assessed in detail the well-to-tank GHG emissions of bioenergy for Japanese transport use. Among the various bioenergy value chains considered in this report, Figure 3.11 shows the well-to-tank GHG emissions of ethanol production for transport use. Please note that the GHG emissions attributed to LUC (step 3 of the GBEP framework) were not included in the calculation. Imported ethanol to Japan produced from sugarcane showed low GHG emissions. The emissions from feedstock cultivation in Brazil tended to be smaller than in Southeast Asia due to higher sugarcane yield and different raw material in ethanol production system (cane juice in Brazil and molasses in Southeast Asia). The emissions from Japanese rice became far larger than those from sugarcane. The reason for the particular large emissions from feedstock cultivation was that rice is usually farmed in paddy fields and the methane emissions from paddy fields are large. It was also estimated that the emissions from residual wood could be almost the same level (maximum value) as imported ethanol from sugarcane, and the emissions could be reduced further by using bioelectricity instead of grid electricity in fuel production stage (minimum case).

Figure 3.11. Ethanol Well-to-Tank GHG Emissions Calculated in Toyota and Mizuho (2008)

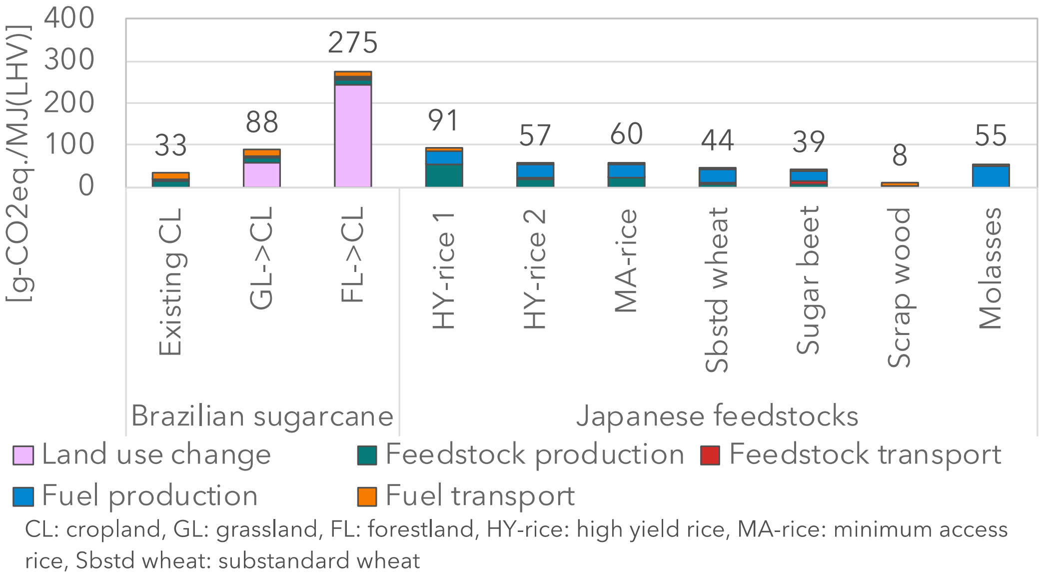


GHG = greenhouse gas.
Source: Toyota and Mizuho (2008).

- Ministry of Economy and Trade (2010)

  The Ministry of Economy and Trade (METI) study group calculated the ethanol well-to-tank GHG emissions from various pathways, which are shown in Figures 3.12. The difference from the Figure 3.11 assumption in the Toyota and Mizuho report (2008) was that Figure 3.12 included the direct LUC[5] (dLUC) emissions for Brazilian sugarcane-ethanol value chain. In this calculation, CO_2 emissions due to the above- and below-ground carbon stock change by converting the land to cropland were calculated and equally allocated over 20 years, which was found to be significant for Brazilian sugarcane case. It can be also confirmed from Japanese feedstock cases in Figure 3.12 that the emissions from scrap wood, one of the second-generation feedstocks, tended to be smaller than the other cases.

Figure 3.12. Ethanol Well-to-Tank GHG Emissions Calculated in METI (2010)



GHG = greenhouse gas.
Source: METI (2010).

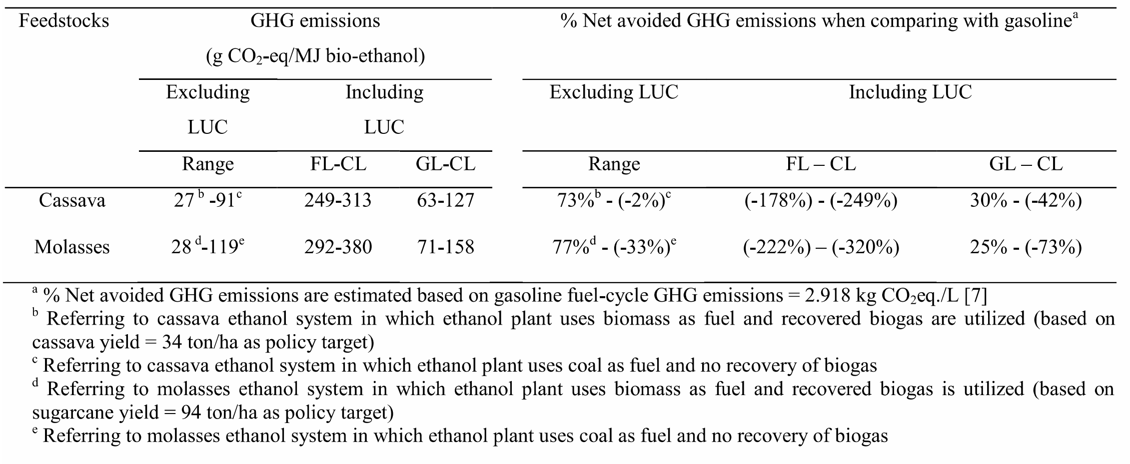
- Silalertruksa and Gheewala (2011)

  Silalertruksa and Gheewala evaluated the GHG emissions from bioethanol production in Thailand. Cassava and molasses were selected as the target feedstock and the emissions from dLUC were included in their calculation. It can be confirmed from Table 3.7 that if the land use changes from tropical forestland (FL) and/or grassland (GL) to cropland (CL) were included, the GHG emissions could possibly increase from 1 to 10 times as compared to the case where LUC was excluded.

---

[5] Direct LUC accounts for changes in land used associated with the direct expansion of bioenergy feedstock production, such as the displacement of food or fiber crops, pastures and commercial forests or the conversion of natural ecosystems.

Table 3.7. Life Cycle GHG Emissions of Bioethanol in Thailand Calculated in Silalertruksa and Gheewala (2011)



Feedstocks	GHG emissions (g CO_2-eq/MJ bio-ethanol)			% Net avoided GHG emissions when comparing with gasoline[a]		
	Excluding LUC	Including LUC		Excluding LUC	Including LUC	
	Range	FL-CL	GL-CL	Range	FL – CL	GL – CL
Cassava	27[b]-91[c]	249-313	63-127	73%[b] - (-2%)[c]	(-178%) - (-249%)	30% - (-42%)
Molasses	28[d]-119[e]	292-380	71-158	77%[d] - (-33%)[e]	(-222%) – (-320%)	25% - (-73%)

[a] % Net avoided GHG emissions are estimated based on gasoline fuel-cycle GHG emissions = 2.918 kg CO_2eq./L [7]

[b] Referring to cassava ethanol system in which ethanol plant uses biomass as fuel and recovered biogas are utilized (based on cassava yield = 34 ton/ha as policy target)

[c] Referring to cassava ethanol system in which ethanol plant uses coal as fuel and no recovery of biogas

[d] Referring to molasses ethanol system in which ethanol plant uses biomass as fuel and recovered biogas is utilized (based on sugarcane yield = 94 ton/ha as policy target)

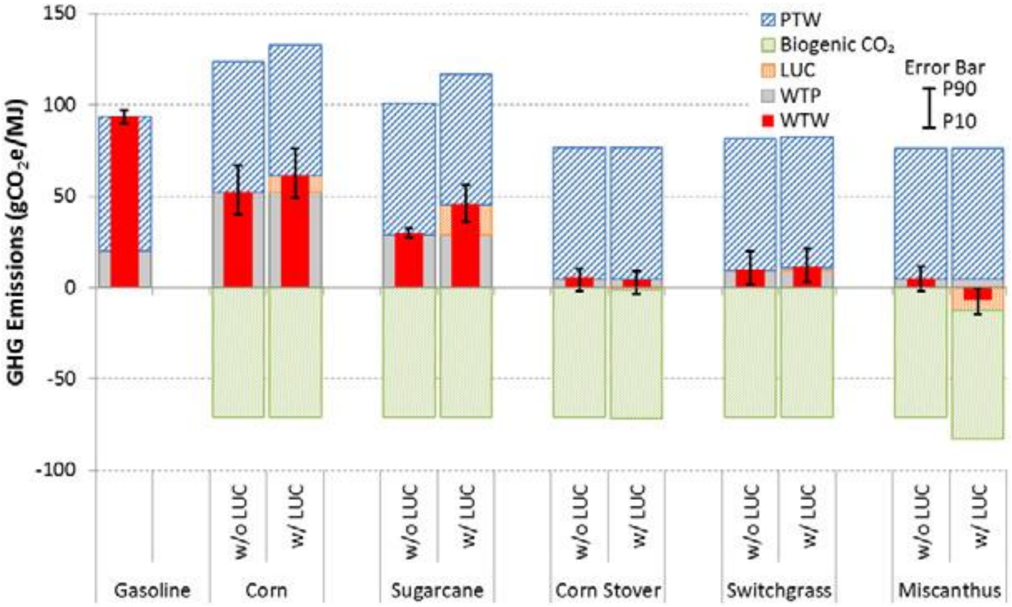
[e] Referring to molasses ethanol system in which ethanol plant uses coal as fuel and no recovery of biogas

Source: Silalertruksa and Gheewala (2011).

- Wang et al. (2012)

  Wang et al. calculated well-to-wheel GHG emissions of gasoline and five bioethanol pathways in the United States as shown in Figure 3.13. The emissions were separated into well-to-pump (WTP, equivalent to well-to-tank), pump-to-wheel (PTW, equivalent to tank- to-wheel), biogenic CO_2 (i.e. carbon in bioethanol) and LUC GHG emissions. Figure 3.13 suggests that cellulosic bioethanol (ethanol from corn stover, switchgrass, and miscanthus) was projected to have larger GHG emissions reductions compared to gasoline than the current commercial bioethanol (ethanol from corn and sugarcane), even if the emissions from LUC were accounted.

Figure 3.13. Well-to-Wheel GHG Emissions of Gasoline and Bioethanol Pathways Calculated in Wang et al. (2012)



GHG = greenhouse gas.
Source: Wang et al. (2012).

- SCOPE (2015)

In 2015, the Scientific Committee on Problems of the Environment (SCOPE) launched its report on ‘Bioenergy and Sustainability: Bridging the Gaps’ to answer the question whether modern bioenergy technologies can make a significant contribution to our future energy demands with positive contributions to the environment, and to social development.

The report includes the discussion on the GHG/CO$_2$ emissions from LUC, which has been the most contentious issue in evaluating GHG effects of bioenergy. Among the LUC categorisation of dLUC and indirect LUC[6] (iLUC), the significance of iLUC had been regarded to be large enough to negate the GHG emission benefits of an otherwise low-emitting biomass-based fuel supply chain, as shown in Figure 3.12 and Table 3.7. Recently, it is deemed that this is no longer the case for ethanol crops due to the result of the reduction in the estimated magnitude of iLUC-induced emissions over time. Current trends relevant of iLUC observable in most parts of the world include ongoing improvements in the efficiency of feedstock production and conversion processes, decreased rates of deforestation, and more stringent regulation of agricultural practices.

---

[6] Indirect LUC comprises induced effects of biofuel feedstock expansion promoting land use changes elsewhere than where the expansion has taken place.

Findings for Bioenergy LCA

From the reviews of studies and reports in this section, the findings of bioenergy LCA can be summarised as follows:

- Bioenergy GHG/CO_2 results vary significantly amongst different bioenergy types and regions, and are affected by LCA methodology, technology modelling and data availability. This includes the system boundary settings, how the bioenergy co-products are treated, whether and how the LUC emissions are considered, and whether the technology advancement is considered or not.
- Second-generation bioenergy may have a higher life cycle GHG/CO_2 mitigation potential than the first-generation bioenergy.
- Emissions from LUC tended to have significant impact and there were still considerable uncertainty for the quantification of indirect LUC emissions, but in recent studies it is regarded that LUC emissions can be avoided if land demand for biofuels expansion is managed, if yield increase exceeds increase in demand and as long as deforestation rates are decreasing.

Last but not least, the selection of the right biomass feedstock, the right conversion technology, and the right LCA methodology become important to identify the role of bioenergy in GHG/CO_2 mitigation. Further reviews and continuous studies on bioenergy LCA are indispensable to achieve this goal.

References

Badan Pusat Statistik (BPS) (2015), *Statistical Yearbook of Indonesia 2015*. Jakarta: BPS.

Badger, P.C. (2002), 'Ethanol From Cellulose: A General Review'. In J. Janick and A. Whipkey (eds), *Trends in New Crops and New Uses*. Alexandria, VA: ASHS Press, pp.17–21.

Center for Data and Information Technology MEMR (2017), *Handbook Energy Economics Statistic Indonesia 2015*. http://www.esdm.go.id/statistik/handbook.html

Conrad, L. and I. Prasetyaning (2014), *Overview of the Waste-toEnergy Potential for Grid-connected Electricity Generation (Solid Biomass and Biogas) in Indonesia*. http://www.fao.org/DOCREP/005/y4355e/y4355e03.htm

DEN-Dewan Energi Nasional (2017), Perpres Nomor 22 Tahun 2017 Tentang Rencana Umum Energi Nasional.

Global Bioenergy Partnership (GBEP) (2010), 'GBEP Common Methodological Framework for GHG LCA of Bioenergy Version One', http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/GHG_clearing_house/GBEP_Meth_Framework_V_1.pdf

Government Regulation No. 79/2014 National Energy Policy (2014).

Loh, S.H., M.A. Kassim, and N.A. Bukhari (2018), 'Optimization of Process Conditions for Ethanol Production from Enzymatically Saccharified Empty Fruit Bunch using Response Surface Methodology (RSM)', *J. Oil Palm Res.*, 30(4), pp.642–54.

Melis, A., L. Zhang, M. Forestier, M.L. Ghirardi, and M. Seibert (2000), Sustained Photobiological Hydrogen Gas Production upon Reversible Inactivation of Oxygen Evolution in the Green AlgaChlamydomonas reinhardtii. *Plant Physiology,* 122(1), pp.127–36.

Ministry of Economy, Trade and Industry (METI) (2010), 'Study Group Interim Report on Biofuel Sustainability Standard' (in Japanese).

Ministry of Forestry of Indonesia. (2014), Statistik Kehutanan Tahun 2013.

Nakanishi, S.C., V.M. Nascimento, S.C. Rabelo, I.L.M. Sampairo, and T.L. Junqueira (2018), 'Comparative Material Balances and Preliminary Technical Analysis of the Pilot Scale Sugarcane Bagasse Alkaline Pretreatment to 2G Ethanol Production', *Ind. Crops Products*, p.120, p.187.

Pandiyan, K., A. Singh, S. Singh, A.K. Saxena, and L. Nain (2019), 'Technological Interventions for Utilization of Crop Residues and Weedy Biomass for Second Generation Bio-ethanol Production', *Renewable Energy*, 132, pp.723–41.

Pertamina (2015),'Updates on the Implementation of Advanced Biofuel',

http://www.globalbioenergy.org/fileadmin/user_upload/gbep/docs/2015_events/3rd_B ioenergy_Week_25-29_May_Indonesia/28_5_4_HIDAYAT.pdf

Schenk, P.M. et al. (2008), 'Second Generation Biofuels: High-efficiency Microalgae for Biodiesel Production', *Bioenergy Research,* 1(1), pp.20–43.

Scientific Committee on Problems of the Environment (SCOPE) (2015), 'Bioenergy and Sustainability: Bridging the Gaps'.

Sheehan, J., T. Dunahay, J. Benemann, and P. Roessler (1998), *Look Back at the US Department of Energy's Aquatic Species Program: Biodiesel from Algae;Close-out Report*. Golden Colorado, US:National Reneweable Enery Laboratory.

Silalertruksa, T. and S.H. Gheewala (2011), 'The Environmental and Socio-economic Impacts of Bio-ethanol Production in Thailand', *Energy Procedia*, 9, pp.35–43.

Simangunsong, B.C.H., V.J. Sitanggang, E.G.T. Manurung, A. Rahmadi, G.A. Moore, L. Aye, and A.H. Tambunan (2017), 'Potential Forest Biomass Resource as Feedstock for Bioenergy and its Economic Value in Indonesia', *Forest Policy and Economics,* 81, pp.10–17. doi:https://doi.org/10.1016/j.forpol.2017.03.022

Singh, D.P. and R.K. Trivedi (2014), 'Biofuel from Wastes an Economic and Environmentally Feasible Resource', *Energy Procedia*, 54, pp.634–41.

Toyota Motor Corporation & Mizuho Information and Research Institute (2008), 'Well-to-Wheel Assessment of Transportation Fuel: Study Report on Well-to-Tank GHG Emission from Transportation Fuel Production Including Biofuel' (in Japanese).

United States Environmental Protection Agency (US EPA). (2012), *Notice of Data Availability Concerning Renewable Fuels Produced From Palm Oil Under the RFS Program*. https://www.federalregister.gov/articles/2012/01/27/2012-1784/notice-of-data-availability-concerning-renewable-fuels-produced-from-palm-oil-under-the-rfs-program

Wang, M., J. Han, J.B. Dunn, H. Cai, and A. Elgowainy (2012), 'Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Ethanol from Corn, Sugarcane and Cellulosic Biomass for US Use', *Environmental Research Letters*, 7, 045905, 13pp.

Yu, N., L. Tan, Z.-Y. Sun, H. Nishimura, S. Takei, Y.-Q. Tang, and K. Kida (2018), 'Bioethanol from Sugarcane Bagasse: Focused on Optimum of Lignin Content and Reduction of Enzyme Addition', *Waste Management*, 76, pp.404–13.

Zabed, H., J.N. Sahu, A. Suely, A.N. Boyce, and G. Faruq (2017), 'Bioethanol Production from Renewable Sources: Current Perspectives and Technological Progress', *Renewable Sustainable Energy Rev*., 71, p.475.

Zech, K.M., K. Meisel, A. Brosowski, L.V. Toft, and F. Müller-Langer (2016), 'Environmental and Economic Assessment of the Inbicon Lignocellulosic Ethanol Technology', *Appl. Energy*, 171, pp.347–56.