Chapter 8
Biofuel Production from Sugarcane in Thailand

Shabbir H. Gheewala, Thapat Silalertruksa, Patcharaporn Pongpat, and Sébastien Bonnet

8.1 An Overview of the Thai Sugarcane Industry

Thailand is recognized as an agro-industrial-based country where several crops such as rice, cassava, and sugarcane are grown and exported as commodities. Sugarcane is a staple crop playing an important role in the Thai economy, not only for sugar production but also for bioenergy such as bioelectricity and biofuel production.

8.1.1 Sugarcane Production

Sugarcane can be grown well nationwide due to the tropical climate with average annual rainfall of about 1200–1600 mm. a year, except in the Southern region where the average rainfall is much higher, i.e., around 4500 mm a year, which is not suitable for sugarcane cultivation. With a total annual sugarcane production of about 94 million tons and the exportation of about 6.5 million tons of sugar in 2015/2016 (Office of Agricultural Economics Bangkok [OAE] 2016), Thailand has become the fifth largest producer and second largest exporter of sugar in the world. The country's average sugarcane yield is about 57 tons ha^{-1} (OAE 2017). In 2016, sugarcane plantations covered a total area of about 1.65 million ha. Figure 8.1 shows the expansion of sugarcane plantations in the country over the past decade, increasing on average by about 3% per year over the period 2008/2010 to 2016/2017

S. H. Gheewala (✉) · T. Silalertruksa · P. Pongpat · S. Bonnet
The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok, Thailand

Center for Energy Technology and Environment, Ministry of Education, Bangkok, Thailand
e-mail: shabbir_g@jgsee.kmutt.ac.th

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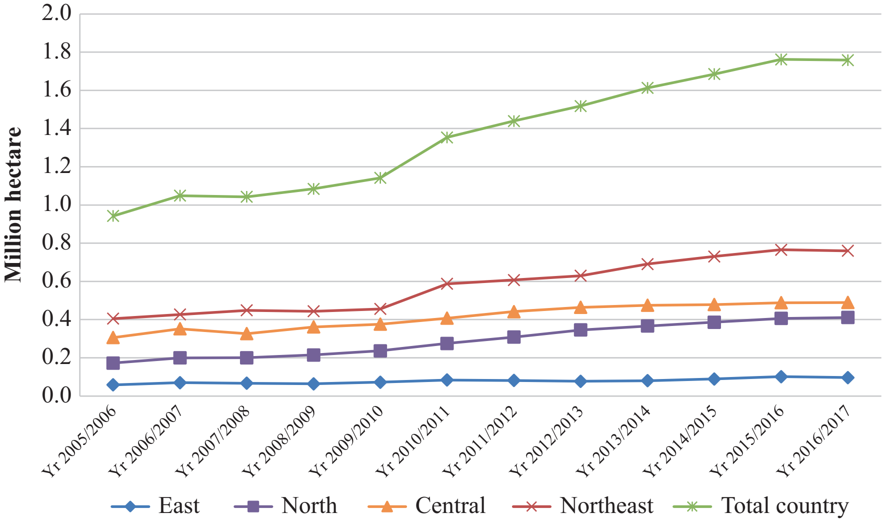

Fig. 8.1 Sugarcane plantation areas in Thailand by regions from year 2005–2016

(OAE 2017). Nevertheless, sugarcane cultivation in Thailand is mainly rainfed; the sugarcane production therefore could vary slightly year by year due to the climate situation such as drought and floods. For example, in the crop year 2016/2017, the harvested area decreased by 4% from the year 2015/2016 due to the drought impacts. This led to a decrease in sugarcane production from 94 million tons in 2015/2016 to 90 million tons in 2016/2017. The Northeastern region shared about 45% of the total sugarcane production, followed by the Central 29% and Northern 26% regions, respectively (OAE 2016).

8.1.2 Sugar Production

As per 2016, there are 52 sugar mills with a total annual sugarcane production capacity of about 94 million tons (OAE 2016). This corresponds to an annual sugar output of about 11.2 million tons. Since the annual domestic consumption of sugar was only 2.6 million tons, this surplus sugar production led Thailand to be the 2nd largest sugar exporter. The domestic consumption of sugar can be classified into direct consumption (52%) and indirect consumption by the industries including beverages (21%), food (12%), dairy products (10%), and others (5%). For export, the sugar products can be classified into raw sugar and refined sugar with an export of about 3.4 and 2.7 million tons, respectively (OAE 2016). The two major producers are Mitr Phol and Thai Roong Ruang, which contribute 21% and 15% of the total production capacity of sugar, respectively (Petchseechaung 2016). Worldwide, both groups are ranked the third and fourth largest exporter of sugar, respectively.

In 2016, the Thai sugarcane industry brought an income of more than 2578 million USD to the country from the export of sugar, as reported by the Office of the Cane and Sugar Board, Bangkok (OCSB 2017a). In addition, the sugarcane industry contributes a major role in the development of the Thai rural economy with over 364,000 households nationwide associated with sugarcane plantations, which are mostly represented by small-scale farmers (OAE 2016). At present, more than 75% of the total production of sugar is exported to major customers in the Asian region where Thailand has advantage due to cheaper transportation costs. This includes, notably, Indonesia (20% of total domestic sugar output), Myanmar (13%), China (13%), and Japan (9%). With regard to domestic consumption, direct household consumption contributes 55%, while the remaining portion is used in the manufacturing sector, including for the production of beverages, foods, and dairy products (OCSB 2017b).

8.1.3 Power Generation

One of the by-products of sugar milling, bagasse, has been used as fuel for heat and power generation for sugarcane production with excess electricity being sold to the national grid. Currently, the total installed capacity of electricity generation using alternative energy in Thailand is 9437 MW, comprising large hydropower plants (31%), biomass (30%), solar energy (26%), wind (5%), biogas (5%), small hydropower (2%), and municipal solid waste (1%) (Department of Alternative Energy Development and Efficiency [DEDE] 2016). For biomass power plants, the sugar industry plays an important role as power producer. The potential of power generation depends on the type of boilers and turbines and operating configurations (pressure and temperature) of the cogeneration systems. In general, sugar mills in Thailand operate boilers and back pressure steam turbines with a steam pressure of about 20 bar and temperature 350–360 °C. The plants produce energy for their own needs (sugar milling) with only some excess electricity being exported to the national grid (Jenjariyakosoln et al. 2014). However, due to the promotion of Small Power Producer (SPP) (10–90 MW) and Very Small Power Producer (VSPP) (<10 MW) schemes, recently, several sugar mill owners have established units of high-pressure boilers that produce steam at 103 bar and 515 °C in their new businesses which generate high amount of surplus electricity for exporting to the grid. However, this type of power plant will require biomass fuel in addition to bagasse during the off-season period of sugar milling. The 48 sugar mills in Thailand surveyed by Jenjariyakosoln et al. (2014) used 20 bar, 30 bar, 40 bar, 70 bar, and 103 bar steam pressure boilers. The major group of cogeneration technologies used in Thai sugar mills is the 20 bar configuration, found in 28 sugar mills; this actually represents a small range of boilers with pressures varying between 20 and 28 bars. Meanwhile, there were 6 sugar mills that used extraction condensing steam turbines ranging between 70 bar and 103 bar.

Several supporting schemes and incentives for SPP and VSPP have been adopted such as the feed-in premium tariff, exemption of investment tax scheme, soft loans for renewable energy, and fund provisions for renewable energy investments (Jenjariyakosoln et al. 2014). Table 8.1 shows the installed capacity of SPP and VSPP of the Thai sugarcane industry in 2015 (DEDE 2016)

8.2 Sugarcane Biofuel Development in Thailand

Sugarcane molasses, a by-product from sugar milling, has been promoted as feedstock for ethanol production. Its production has continuously been increasing since 2004 when it was first introduced on the market as a result of the Thai government policy to promote renewable energy (Silalertruksa and Gheewala 2010). In 2016, about 59% of the total production of ethanol came from molasses, followed by cassava (37%) and sugarcane juice (4%). The production of ethanol directly from sugarcane juice is not yet established in Thailand as a result of the restriction of the Cane and Sugar Act B.E.2527 (A.D.1984) which specifies that sugarcane juice is to be used only for sugar production.

8.2.1 The Government Policy on Biofuel Promotion

Since 2004, the Thai government has been promoting biofuels for transport in order to reduce oil imports and spur rural development. In 2008, Thailand's 15-Year Renewable Development Plan (REDP 2008–2022) was implemented, and ethanol derived from cane molasses, cassava, and sugarcane was strongly promoted by the government to partially substitute conventional gasoline. At the beginning, promotion strategies started from blending 10% ethanol in gasoline (so-called E10), the ethanol replacing the methyl tertiary butyl ether (MTBE). In 2008, as E10 was already well-established on the market, a 20% ethanol blend (E20) was introduced. Later on in the same year, E85 gasohol was launched. At that time, ethanol producers were also encouraged to support the market through Board of Investment (BOI)

Table 8.1 Installed capacity of SPP and VSPP of the Thai sugarcane industry

		Sugar mills	New power plants owned by sugar mills
	Type of contract	Installed capacity (MW)	Installed capacity (MW)
VSPP	Non-firm	737	355
SPP	Non-firm	131	476
SPP	Firm	–	193
Total		868	1024

Remark: Firm power purchasing agreement (Firm PPA) is a contract under which operators need to supply power as required by the Electricity Generating Authority of Thailand to ensure the state enterprise gets the exact energy supply specified in the contract privileges for fuel ethanol plants (Silalertruksa and Gheewala 2010). At present, all three gasohol blends are available nationwide. In 2012, the 10-Year Alternative Energy Development Policy (AEDP 2012–2021) was adopted to replace the REDP 2008. In that plan, the Thai government set a target where renewable energy should contribute 25% of the country's final energy consumption by 2021 (DEDE 2012). Energy from biomass, biogas, municipal solid wastes, as well as first-generation biofuels from indigenous feedstocks like molasses and cassava and advanced generation biofuels from agricultural residues have therefore been gaining much attention and been expanded.

As shown in Table 8.2, the production of ethanol has continuously been increasing from 1.2 ML per day in 2010 to 3.7 ML per day in 2016 (DEDE 2017). One of the reasons for the significant increase in the production of ethanol for transport in recent years is the embargo on the use of gasoline 91 (octane 91) by the government in January 2013. The growing demand for biofuels in the country so far is the result of a variety of policy instruments such as price subsidies, blending mandates, and tax exemption. In 2015, the renewable development plan was revisited and updated again into what is known as the Alternative Energy Development Plan: AEDP 2015 (2015–2036). In the new AEDP 2015, ambitious goals for ethanol production have been set with a production target of 11.3 ML per day to be achieved by 2036 (Energy Policy and Planning Office [EPPO] 2015).

8.2.2 Current Situation of Ethanol Production and Use

As of 2016, there are 21 existing ethanol plants in Thailand which consist of 14 molasses-based ethanol plants, 6 cassava-based ethanol plants, and 1 sugarcane juice-based ethanol plant (Table 8.3). The total ethanol production capacity amounts to 4.19 million liters (ML) per day with 64% from molasses, 31% from cassava, and 5% from sugarcane juice (Bank of Thailand 2017).

As mentioned earlier and also illustrated in Fig. 8.2, there has been a continuous increase in the production and consumption of ethanol in Thailand over the period 2007–2016. This is consistent with the increasing trend in the consumption of gasohol in the form of E10, E20, and E85 as illustrated in Fig. 8.3. Although ethanol is promoted mainly for domestic consumption, there is a great potential for export. Statistics reveal that since 2007 up to the end of 2009, 91 million liters of surplus

Table 8.2 Biofuel production in Thailand (ML per day)

	2010	2011	2012	2013	2014	2015	2016
Ethanol	1.2	1.2	1.4	2.6	3.2	3.5	3.7
Biodiesel	1.7	2.1	2.7	2.9	2.9	3.3	3.4
Total	2.9	3.3	4.1	5.5	6.1	6.8	7.1

DEDE (2017)

Table 8.3 Ethanol factories in Thailand (as of 2016)

	No. of ethanol plants by feedstocks used				Production capacity			
Region	Molasses	Cane juice	Cassava	Total	Molasses	Cane juice	Cassava	Total
North	1	1	–	2	0.23	0.23	–	0.46
Northeast	4	–	2	6	0.98	–	0.53	1.51
Central	8	–	1	9	1.32	–	0.20	1.52
East	1	–	3	4	0.15	–	0.55	0.70
Total	**14**	**1**	**6**	**21**	**2.68**	**0.23**	**1.28**	**4.19**

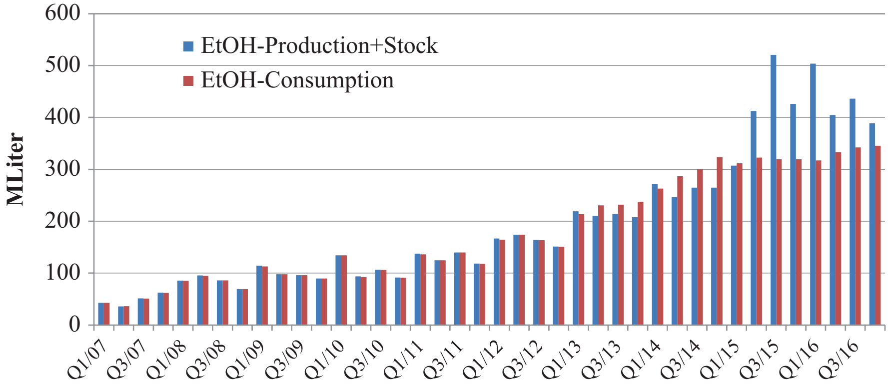

Fig. 8.2 Ethanol production and consumption in Thailand during 2007–2016 (by quarter). (Data sources: DEDE (2017) and BOT (2017))

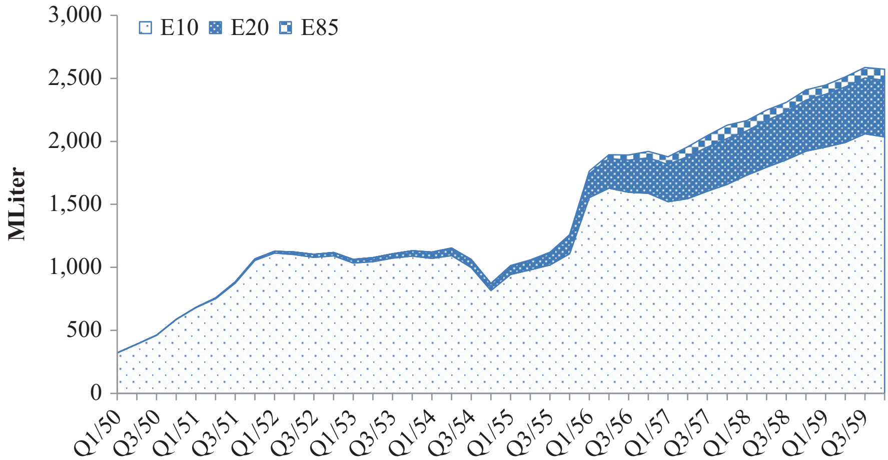

Fig. 8.3 Gasohol consumption in Thailand during 2006–2016 (by quarter) (Department of Energy Business 2017)

ethanol was exported to countries such as Singapore, EU, Australia, and the Philippines (Silalertruksa and Gheewala 2010).

The biofuel industry has been growing steadily, boosted by supportive government measures. One of the key policy measures driving the biofuel growth in the country is the mandate requiring the replacement of a certain volume of petroleum-based fuel by biofuel. In addition, for the consumer side, tax exemption has been used to spur the biofuel demand. The key reason behind the government's support for biofuels is to curb reliance on fossil fuel imports and strengthen Thailand' energy security. In addition, biofuel production from agricultural raw materials provides an alternative outlet for farmers and adds value to agricultural products.

8.3 Challenges on Sustainability of Sugarcane Ethanol Production

Although sugar and sugarcane bioenergy have now developed into a relatively mature industry in Thailand, there still are several issues of concern regarding certain aspects of environmental sustainability, such as open burning of cane trash and related emissions, life cycle greenhouse gas emissions of sugarcane ethanol production, and eutrophication impacts associated with vinasse production from molasses ethanol plants (Gheewala et al. 2011; Silalertruksa and Gheewala 2009; Silalertruksa et al. 2017). In addition, to fulfill the ambitious goals of the Thai government's ethanol policy development plan, there are a number of risks and undesirable development effects associated with large-scale production and use of sugarcane for bioenergy as well as unregulated expansion of bioenergy (Pereira and Ortega 2010). For example, the rapid increase in the demand for sugarcane ethanol has led to increasing concerns over the potential competition between food and biofuels for arable land and freshwater resources as well as greenhouse gas (GHG) emissions from the various life cycle stages leading to biofuel production (Global Bioenergy Partnership [GBEP] 2011). The use of inputs, including agrochemicals, fertilizers, fuel and materials, as well as the emissions and wastes generated from sugarcane production systems, contributes to environmental impacts such as climate change, eutrophication, resource depletion, etc. (Silalertruksa and Gheewala 2009; Pongpat et al. 2017). The future expansion of sugarcane plantations for ethanol production may also potentially lead to water scarcity impact in some Northeastern areas of Thailand (Gheewala et al. 2013). Moreover, monocultures may contribute to soil degradation and natural ecosystem destruction.

Apart from the broad sustainability concerns associated with the expansion of sugarcane bioenergy, the sugar industry needs to improve its environmental and economic performance. Over the past few years, many initiatives have been developed to address the environmental and socioeconomic impacts associated with the production of biofuels or specific biofuel feedstocks. These initiatives include regulatory frameworks and voluntary standards/certification schemes. The key sustainability standards that are relevant to sugarcane ethanol and gaining attention among academia, industries, and policy makers include the following: EU-RED (2016) (EU Renewable Energy Directive), US-RFS (US Renewable Fuel Standards), Bonsucro (Bonsucro 2015), GBEP (Global Bioenergy Partnership) (GBEP 2011), and SAFA (Sustainability Assessment of Food and Agriculture) (FAO 2014) (Table 8.4). Currently, there is relatively little scientific information available regarding the sustainability of the sugarcane supply chain, taking into consideration all of the environmental, economic, and societal aspects. Only some particular aspects, especially GHG emissions, have been investigated and discussed through the view of life cycle assessment (LCA) (International Organization for Standardization 2006) and carbon footprint of products.

8.3.1 Life Cycle Greenhouse Gas Emissions

Based on the principle that plants grown as feedstocks for biofuel production absorb carbon dioxide (CO_2) from the atmosphere through the photosynthesis process, it is considered that the combustion of ethanol simply releases the CO_2 previously absorbed by the plant. This carbon neutral concept is one of the environmental advantages of ethanol as compared to fossil fuels. However, one of the controversial issues related to biofuel production systems is whether they can help reduce dependency on fossil energy and reduce GHG emissions over their entire life cycle. Life cycle assessment (LCA) has therefore been widely used to identify and evaluate the potential environmental implications of biofuels in order to improve their environmental performance. The studies have so far largely been limited to greenhouse gas (GHG) emissions of molasses ethanol (Silalertruksa and Gheewala 2011). The GHG emissions of molasses ethanol have been found to vary over a wide range from 28 to 119 g CO_2 eq MJ^{-1} depending on the production systems considered. The emissions depend on a large number of factors, including, for instance, the types of fuel used for steam generation in the ethanol plant, the system of biogas recovery, etc. (Silalertruksa and Gheewala 2011). The highest GHG emission value reported above is specific to a molasses ethanol plant where imported coal is used as fuel for its boiler. The lowest value is derived from an integrated sugar mill and ethanol plant where steam and power are produced from bagasse. In general, the results indicate that molasses ethanol production is a good substitute for gasoline in terms of GHG emissions. Nevertheless, the inclusion of land-use change (LUC), both direct and indirect, in the assessment of life cycle GHG emissions of biofuels is still a controversial issue. It can contribute significantly to increase the overall GHG emissions of biofuels (Kim et al. 2009; Silalertruksa and Gheewala 2011; Prapaspongsa and Gheewala 2016). However, a wide range of GHG emissions from LUC can be observed depending on the modelling choices made and systems affected (Prapaspongsa and Gheewala 2016).

Table 8.4 Sustainability standards and aspects of sugarcane biofuel production

Standards	Product categories	Environmental aspects								Economic aspects			Social aspects			
		Resource consumption				Emission										
		Land use	Water quantity	Fossil fuel	Biodiversity	Air quality	GHGs and other impacts	Water quality	Soil quality	Productivity	Profitability	Trade	Human rights	Social well-being	Social acceptability	Food security
GBEP	Bioenergy	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
SAFA	Food and agricultural systems	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
EU-RED	Bioenergy	✓	✓	✓	✓	✗	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗
Bonsucro	Sugarcane and related products	✓	✓	✓	✓	✓	✓	✗	✓	✓	✗	✗	✓	✓	✓	✗

8.3.2 Land and Water Competition

In recent years, concerns over the impacts of the biofuel boom on food security have been the subject of much debate worldwide. Arable land is very limited and land demand for growing crops to serve both food and energy production has continuously been increasing. Could this result in an increase in food prices? Of course, biofuels should not be considered as being mainly responsible for the rise in food prices. There is a plethora of factors which may contribute to this increase. These include higher production costs due to rising oil prices, production shortfalls due to climatic events, changes in consumption patterns due to changes in income, weak currency exchange rates, stock level, and market volatility.

In Thailand, agricultural land covers 23.9 million ha and represents around 46% of the nation's surface (OAE 2016). Rice is the main cash crop grown nationwide, covering an area representing about 47% of the agricultural land (or 11.2 million ha), followed by perennial crops (including orchards) and cropland which share about 23 and 21% of the agricultural land, respectively. Para rubber and oil palm are the major perennial crops grown in the Southern part of the country covering 3.7 million ha and 0.7 million ha, respectively. For cropland, aside from rice, sugarcane, cassava, and maize are among the main cash crops grown in Thailand covering an area of 1.4, 1.3, and 1.2 million ha, respectively (OAE 2016). Also, the promotion of sugarcane plantation, including its expansion on areas occupied by low-productivity upland paddy fields, has been introduced as an option to increase farmers' income, reduce water consumption, and fulfill the excess capacity of existing sugar mills. The current target is set at about 0.37 million ha in areas occupied by low-productivity upland paddies in the Northeastern and Central regions of the country. This regional expansion of sugarcane may lead to various impacts on land, water, and GHG emissions depending on factors such as soil conditions, rainfall, water stress situation, agricultural practices, and productivity.

Apart from the land-use issue, freshwater scarcity and competition are other challenges of interest as agriculture is recognized as the world's largest water-consuming sector. It accounts for about 70% of global freshwater withdrawal (WWAP 2012). Thus, for instance, it has been estimated that, to achieve the Thai government policy production target of 9 million liters per day ethanol by 2021, additional irrigation water of 1625 million m^3 $year^{-1}$ would be required. In the *Mun* and *Chi* watersheds of Thailand, water competition issues have been identified among domestic, industry, and agricultural sectors for food and biofuel production if the water resources there are not properly managed (Gheewala et al. 2013). Measures to reduce the water scarcity footprint are, therefore, to be addressed by policy makers to not compromise the sustainability of biofuel production. In addition, the policy related to the conversion of low-productivity upland paddy fields to sugarcane plantations has been evaluated to determine its implications on the monthly water stress index of relevant watersheds and the water scarcity footprint potentials of rice and sugarcane production (Gheewala et al. 2017). The results have shown that proper policy measures can help in reducing the amount of water required for agriculture in the months of June, July, August, and September by about 60–220 Mm^3, which in turn results in the decrease in monthly water stress index values (Gheewala et al. 2017). Nevertheless, appropriate measures of water resource management for agriculture still need to be designed to avoid water competition issues as well as to protect the ecosystem.

8.3.3 Waste and By-Product Management

Although sugar and sugarcane bioenergy have now been developed into a relatively mature industry in Thailand, there are several issues of concern regarding environmental sustainability. For example, cane-trash burning during harvesting is recognized as a major issue of air pollution and soil degradation, which needs to be appropriately addressed (Silalertruksa and Gheewala 2009; Souza et al. 2012).

The potential environmental impact related to the production of vinasse from molasses ethanol plants is also another important challenge for the sugarcane ethanol industry (Gheewala et al. 2011). Moreover, there is a variety of by-products generated from the sugarcane value chains, such as cane trash (if green-cane harvesting were adopted) from sugarcane cultivation, filter cake and wastewater from sugarcane milling, vinasse from ethanol production, and ash from steam and power generation. All these biomass streams need to be managed properly to secure their benefits (Silalertruksa et al. 2017). The promotion of both appropriate farming practices and the integrated utilization and management of the by-products and wastes generated over the entire life cycle of sugarcane production systems is essential to the future competitiveness of the sugarcane industry. The integrated use of sugarcane biomass materials generated from the mills can be highly competitive with other crops as preferred feedstock for a biomass-based industry (Renouf et al. 2008).

8.3.4 Socioeconomic Risks

Large-scale industrialized investment impacts and labor working conditions are social and economic risks relevant to biofuels. These are aspects of concern covered in international standards for sustainable agriculture and bioenergy production, including the GBEP, Bonsucro, as well as SAFA. In the world of rural agriculture, family businesses or cooperatives may be displaced by large-scale industrialized farms. The strength or weakness of this transformation is difficult to assess as large-scale industries may be able to achieve much larger crop yields and production volumes than small farms. However, this also leads to dispossession of land from local farmers which is a very sensitive issue as well as employment problems. The standard of labor conditions needs to be taken into account to ensure that workers can get acceptable levels of wages and working hours as well as to prevent child labor (FAO 2014; GBEP 2011; Smeets et al. 2008). In Thailand, nowadays, the sugarcane industry is trying to shift from traditional sugarcane production systems to more mechanized ones (from cultivation to harvesting). This is to solve the issue of labor shortage occurring during the harvesting season as well as to increase benefits from sugarcane biomass utilization. The Thai sugarcane industry is currently very strict on the standards of labor conditions covering labor in the farms and in the processing industries. Several activities have been initiated involving participation of both sugar millers and local communities to improve the local economy, cultural conservation, education as well as other activities pertaining to the corporate social responsibility policy of each mill. The survey on social aspects of concern for different stakeholders involved in the sugarcane supply chain has revealed that workers attached more significance to issues relating to fair wages, followed by occupational health and safety (Gheewala et al. 2016). The sugar industry is thought to help improve local employment and contribute to economic development, delocalization, and migration by local community groups. However, there still are some concerns on health issues related to air pollution from cane open burning and transport. Water and land rights are also gaining increasing attention from the value-chain actors.

8.3.5 Competitive Crops for Ethanol Production

Several competing crops to sugarcane for biofuel production have been considered by the Thai government so far such as cassava, sweet sorghum, and maize, as well as second-generation ethanol from agricultural residues. At present, only cassava is considered as alternative feedstock to sugarcane in view of its availability and technical and economic viability for commercialization. Thailand is recognized as one of the world's top exporters of cassava products. As mentioned earlier, cassava plantations occupy an area of about 1.3–1.4 million ha nationwide as for sugarcane (OAE 2016). In general, cassava farmers can easily shift their cultivations between cassava and sugarcane depending on the price of their products. Cassava is used for food and feed production in the form of starch, chips, and pellets as well as for ethanol production. With regard to ethanol, there is an increasing number of cassava-based ethanol plants in the country which include new individual cassava ethanol plants and multi-feedstock ethanol plants (molasses and cassava). There are currently 47 ethanol plants officially registered with the government to produce ethanol for transport with a total capacity of around 12.3 million liters per day. This consists of 14 factories using molasses with a total production capacity of 2.48 million liters per day, 25 factories using cassava with a total production capacity of 8.59 million liters per day, and one factory using sugarcane juice with a total production capacity of 0.2 million liters per day (Sriroth et al. 2010). A multi-feedstock process using both molasses and cassava is however preferred in some factories

(7 factories with a total production capacity of 1.02 million liters per day) in order to avoid shortages of feedstock which eventually ends up with high-priced feedstock (Sriroth et al. 2010).

8.4 Sugarcane Biorefinery for Sustainability of Sugarcane and Sugarcane Ethanol Industry

8.4.1 Existing Sugarcane Biorefinery in Thailand

Nowadays, the Thai sugarcane industry is trying to shift to more mechanization in the farming stage as well as to increase benefits from sugarcane biomass utilization. The production systems that integrate biomass conversion processes to produce fuels, heat, electricity, and value-added products from biomass, or so-called biorefineries, are therefore gaining increasing attention in the sugarcane industry, e.g., the sugar-ethanol-electricity mills and the integrated first- and second-generation ethanol production (Dias et al. 2013; Silalertruksa et al. 2017). As per the biorefinery concept, if the waste is properly treated, the industries will be able to benefit from both the reduction of end of pipe treatment costs and the creation of value from waste utilization. The promotion of adequate farming practices as well as the integrated utilization and management of by-products and wastes generated over the entire life cycle of sugarcane production systems are essential to the future competitiveness of the sugarcane industry.

An example of a sugarcane biorefinery (sugar-power-ethanol production) in Thailand is shown in Fig. 8.4. The system integrates sugar production from sugarcane juice and biomass conversion processes to produce molasses ethanol, steam, and electricity. In this system, mechanized farming is adopted, and 50% of cane trash is recovered for power generation. In addition, vinasse is recovered and returned to the sugarcane field as organic fertilizer and soil conditioner. This type of sugarcane biorefinery can contribute to significantly reduce several environmental impacts as compared to a traditional (sugar-power-ethanol) system in which cane trash is subject to burning before harvesting (conventional farming practices) and vinasse and wastewater from ethanol conversion processes are kept in open ponds. The biorefinery system illustrated in Fig. 8.4 contributes to reduce the environmental impact potentials of molasses ethanol as compared to a conventional system by 40% for climate change, 60% for acidification, 90% for photo-oxidant formation, 63% for particulate matter formation, and 20% for fossil depletion. These results are summarized in Table 8.5 (Silalertruksa et al. 2017). The reduction in these environmental impacts comes from the avoidance of cane-trash burning and the additional credits obtained from cane-trash recovery for power generation where the surplus electricity is sold to the Thai grid, thus substituting for electricity generated from fossil fuels, i.e., natural gas and coal. The use of vinasse as organic fertilizer provides credits from the substitution of chemical fertilizers.

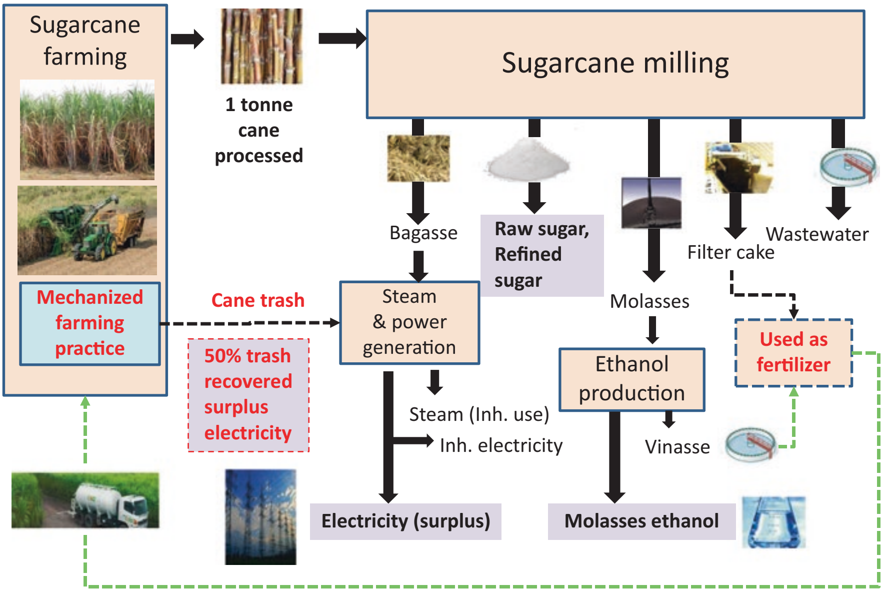

Fig. 8.4 Sugarcane biorefinery system in Thailand

Table 8.5 Environmental impact potentials of 1000 liters molasses ethanol

Impact category	Unit	Traditional system	Improved system (as in Fig. 8.4)
Climate change	kg CO_2 eq	509	309
Terrestrial acidification	kg SO_2 eq	3.3	1.3
Freshwater eutrophication	kg P eq	0.07	0.07
Human toxicity	kg 1,4-DB eq	99	94
Photochemical oxidant formation	kg NMVOC eq	8.0	0.9
Particulate matter formation	kg PM10 eq	1.2	0.5
Terrestrial ecotoxicity	kg 1,4-DB eq	0.05	0.05
Freshwater ecotoxicity	kg 1,4-DB eq	2.5	2.3
Fossil depletion	kg oil eq	70	56

Silalertruksa et al. (2017)

8.4.2 Prospective Sugarcane Biorefinery

At present (year 2017), the Thai government is taking serious steps to move the country toward Thailand 4.0 which is a new economic model focusing on a value-based economy in order to pull Thailand out of the middle-income trap and develop it as a high-income country. The bio-economy industry is one of the government's target industries and is part of the five future industries in the New S-Curve under the Thailand 4.0 policy. Existing cash crops like sugarcane and cassava are expected

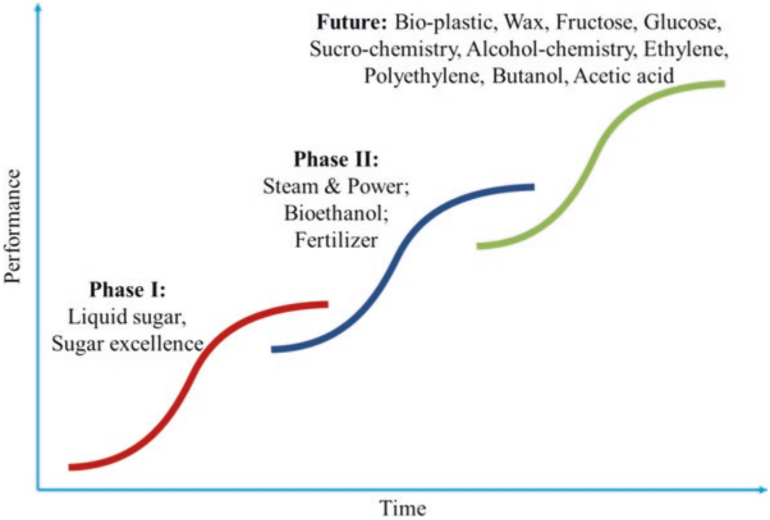

Fig. 8.5 Development of sugarcane products under sugarcane biorefinery concept

to be used to develop high-value products in an effort to build a bio-economy. Figure 8.5 shows the prospective sugarcane-based products which the sugarcane industry as well as the government are looking forward to develop in the future, not only with regard to high-quality biofuels but also high value-added products, including biochemicals and bioplastics.

8.5 Conclusion

Sugarcane ethanol plays an important role for transport as a substitute to fossil fuel in Thailand. With a total production capacity of 4.19 million liters per day, sugarcane accounts for 69% of the total ethanol production (molasses ethanol represents 64%, whereas sugarcane juice accounts for 5% of the total production), the remaining 31% being contributed by cassava. The demand for ethanol is expected to continue to increase in future based on the AEDP policy production target set by the Thai government, which stands at 11.3 million liters per day by 2036. In line with rising global concerns over climate change and its mitigation, efforts in promoting renewable energy via the AEDP are guaranteed to be sustained as providing key policy measures to drive the country toward achieving its Intended Nationally Determined Contributions (INDC), i.e., 20% reduction in GHG emissions by 2030 and a maximum target of 25% as compared to 2005 level (Business as Usual scenario). Under the AEDP, the sugarcane industry is expected to play an important role not only for sugarcane ethanol production but also for power generation from bagasse under the Independent Power Producers (IPP) and Small Power Producers

(SPP) schemes. However, there are risks and undesirable developments that may result from large-scale expansion of sugarcane plantations as well as sugarcane ethanol and bioenergy production unless adequate regulatory measures are implemented. Key sustainability concerns include life cycle GHG emissions, land and water use competitions for food and fuels, water scarcity and water deprivation potential, as well as impacts on human health and the ecosystem due to wastewater and air pollutant emissions. However, there is increasing awareness that sugarcane and its co-products, such as cane trash, bagasse, molasses, and filter cake, can be used as part of a biorefinery system to produce a wide range of products, including, ethanol, electricity as well as chemicals, in particular a variety of polymers. LCA studies have shown that sugarcane-based biorefinery systems involving a mechanized farming stage and maximized utilization of cane trash and vinasse for power and fertilizer can bring a number of enhanced environmental benefits, notably with regard to climate change, acidification, photo-oxidant formation, particulate matter formation, and fossil fuel depletion. Finally, according to the country's strategy on Thailand 4.0, a new economic model focusing on a value-based economy, sugarcane is one of the main cash crops expected to contribute developing high-value products in an effort to build a bio-economy. Hence, the sugarcane industry in the future is anticipated to play a major role not only for the production of ethanol and sugar but also for the production of biochemicals and bioplastics.

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