

CHAPTER 6

CARBON FLOW AND BUDGETS IN SUGAR MILLS

6.1 Introduction

In this chapter, budget and flow of carbon in sugar mill processes including sugar production, molasses, filter cake, bagasse are investigated. In addition, the potential of using by-products of sugar for bioenergy production and greenhouse gas emissions mitigation are also considered.

6.2 Carbon budget in sugar products

6.2.1 Sugar production in Eastern Thailand

Totally, 46 sugar mills are located in Thailand in 2006/07 production years. This study includes 4 out of 5 sugar mills in Eastern Thailand (Figure 6.1 and Table 6.1). Sugarcane area under investigations covered 70,069 ha in 2006/07 production years, or about 6.68 % of the total sugarcane planting area in Thailand. The average sugarcane planting area during 2003/04 to 2007/08 was 66,758 ha, or 6.28% of the total sugarcane planting area in Thailand. The average productivity is 48 to 56 ton/ha (Table 6.1). Sugarcane area in Eastern Thailand covered 6 provinces; Chonburi, Rayong, Srakaew, Chantaburi, Chachoengsao and Prachinburi provinces. More than 37 percent of sugarcane area in Eastern Thailand located in Chonburi province (37.66%, 26,093 ha) followed by Srakaeo (32.98%, 23,112 ha), Chachoengsao (16.41 %; 11,501 ha), Chantaburi (5.56 %, 3,894 ha), Prachinburi (3.93 %, 2,753 ha) and Rayong provinces (3.88 %, 2,716 ha) (Office of the Cane and Sugar Board, 2007). There are 5 sugar mills in the eastern region, the majority of which are located in Chonburi (4 sugar mills) and Srakaew province (1 sugar mill). The five sugar mills in Eastern Thailand accounted for 3.3 million tons of cane annually. From the survey, it was found that the sugar mills produced over 0.92 million tons of bagasse (1 ton of sugarcane generates 277.02 kg of bagasse).

Table 6.2 presents the products from using sugarcane sugar, molasses, filter cake, bagasse which is consumed in Eastern Thailand from 2003/04 to 2007/08 production years

from 4 sugar mill factory data. The percentage of each product in sugarcane yield was calculated by using the data from 4 sugar milling in Eastern Thailand. In addition, it assumed from the average 56 ton cane yield/ha and estimated carbon budgets in each product. The percentage yield of product consists of 6.13 % of total sugar, 4.83 % of molasses 3.52 % of filter cake, and 27.70 % of bagasse (calculated based on 4 sugar mills in Eastern region). This is based on the fact that 1 hectare yields about 56 ton cane (Table 6.1). In addition, the background information of 4 sugar mills in Eastern Thailand was presented in Table 6.3. Different sugar mill are different in capacity, cane yield, bagasse production, and electricity utilization.

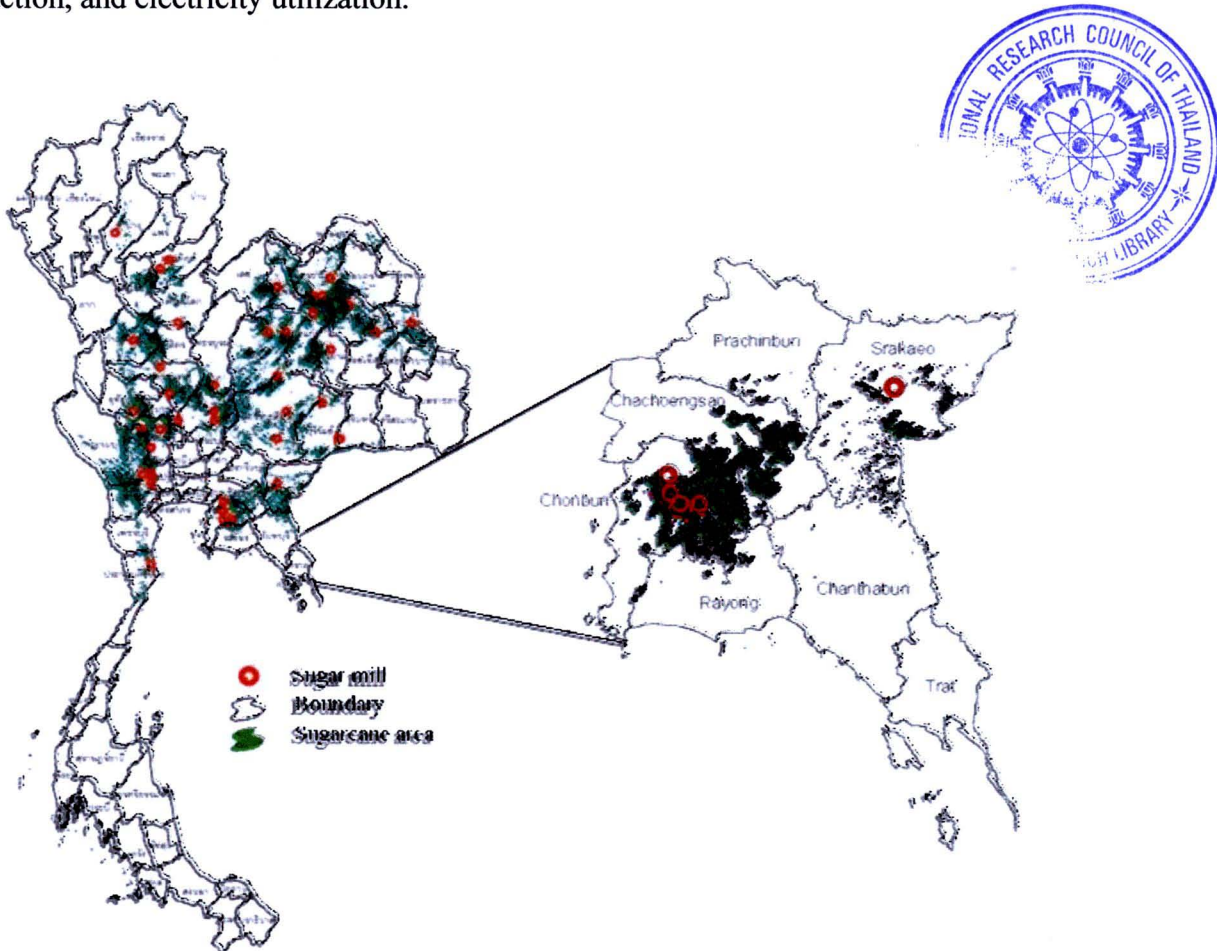


Figure 6.1 Map showing the sugar mill factories in Thailand and sugarcane area in 2006/07 cropping years

Table 6.1 Sugarcane area, yield, and productivity in Chonburi and Rayong provinces, Eastern region and the whole area in Thailand

Details	Unit	Mean	Median	Min	Max
1. Sugarcane area in Thailand from 2003-2008	ha	1,049,288	1,048,985	942,468	1,197,426
2. Sugarcane area in Eastern from 2003-2008	ha	66,573	66,758	58,270	75,154
3. Sugarcane area in Eastern region 2006/07	ha	70,069	-	-	-
4. Sugarcane Yield in Thailand, from 2003-2008	tons	59,275,23 5	63,797,80 8	46,689,72 2	73,588,187
5. Sugarcane Yield in Eastern Thailand, from 2003-2008	tons	3,187,391	3,304,490	2,493,069	4,102,160
6. Sugarcane yield/ha in Thailand, 2003-2008	ton/ha	56.38	53.85	39.93	70.15
7. Sugarcane productivity in Eastern, 2003-2008	ton/ha	47.70	46.45	40.67	61.45
8. Sugarcane productivity in Chonburi & Rayong provinces in 2006/07	ton/ha	48.75	-	-	-



Table 6.2 Sugar and by-product of sugar; molasses, filter cake, bagasse from sugar mill in Eastern Thailand from 2003/04 to 2007/08 production years

Details	Unit	Mean	Median	Min	Max
1. Molasses, the amount of molasses/sugar mill	Tons	21,531	21,231	10,878	35,419
2. % of molasses/yield	%	4.83	4.87	4.00	5.95
3. Molasses	kg/ton cane	48.34	48.67	40.00	59.50
4. Molasses, Carbon content	ton C/ha	0.69	0.70	0.57	0.85
5. Molasses, Carbon content	ton C/ton cane	0.012	0.012	0.010	0.015
6. Filter cake, the amount of filter cake/ sugar mill	Tons	16,181	16,795	5,668	26,242
7. % of filter cake/yield	%	3.52	3.48	2.40	4.01
8. Filter cake	kg/ton cane	36	35	24	40
9. Filter cake, Carbon content	ton C/ha	0.22	0.22	0.15	0.26
10. Filter cake, Carbon content	ton C/ton cane	0.004	0.004	0.0027	0.0046
11. Sugar, the amount of sugar/ sugar mill	tons	30,716	36,641	322	65,035
12. % of sugar/yield	%	6.13	8.73	0.16	10.13
13. Sugar	kg/ ton cane	61.29	87	80	101
14. Sugar, Carbon content	ton C/ha	0.095	0.13	0.002	0.15
15. Sugar, Carbon content	ton C/ton cane	0.026	0.0367	0.0007	0.042
16. Bagasse, the amount of bagasse/sugar mill	tons	124,015	127,856	55,804	181,447
17. % of bagasse/yield	%	27.70	-	-	-
18. Bagasse	kg/ ton cane	277.02	-	-	-
19. Bagasse, Carbon content	ton C/ha	3.26	-	-	-
20. Bagasse, Carbon content	ton C/ton cane	0.06	-	-	-
21. Electricity utilization	kWh/ton cane	29.14	28.70	14.85	46.04

Table 6.3 Background information of 4 sugar mills factory in Eastern Thailand

NO.	Descriptions	Sugar mill	Sugar mill	Sugar mill	Sugar mill
		1	2	3	4
1	Age of sugar milling (years)	46	53	49	36
2	Capacity (ton cane/day)	6,000	5,000	6,747	5,560
3	Operating day (days)	87	95	96	105
4	Operating time/day (hours)	24	24	24	24
5	Total sugarcane yield (tons)	521,761	293,127	549,920	448,854
	<i>Fresh cane (tons)</i>	156,528	199,978	175,965	167,134
	<i>Burn cane (tons)</i>	356,233	93,149	373,964	281,720
6	Total electricity on the operating periods (kWh)	10,848,628	6,360,540	18,355,768	15,427,002
	<i>Electricity from Grid (kWh)</i>	305,753	265,472	1,000 kWh (in case T.G.broken)	118,627
	<i>Electricity from Bagasse (kWh)</i>	10,542,875	6,095,067	18,355,768	15,308,378
7	The electricity utilization (kWh/ton cane)	20.79	21.70	33.38	34.37
8	The electricity utilization (kWh/ton sugar)	205.06	252.19	343.35	389.43
9	Sugar (tons)	52,904	25,221	53,461	39,614
10	Molasses (tons)	23,168	13,307	26,042	25,111
11	Filter cake (tons)	20,881	8,748	20,457	12,781
11	Bagasse (tons)	144,538	81,202	152,339	124,342
12	Sugar/Yield (kg sugar/ton cane)	101.39	86.04	97.22	88.26

6.2.2 Carbon budget in products and waste materials

This part characterizes the carbon budget in products and waste materials from sugar production (Table 6.4). The computation is based on carbon budget in each sugarcane component by mass of product per sugarcane yield. The yield is 56 ton cane yield/ha. It was estimated by dividing the sugarcane plant component (out of 100 ton) into 55.82 ton of stalk or cane yield, 10.52 ton of root system, and 33.67 ton of top and leaves (section 5.4). The estimate was aimed for the whole full carbon accounting in sugar mill factory. The calculation results indicate that 0.1 ton C/ton cane is absorbed annually by product and waste materials. Total carbon sequestered in all products is 5.62 ton C/ha.

This was sub-divided into sugar (share of 6.13 % of millable cane, 3.43 ton C, 0.03 ton C/ton cane), molasses (share of 4.83 % of millable cane, 2.16 ton C, 0.012 ton C/ton cane), filter cake (share of 3.52 % of millable cane, 0.59 ton C, 0.004 ton C/ton cane) and bagasse (share of 27.7 % of millable cane, 7.8 ton C, 0.058 ton C/ton cane) (Table 6.4).

Previous studies in Thailand reported that 1 ton of cane yield can produce sugar 105-120 kg (10.5 -12 % of millable cane), water 500-510 kg (50-51%), bagasse with 50 - 52% H₂O about 270-290 kg (27-29%), filter cake with 70-72% H₂O about 28-40 kg (2.8-4%) and molasses 50-60 kg (5-6%), respectively (Precha *et al.*, 2002). Moreover, Sombat (2003) reported that for 1 ton of cane, 100-200 kg of sugar, 250-300 kg of bagasse, 50-60 kg of molasses and 30-40 kg of filter cake, were produced.

Table 6.4 Total carbon stocks in sugar products and waste materials

Component	Share of millable cane	Moisture	Dry biomass	Carbon content (dry basis)	Carbon budget	Carbon budget	Carbon budget
	(%)	(%)	(ton)	(%)	(ton C/ha)	ton C/ton cane	kg C/ton cane
Sugar	6.13 ^g	0 ^d	3.43	42.1 ^b	1.45	0.026	25.81
Molasses	4.83 ^g	20 ^d	2.16	31.99 ^c	0.69	0.012	12.36
Filter cake	3.52 ^g	70	0.59	37.95 ^f	0.22	0.004	4.01
Bagasse	27.7 ^g	50 ^h	7.76	42 ^h	3.26	0.058	58.17
<i>Total</i>	<i>42.18</i>	<i>-</i>	<i>13.94</i>	<i>-</i>	<i>5.62</i>	<i>0.100</i>	<i>100.35</i>

^a Cane yield=56 ton/ha (based on calculation from 2003-2008 in Eastern Thailand)

^b Assuming sugar in pure sucrose [C₁₂H₂₂O₁₁]

^c Brix =0.88 (sucrose/dry/solids), assume to be 76% sucrose in molasses (Sombat, 2003)

^d Beeharry, 2001

^f Field experiments and laboratory analysis

^g Questionnaire from sugar mill in Eastern Thailand 2003-2008

^h Kuprianov *et al.*, 2005

6.3 GHG emissions from wastewater treatment

For this estimate, only data from two sugar mills available. The two sugar mills used oxidation pond and stabilization pond system for their wastewater treatments (Table 6.5). This is simply due to low cost and most of sugar mill in Eastern Thailand are located in the rural area with large area available within the sugar mill boundary. For the case study in Eastern region, some sugar mill factories have managed by to use the treated water for sugar mill cooling system. In addition, there are some sugar mill factories released the

treated wastewater into public canals. Generally, the property of wastewater before treated is 2300-4700 mg COD/l and 2800-4500 mg BOD/l. The properties of that treated wastewater are as followed: BOD was ranged from 14.5 to 57 mg/l and COD was ranged from 94.35 to 100 mg/l (Table 6.5).

Greenhouse gas emissions from water treatment were estimated following the methodology described in the IPCC, 2006 guideline. The results were 0.246 ± 0.02 kg CH₄/ton cane, equivalent to CO₂ emission on 5.12 ± 0.00005 kg CO₂ eq/ton cane (mean \pm S.D. represents data from 2 sugar mills factory, and the data are 4 years record). High CH₄ emission was related to high organic content in term of COD and BOD in wastewater (Table 6.6).

Table 6.5 Background information of wastewater and treated wastewater properties

Sugar mill No.	Wastewater System	Wastewater	Flow rate (m ³ /day)	BOD (mg/l)	COD (mg/l)	SS (mg/l)	TDS (mg/l)	pH
1	Oxidation pond	Wastewater	1500	2300	4500	ND	ND	ND
		Treated*	1500	14.5	94.35	ND	ND	ND
3	Stabilization pond, 8 pond/system	Wastewater	1350-1500	2800	4700	380	1000	5.75
		Treated**	150	57	100	55	1700	7.28

* Treated wastewater, release to public canal

** Treated wastewater, 10 % reused for cooling system and some remain are use in farm

No. of sugar mill was based on Table 6.3, ND= No data

Table 6.6 Average wastewater, treated wastewater properties and greenhouse gases emission from wastewater treatment from sugar mill process

Properties	Unit	Values
Sugarcane yield	tons	549,930
Operating date	days	87-96
Influent flow rate	m ³ /d	1,500
Total Influent flow rate	m ³ /yr	144,000
COD (Wastewater)	kg/l	4.7
Total CH ₄ emissions from wastewater	kg CH ₄ /yr	135,360
CH ₄ emission	kg CH ₄ /ton cane	0.246
CH ₄ emission , equivalent to CO ₂ emission	kg CO ₂ -eq/ton cane	5.12

6.4 Potential of sugarcane biomass (bagasse) for bioenergy generation

This part examines the potential of bagasse for bioenergy production and evaluates the potential greenhouse gas reduction potential as a result of such activity. To be able to estimate the mitigation potential of greenhouse gases, two scenarios (i) the baseline scenarios in which fossil fuel was used (100 % electricity utilization from grid) and (ii) bioenergy scenario (bagasse for surplus electricity base case in Eastern region), were compared.

6.4.1 Sugarcane biomass resources and power generation potential in sugar mill

In Thailand, the annual grinding season of sugarcane starts in November and ends in May of the following year depending on the amount of sugarcane supply to the mills. The largest factory in Thailand is Kaset Thai with production capacity of 40,000 tons cane per day while the smallest one is Uttaradit with production capacity of 2,683 tons cane per day. In Eastern Thailand, survey results show that the capacity of 17,978, 6,838, 6,479, 5,800 and 5,560 tons cane per day, respectively for the following mills: Eastern Sugar and Cane, Chonburi Sugar Industry, New Kwang Soon Lee, Chonburi Sugar & Trading and Rayong Sugar (Office of the cane and sugar board, 2005).

Bagasse is the fibrous residue left after extraction of sugar from the cane and can be used to generate electricity. In Thailand, normally, the bagasse left after juice extraction contributes approximately 30% by weight of crushed sugarcane (Therdyothin, 1992). All bagasse left from sugar mills is burnt in the boiler to generate high pressure steam. Then, the major of which is used in the sugar production process. The excess high pressure steam is used to drive the power generator in order to produce electricity to use in sugar process and the left is sold to commercial grid; the electricity generating authority of Thailand (EGAT).

Five sugar mills in Eastern Thailand in the 2006/07 production year produced over 915,410 tones of bagasse, calculated based on the percentage of bagasse produce obtained from the average data from the field experiments (1 ton of sugarcane can be generated 277.02 kg of bagasse). The uses of sugarcane in bioenergy systems for electricity cloud reduce total CO₂ emissions around 93% when compared with fossil fuel consumption (Beeharry, 2001). Other publishes reported the base case in Thailand by 1 ton of bagasse

can be used to generate 0.689 MWh of electricity (for this study 0.102 MWh is used) (Kiatkittpong *et al.*, 2009). Thus, calculating based on these values the bagasse in the region can generate 596,340 MWh of electricity. The forecasted energy potential of bagasse in Thailand are 90.65 PJ in 1997, 102.15 PJ in 2005 and 110.14 PJ in 2010. In addition, energy potential of sugarcane top and trash are 114.52 PJ in 1997, 129.18 PJ in 2005 and 139.27 PJ in 2010 (Boonrod *et al.*, 2005). The estimation for year 2005 and 2010 is based on the assumptions; during 1998 and 2000 sugarcane harvested area has been more or less constant while yield per hectare has improved at an average annual rate of 1.5%. Production of sugarcane has therefore been projected to increase at a rate of 1.5% per annum (Boonrod *et al.*, 2005).

In Eastern region from this case study, sugar mill factories have used bagasse to generate electricity for the sugar operating season for 4-5 months during December to March on the next year. Use of bagasse could generate electricity amounted to 80 % of the total needs.

In order to study the greenhouse gas emission reduction potential by using bagasse, two scenarios of energy consumption were compared. The first one is sugar mill uses all of their electricity from grid, which in turn supplies the electricity mainly from natural gas. The emission factor for electricity produced from natural gas is 0.0564 kg CO₂/MJ, 1 kg CH₄/TJ and 0.1 kg N₂O/TJ (IPCC, 2006). Secondly, sugar mill generates their electricity from all bagasse available for them. In the part of bagasse combustion, CO₂ emission was not accounted for GHG emissions. In this case, emission factor for electricity produced from bagasse is 30 kg CH₄/TJ and 4 kg N₂O/TJ (IPCC, 2006).

6.4.2 Power supply and GHG emission in sugar mill process

For fossil fuel scenario, the amount of electricity needs were estimated from the amount of electricity used in real operations, but assumed that this was generated solely from natural gas. From the surveys of 4 sugar mills in Eastern Thailand and the recorded used of electricity during 2003/04 to 2007/08, the total electricity consumed was 28.55 kWh/ton cane (5.80 kg CO₂-eq/ton cane: CH₄, 0.0022 kg CO₂-eq/ton cane; N₂O, 0.0032 kg CO₂-eq/ton cane. For the whole region, total energy electricity consumption was about 94,343 MWh and equivalent to 19,116 ton CO₂ (Table 6.8). The electricity consumption

from sugar mill process in this region is only about 0.07% of electricity consumption in this country (133,178,000 MWh) (DEDE, 2007).

For the bioenergy scenario (current situation in Eastern region), it was found that all sugar mills currently use bagasse to generate their own electricity (95% of all electricity consumed). The amount of energy consumed in the case of bioenergy scenario was 28.18 kWh/ton cane. However, as mentioned above, only those emitted as CH₄ and N₂O are considered in case of bagasse use. Thus, the emission in this case was 0.19 kg CO₂-eq/ton cane from bagasse (as CH₄ and N₂O from combustion) plus that were emitted from fossil use of 0.37 kWh/ton cane, which is equivalent to 0.08 kg CO₂-eq/ton cane (Table 6.7). The net emission in bioenergy scenario was 0.27 kg CO₂-eq/ton cane. For the all sugar mills in the eastern region, the amount of avoided emission when use of bagasse to substitute fossil fuel was 18,290 ton CO₂-eq/yr (Table 6.8). It is thus can be said that use of bagasse has a high potential to CO₂ mitigation in sugar mill process.

Table 6.7 Average electricity utilization (kWh) and CO₂ emission estimated from 4 sugar mills in Eastern region during 2003/04 to 2007/08 production years

Scenario	Fuel source	Electricity utilization (kWh/ton cane)	CO ₂ emission (kg CO ₂ -eq/ton cane/yr)				% of Emission
			CO ₂	CH ₄	N ₂ O	Total	
Fossil fuel (C _{fos})	100% from natural gas	28.55	5.80	0.00220	0.003200	5.80	100
	Grid	0.37	0.075	0.00003	0.000041	0.08	1.4
	Bagasse	28.18	-	0.06400	0.126000	0.19	3.3
Bioenergy (C _{bio})	Total	28.55	0.075	0.06403	0.126041	0.27	4.7
Avoided CO ₂ emission (C _{fos} -C _{bio})						5.53	

Table 6.8 Average electricity utilization (MWh) and equivalent to CO₂ emission for the whole area of Eastern Thailand from 2003/04 to 2007/08 production years

Scenario	Fuel source	Electricity utilization (MWh)	ton CO ₂ equivalent			Total
			Equivalent to CO ₂ emission			
			CO ₂	CH ₄	N ₂ O	
Fossil fuel	100% electricity utilization	94,343	19,166	7.27	10.57	19,166
	Grid	1,223	247.84	0.10	0.14	248.08
Bioenergy	Bagasse	93,120	-	211.48	416.36	627.84
	Total	94,343	248.84	211.58	416.5	876

Note: Sugarcane yield in Eastern Thailand is 3,304,490 ton average from 2003/04 to 2007/08 production years (Office on the Cane and Sugar Board, 2007)

6.4.3 Scaling up the greenhouse gases mitigation potential of bagasse

Sugar making is one of the most important agricultural processing industries in Thailand. Bagasse, a biomass fuel, is the waste generated by such process. As sugar producing plants need electric power and process steam, co-generation using bagasse as an alternate fuel for petroleum has been in use for some time. This will enable a plant to generate more electric power than its in-plant need so that the surplus power can be sold to the commercial grid. Study results from bioenergy scenario from 4 sugar mills in Eastern Thailand show that bagasse could generate electricity and use in the mill process at about 28.18 kWh/ton cane (equivalent to 0.19 kg CO₂-eq/ton cane) (Table 6.7). There are many examples on the role of bagasse to substitute fossil fuel use in sugar mill. For example, in Cuba case, use of bagasse for generate electricity it can generate the energy of 20-25 kWh/ton cane in low-efficiency back pressure steam turbines (Alonso *et al.*, 2006). There are different the amount of electricity that can be generate from bagasse; it depends on the different management in each sugar milling.

In the whole regions of Thailand and based on the estimated obtained from the current study, bagasse can replace electricity from grid of about 20.29 GWh equivalent average from 2003/04 to 2007/08 production years (calculated from Table 6.7 and 6.9 = 28.81 kWh/ton cane × 0.72 million tons cane). Since the portion of electricity derived

from bagasse and fossil fuels varied from year to year and from factory to factory, the amount of CO₂ emitted was quite different among years depended on electricity produced. The lowest from electricity utilization from grid was appear in 2005/06 and highest was appeared in 2007/08. In the fossil fuel scenario where all electricity used is generated from natural gas, the amount of CO₂ emissions from the whole regions would be 20.42 millions ton CO₂ (5.80 kg CO₂/ton cane × 3.52 millions ton cane). However, since on average 95.4% of all sugar mill factories have produced their own electricity and with the fact that only minor fraction was acquired from grid, these bagasse uses have helped reduce CO₂ emission of 19.50 millions ton CO₂ during 2004-2008 (Calculated based on data shown in Table 6.7 and 6.9).

The previous studies recorded that in a typical Thai sugar plant, at 90% oil-burning boiler efficiency, 5.95 kg of bagasse would replace 1 kg of oil but the Kyoto Mechanism defines CO₂ generation by fuel oil as 2.65 kg per liter. Using 0.85 for the specific gravity of fuel oil, the amount of CO₂ generation will be 3.12 kg CO₂/kg. Moreover, CO₂ reduction per ton of bagasse in terms of fuel oil was 0.524 kg CO₂/kg bagasse. As 1 kg of bagasse generates 2 kg of steam, the CO₂ reduction of a 100 ton/h steam boiler was 112,660 ton/year for an annual operation of 4,300 hours, as follows 112,660 ton CO₂/year (Wakamura, 2003). These results show the efficiency of bagasse that can generate electricity, which will be sold to commercial grid and CO₂ mitigation.

Table 6.9 Sugarcane yield and its potential for power generation in Eastern Thailand and the whole area in Thailand from 2003/04 to 2007/08 production years

Year	The whole area in Thailand (million tons)			Eastern Region (million tons)		
	Yield	Bagasse	Potential for surplus electricity ^a	Yield	Bagasse	Potential for surplus electricity ^a
2003/04	64.48	17.86	14.29	3.5	1.0	0.80
2004/05	47.82	13.25	10.60	2.5	0.7	0.56
2005/06	46.69	12.93	10.35	2.5	0.7	0.56
2006/07	63.80	17.67	14.14	3.3	0.9	0.72
2007/08	73.59	20.39	16.31	4.1	1.1	0.88
Total	296.38	82.10	65.68	15.9	4.4	3.52
Mean	59.28	16.42	13.14	3.2	0.9	0.72
Median	11.64	3.23	2.58	3.3	0.9	0.72
Min	64.48	17.86	14.29	2.5	0.7	0.56

^a Calculate base on 80% of bagasse produced on fresh weight using for surplus electricity (Philanthropic foundation of Energy for Environment, 2006)

^b Office of the cane and sugar board, 2008

6.5 Potential of molasses for bioethanol as a fuel transport: *Conclusion from others publication*

This part reviews the potential of molasses for producing bioethanol as a fuel transport and its relation to greenhouse gases emission and reduction. They were reviewed from other previous studies in Thailand, China, Brazil, USA and etc. This will later be used as a basis to evaluate the greenhouse gas mitigation potential for the eastern region.

The boundary and concept of life cycle energy and environmental impact analysis for conventional transport fuels (i.e. conventional gasoline: CG in this studied) and alternatives (i.e. bioethanol from molasses) is given in Figure 6.2. Estimates of WtT (Well to Tank) and TtW (Tank to Wheel) fossil fuel, petroleum use and GHG emissions for conventional gasoline and bioethanol various life cycle studies are reviewed.

The “Well to Tank” WtT stage of petroleum fuels includes the following main stage: crude oil recovery and transport, fuel refinery and transport. The WtT stage of biofuels includes sugarcane cultivation (agriculture stage), and transport, biofuel conversion (industrial stage) and transport. The “Tank to Wheel” TtW means fuel consumption and combustion. In the conventional gasoline there was estimated term TtW through in biofuels did not accounted for because the CO₂ emission from biofuel combustion will be recovered when biomass plant are re-growth. “Well to Wheel” WtW means combined between WtT and TtW.

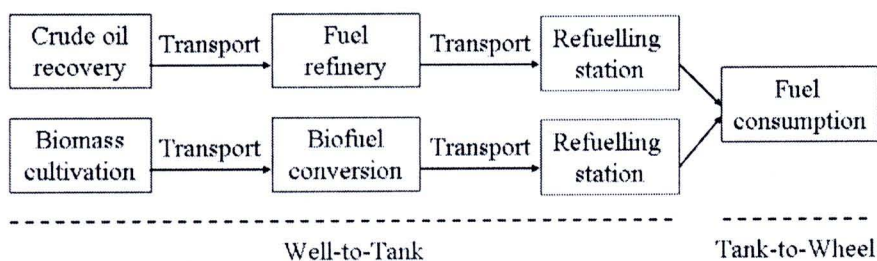


Figure 6.2 Life cycle framework for transportation fuels (Yan *et al.*, 2009)

In order to compare the results from various studies, GHG emissions are normalized to grams of carbon dioxide equivalent per MJ final fuel product (g CO₂-eq/MJ). Normalization of results is based on the net energy content of fuels (lower heating value). The net energy content of conventional gasoline is 33.152 MJ/l and of bioethanol is 21.185 MJ/l. The GWPs (time span of 100 years) of CO₂, CH₄ and N₂O are 1, 23 and 296, respectively (IPCC, 2001).

6.5.1 Well to Tank fossil fuel use and GHG emissions

Fossil fuel production systems have been developed over many years and have reached a high technological maturity. The variations of WtT fossil fuel use and GHG emissions in different countries are mainly due to different assumptions of technology level (crude oil recovery efficiencies, refinery efficiencies, energy efficiencies of various transportation modes, etc.); sources of electricity; distances and modes of transport. WtT fossil fuel and GHG emissions of conventional gasoline in China were estimated to be 20-22 g CO₂/MJ, 18.85 g CO₂/MJ for USA and 10-22 g CO₂/MJ for developed countries (Table 6.10).

Biofuel production systems are relatively new and more complex compared with fossil fuel systems. For comparison purpose, results from various bioethanol studies from molasses are shown in Table 6.11. In Thailand, GHG emission from WtT was about 32.36 g CO₂/MJ, and was 50 g CO₂/MJ for China and 20 g CO₂/MJ for current situation in Brazil (Table 6.11). A correlation of WtT fossil fuel use and GHG emissions data for all fuels available in the present review has been derived and presented in Figure 6.4.

Table 6.10 Well to Tank (WtT) and GHG emissions for fossil fuel

Fuel	GHG emission(g CO ₂ /MJ)	Country	References
CG	20	China	Huang <i>et al.</i> , 2003
	20		Shen <i>et al.</i> , 2006
	22		Zhou <i>et al.</i> , 2007
CG	18.85	USA ^a	Kristin <i>et al.</i> , 2009
CG	10-22	Developed countries	Yan <i>et al.</i> , 2009

CG: Conventional Gasoline

^a Conventional gasoline excludes oxygenates and in Crude oil extraction and transport life cycle stage also included are the GHG emissions associated with acquisition of natural gas liquids and unfinished oils. These two components made up approximately 6% of the input to U.S. refineries in 2005.

Table 6.11 Well to Tank (WtT) and GHG emissions for bioethanol

Fuel	GHG emission(g CO ₂ /MJ)	Country	References
Bioethanol	32.36	Thailand ^a	Silalertruksa <i>et al.</i> , 2009
Bioethanol	50 ^c	China	Yan <i>et al.</i> , 2009
Bioethanol	20	Brazil ^b	Macedo <i>et al.</i> , 2008

^a Based on three MoE Plant in Thailand

^b Current situation in Brazil

^c Using correlation between GHG emission from WtT fossil fuel use and GHG emission

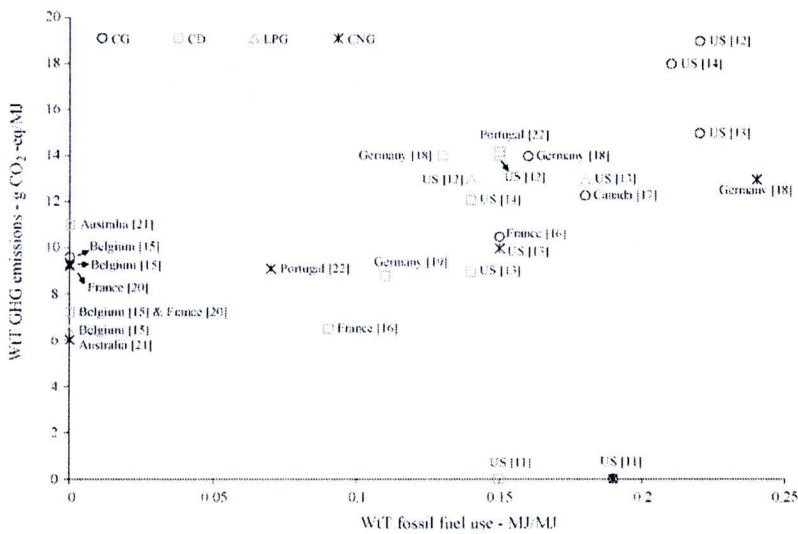


Figure 6.3 WtT fossil fuel use and GHG emissions for fossil fuels in developed countries (results from studies which considered only fossil fuel use or GHG emissions are shown on the axis), Yan *et al.*, 2009.

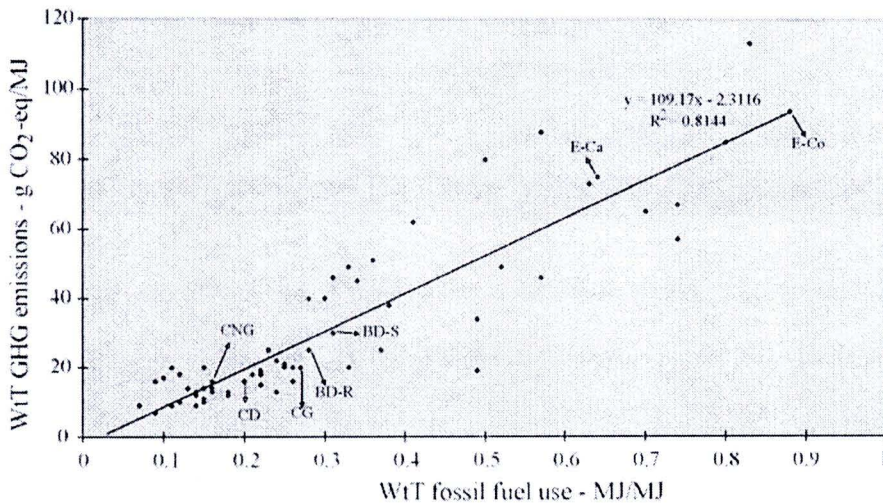


Figure 6.4 A linear correlation of the WtT fossil fuel use and GHG emissions for the data points from various studies, Yan *et al.*, 2009

6.5.2 Tank to Wheel fossil fuel use and GHG emissions

TtW GHG emissions for conventional gasoline were 69.08 g CO₂/MJ in Thailand (based on IPCC, 2006 guideline method and calculation), 72.55 g CO₂/MJ for USA and 69 g CO₂/MJ for China (Table 6.12). TtW GHG emissions are 0 g CO₂/MJ for biofuels because the CO₂ released during biofuel combustion is absorbed from the atmosphere during biomass cultivation. TtW GHG emissions for fossil fuels are calculated by assuming all the carbon in the fuel will become CO₂ after combustion.

Table 6.12 Tank to Wheel (TtW) and GHG emissions for fossil fuel

Fuel	GHG emission(g CO ₂ /MJ)	Country	References
CG	69.08	Thailand	IPCC, 2006
CG	72.55	USA	Kristin <i>et al.</i> , 2009
CG	69	China	Yan <i>et al.</i> , 2009
Bioethanol	zero	-	-

6.5.3 Conclusion of GHG emissions from the whole process

Table 6.13 shows the molasses for producing ethanol. This could avoid CO₂ emission about 41.08-59 g CO₂ eq/MJ (1.18-1.24 g CO₂/L of gasoline or 1.94-2.78 g CO₂/L of ethanol). The calculation is based on the LHV of gasoline, which is 33.152 MJ/L, and for ethanol this is 21.185 MJ/L.

From the present review it can be observed that bioethanol has the lower life cycle GHG emissions than conventional gasoline. Thus, replacing petroleum based fuel (CG) with bioethanol can reduce life cycle GHG emissions from petroleum fuel (CG).

Table 6.13 Conclusion of WtT, TtW, WtW and avoided CO₂ emission

Segment	Well to Tank (g CO ₂ /MJ)	Tank to Wheel (g CO ₂ /MJ)	Well to Wheel (g CO ₂ /MJ)
a. Conventional gasoline (CG)	10-22*	69-72.55***	79-91.08
b. Bioethanol	20-50**	zero	20-50
Avoid emission (C _{fos} - C _{bio})	10-28	69-72.55	41.08-59
Avoid emission (C _{fos} - C _{bio})	0.30-0.84 g CO ₂ /L of gasoline	2.08-2.19 g CO ₂ /L of gasoline	1.24-1.78 g CO ₂ /L of gasoline
Avoid emission (C _{fos} - C _{bio})	0.47-1.32 g CO ₂ /L of ethanol	3.26-3.42 g CO ₂ /L of ethanol	1.94-2.78 g CO ₂ /L of ethanol

Note; LHV gasoline is 33.152 MJ/L, Ethanol is 21.185 MJ/L

* Huang, 2003; Shen, 2006; Zhou, 2007; Kristin, 2009; Yan, 2009

** Silalertruksa, 2009; Yan, 2009; Macedo, 2008

*** IPCC, 2006; Krintin, 2009; Yan, 2009

6.5.4 The potential of molasses for producing ethanol in sugar mill in Eastern Thailand and the whole area of Thailand

This part preliminarily evaluates the potential of molasses for producing ethanol. This was based on computation from 2003/04 to 2007/08 production years in Eastern Thailand. About 0.13 million tons of molasses were produced and about 37.13 million L of ethanol could be produced from this molasses, if it is assumed that all are available for

such purpose. In Eastern Thailand, a total amount of molasses produced during 2003-2008 production year were 0.16 million tons molasses and thus 35.78 million L of ethanol could be produced (Table 6.14).

Table 6.14 Sugarcane yield, molasses productivity and the ethanol production in Eastern Thailand and the whole area in Thailand during 2003/04 to 2007/08 production years

Year	The whole area in Thailand (million tons)			Eastern Thailand (million tons)		
	Yield	Molasses	Ethanol (million L)	Yield	Molasses	Ethanol (million L)
2003/04	64.48	3.22	725.4	3.5	0.18	39.38
2004/05	47.82	2.39	538.0	2.5	0.13	28.13
2005/06	46.69	2.33	525.3	2.5	0.13	28.13
2006/07	63.80	3.19	717.8	3.3	0.17	37.13
2007/08	73.59	3.68	827.9	4.1	0.21	46.13
Total	59.28	2.96	666.86	3.18	0.16	35.78
Mean	63.80	3.19	717.75	3.30	0.17	37.13

For the whole country, during 2003/04 to 2007/08 cropping years, 2.96 million tons were produced and the ethanol production potential was 666.86 million L (Table 6.14). In fact, molasses are used for other purposes rather than for fuel ethanol production. In 2008, for example, out of total 3.68 millions ton, 1.5 millions tons were used in food industries (mostly for liquor production, seasoning powder and other product). The demand for molasses in 2008 was up significantly from the previous year (Sakchai *et al.*, 2008).

6.6 Summary of carbon budget and greenhouse emissions and reduction in sugar mills

6.6.1 Carbon budget in product and waste material

Table 6.15 represents the carbon content of products and waste materials. The total amount of yield is 13.94 ton; it was divided into 3.43 ton sugar, 2.16 ton molasses, 0.59 ton filter cake, and 7.76 ton bagasse. It was estimated into 25.81 kg C/ton cane from sugar, 12.36 kg C/ton cane from molasses, 4.01 kg C/ton cane from filter cake and 58.17 kg C/ton cane from bagasse. The waste material; molasses, filter cake and bagasse can be further used for bioenergy production and organic fertilizer in sugarcane field.

Table 6.15 Summarized of carbon budget from sugar milling, the case study in Eastern region of Thailand

Product and waste material	Amount (ton)	Carbon budget (kg C/ton cane)
- Sugar	3.43	25.81
- Molasse	2.16	12.36
- Filter cake	0.59	4.01
- Bagasse	7.76	58.17
<i>Total</i>	<i>13.94</i>	<i>100.35</i>

6.6.2 Greenhouse gas emissions and reduction potential in sugar mills

This part characterizes the greenhouse gases emission and reduction from sugar process (Table 6.16 and Figure 6.5). This was divided into greenhouse gas emission from wastewater treatment plant and fossil fuel utilization. Total greenhouse gas emission from fossil fuel scenario is 10.92 kg CO₂-eq/ton cane and bioenergy scenario is 5.39 kg CO₂-eq/ton cane (Table 6.16). These can be concluded that bioenergy scenario, have a high potential to CO₂ mitigation in sugar mill process. Avoiding CO₂ emission from fossil fuel base was 5.53 kg CO₂/ton cane or bagasse for renewable energy cloud help to reduce CO₂ emission about 50.64 % of the total emission from fossil fuel (Table 6.7). In addition, the conclusion from the previous studies indicates that molasses to produce bioethanol can be use to replace conventional gasoline. It can help reduce CO₂ emission about 1.94-2.78 g CO₂/L of ethanol produced (Table 6.13).

If considers GHG emission from sugar mill process based on current situation in Eastern region as mention earlier on bioenergy scenario (Table 6.16), per one ton cane the product yields are as followed; 93.23 kg of sugar, 48.34 kg of molasses, 36 kg of filter cake and 277.02 kg of bagasse (data from 4 sugar mills in Eastern Thailand 2003-2008 production years and Table 6.2. Thus, this renders the estimate GHG emission distribution for each product and waste material (Figure 6.5).



Table 6.16 Summary of greenhouse gases emission in sugar milling, the case study in Eastern region of Thailand

Activity	(a)	(b)
	Fossil fuel scenario (kg CO ₂ -eq/ton cane)	Bioenergy Scenario (kg CO ₂ -eq/ton cane)
<i>Sugar milling</i>		
- CH ₄ emission from waste water	5.12	5.12
- C emission from 100% electricity utilization from grid	5.80	-
-C emission from bagasse to surplus electricity	-	0.27
<i>Total</i>	10.92	5.39
<i>Avoid CO₂</i>	5.53 kg CO ₂ /ton cane	

Table 6.17 Calculation of GHGs emission in sugar milling based on bioenergy scenario (the current situation in Eastern Thailand) in term of carbon equivalent by % of product and waste material

Segments	CO ₂ equivalent				
	kg CO ₂ /ton cane	kg CO ₂ /ton sugar	kg CO ₂ /ton molasses	kg CO ₂ /ton filter cake	kg CO ₂ /ton bagasse
- CH ₄ emission from wastewater	5.12	54.92	105.92	142.22	18.48
-C emission from electricity utilization from grid & bagasse to surplus electricity	0.27	2.89	5.58	7.50	0.97
<i>Total</i>	5.39	57.81	111.5	149.72	19.45

** Calculate base on 1 ton cane can be produce 93.23 kg of sugar

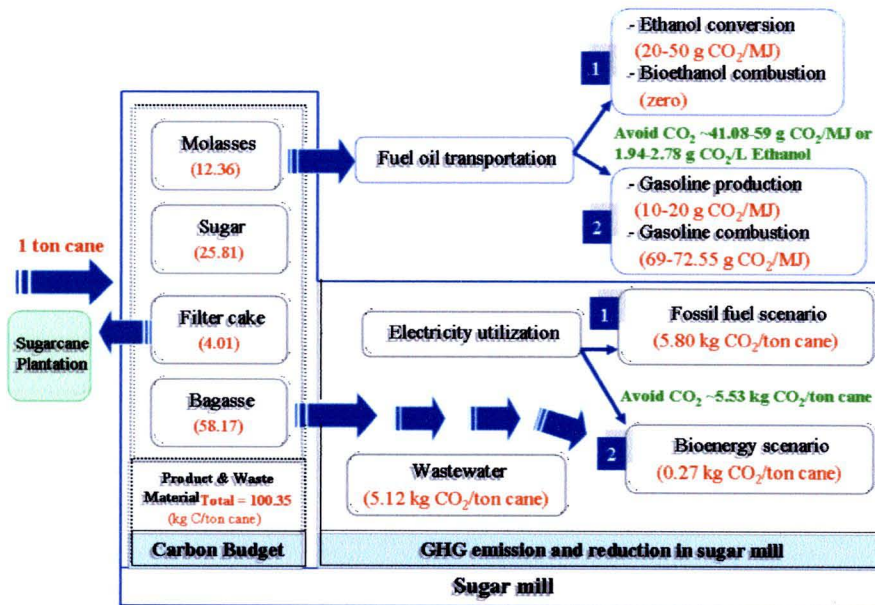


Figure 6.5 Carbon contents, CO₂ emission and reduction equivalent in sugar mill