CHAPTER IV
RESULTS AND DISCUSSION

4.1 Hot-Mixed Asphalt

In this study we can gain acceptance the actual hot-mixed asphalt data from Thaiwat Engineering Co .,Ltd (Bangbuatong) only so we use basis of hot-mixed asphalt data to approach warm-mixed asphalt data with calculation from any research similar to our research.

4.1.1 Description Sites of Data Collection

On Tuesday morning of July 31, the team visited Thaiwat Engineering Co .,Ltd (Bangbuatong) to collect the data in the template firstly as shown in Figure 4.1.

Figure 4.1 The team visited Thaiwat Engineering Co .,Ltd (Bangbuatong).

4.1.1.1 Process of Thaiwat Engineering Co .,Ltd (Bangbuatong)

4.1.1.1.1 Production Process

In the production process, there are 6 main steps as illustrated in Figure 4.2.

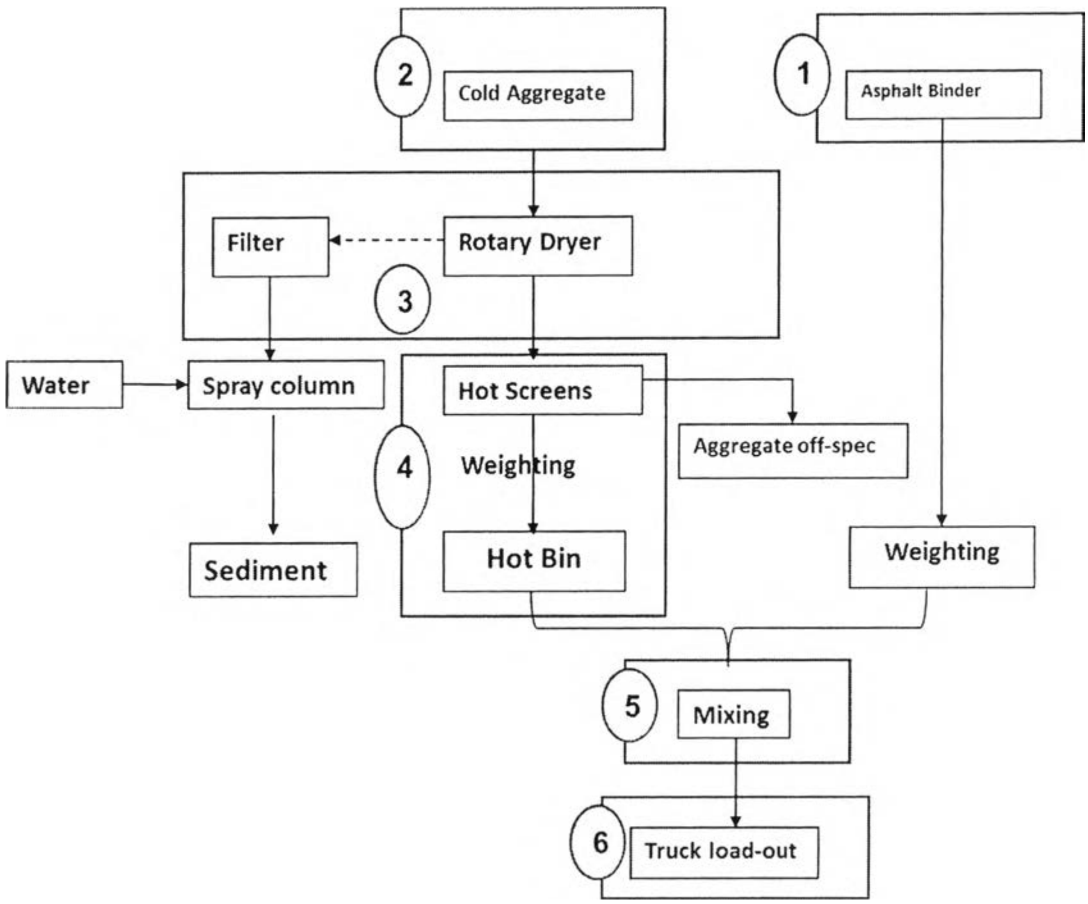
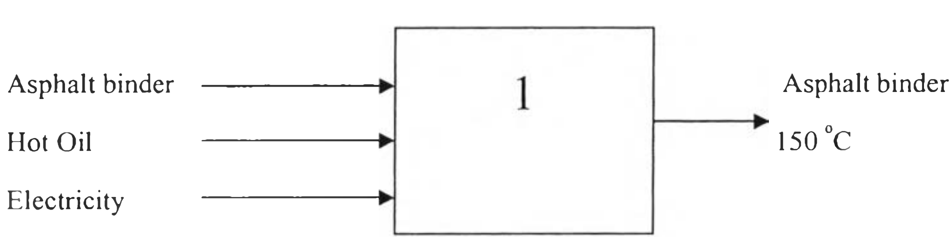


Figure 4.2 The hot-mixed asphalt production of Thaiwat Engineering Co .,Ltd (Bangbuatong).

1. Asphalt Binder



The plant buys asphalt binder from PTT Co .,Ltd and Shell Co .,Ltd(Sriracha at Chonburi) and keep in storage tank with heating at 150 °C by electricity. So asphalt binder is pumped from a heated storage tank to an asphalt bucket, where it is weighed to achieve the desired aggregate-to-asphalt binder. The transferred pipe has 2 layers which asphalt binder is inside and hot-oil is outside. Hot-oil is for keeping temperature at 150 °C and is circulated system. Adding hot-oil when it is not full in outside pipe moreover it has fabric insulation for losing heat.

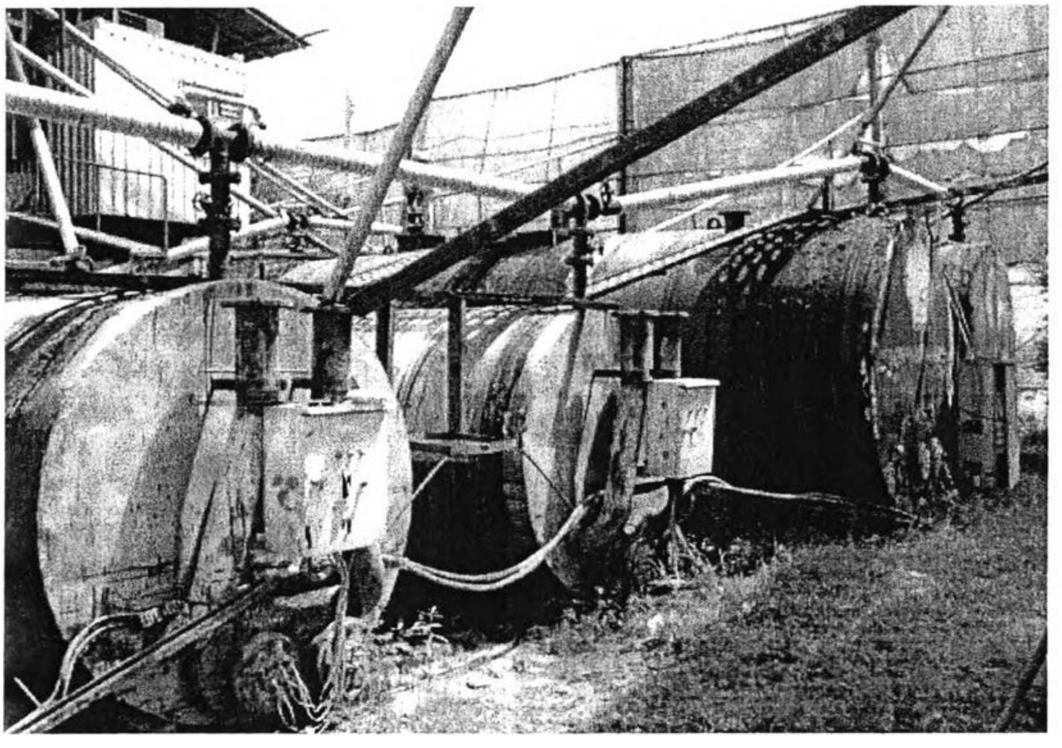
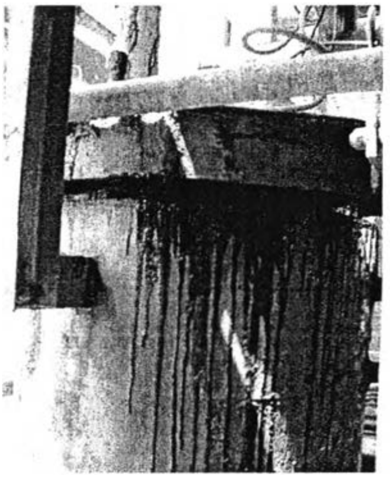


Figure 4.3 Asphalt binders in storage tank.



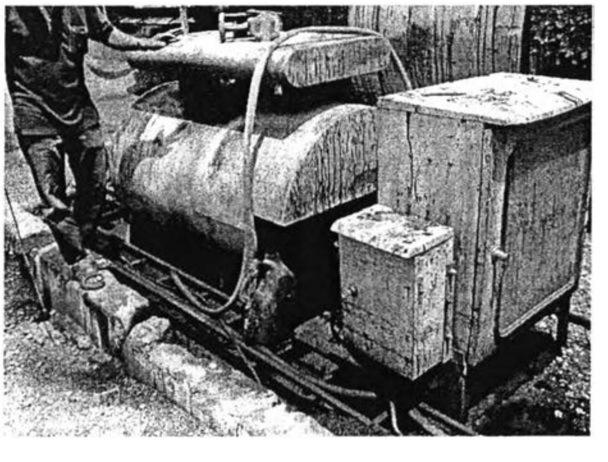
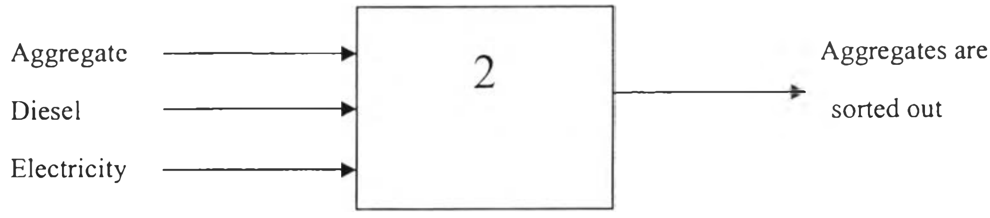


Figure 4.4 Asphalt binders bucket. **Figure 4.5** Hot oil storage tank.

2. Aggregate Preparation



There are 4 aggregate sizes which are fine aggregate, 3/8 inches aggregate, ¾ inches aggregate and ½ inches aggregate. They are piled up and transported to 4 cold aggregate buckets by tractor. Then the aggregate is transported into a rotary dryer.

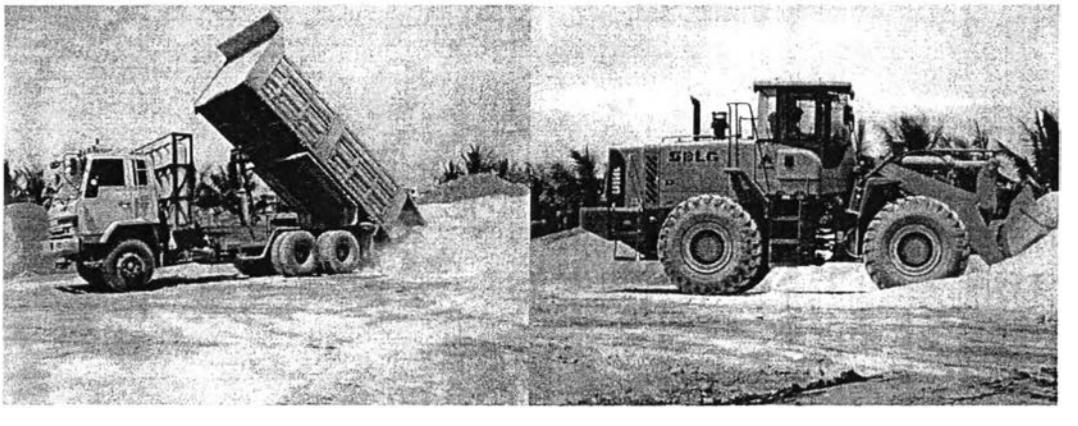


Figure 4.6 Pouring aggregate and transporting inside.

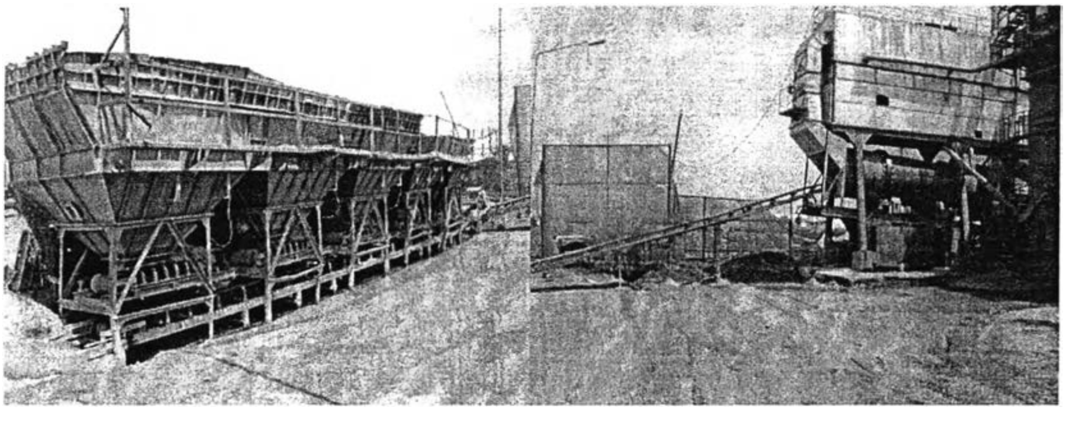
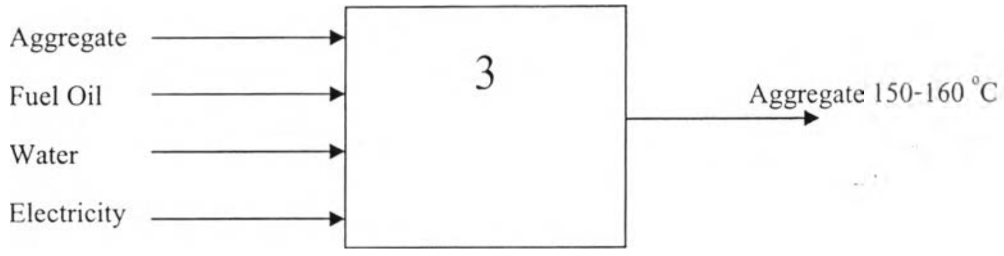


Figure 4.7 Cold aggregate tank and transporting to rotary dryer.

3. Rotary Dryer



Rotary Dryer is for driving away moisture and burn aggregates with fuel oil to 150-160 °C

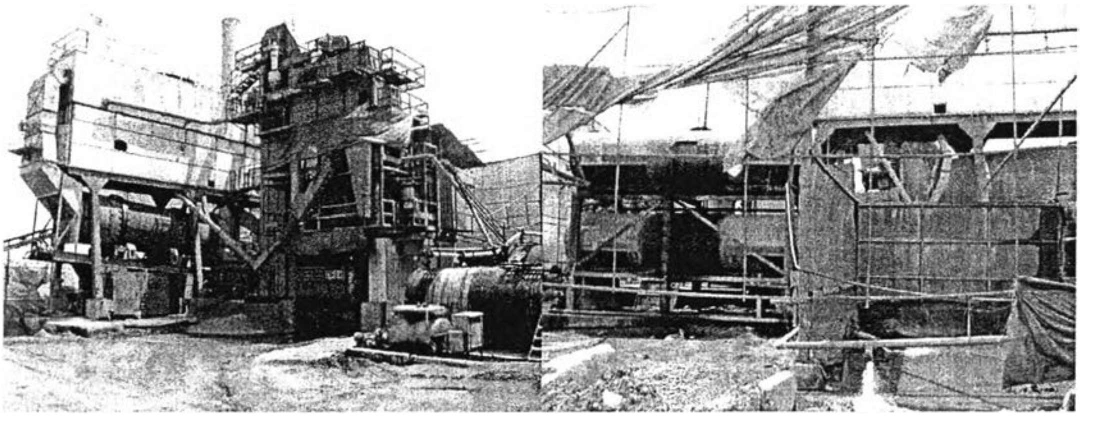


Figure 4.8 Rotary dryer system and fuel oil storage.

There are the dusts abundantly in burning process so the plant uses water to spray for protecting the spread dusts.

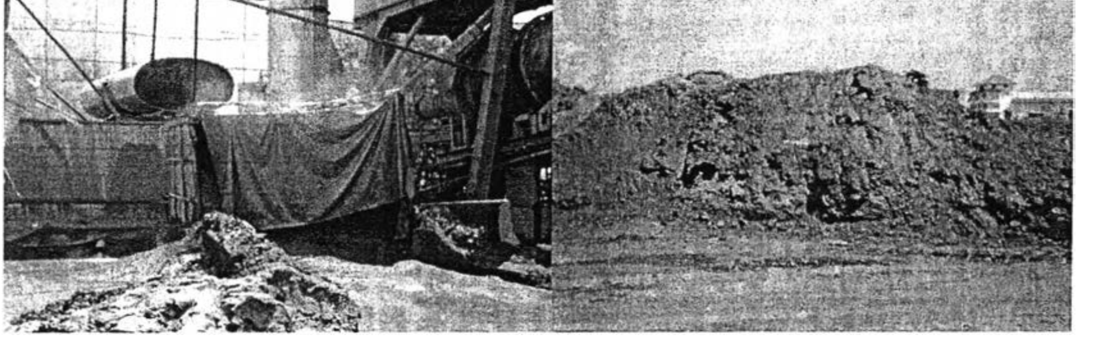


Figure 4.9 Trapping the dust and piling up of sediment.

The plant has pond for spraying at the back. The trapped water will be flow to follow in the ridge which for turning back to pool.

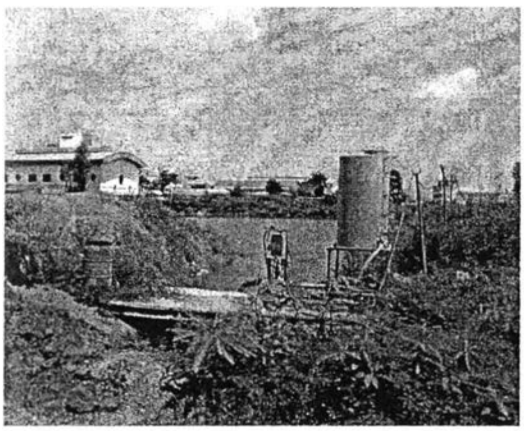
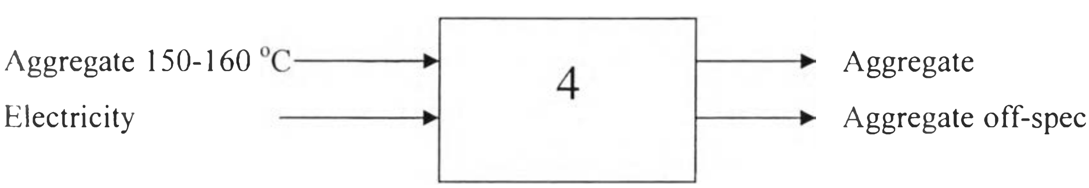


Figure 4.10 Pond of plant.

Figure 4.11 Ridge of plant.

4. Weighting



After burning aggregates, they are transferred to hot screen according to size. There is aggregates off-spec about 2-3%. The proportionate aggregates are kept at hot bin (it is green part in Figure 4.12) which for waiting to weigh and mix with asphalt binder.

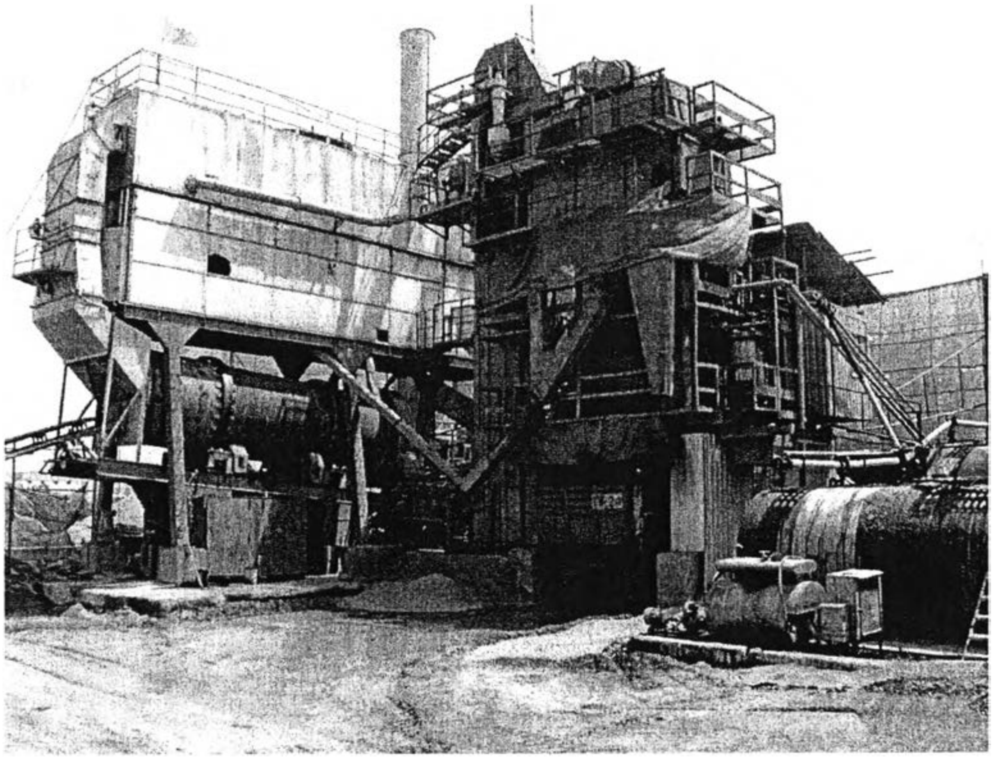
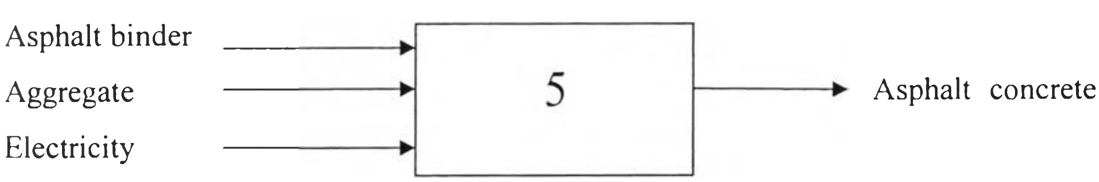


Figure 4.12 Hot-mixed asphalt plant.

5. Mixing



The asphalt binder and aggregates which is prepared are transferred to weight and mix. The mixing use about 45 seconds and all processes are controlled automatically in controlled room.

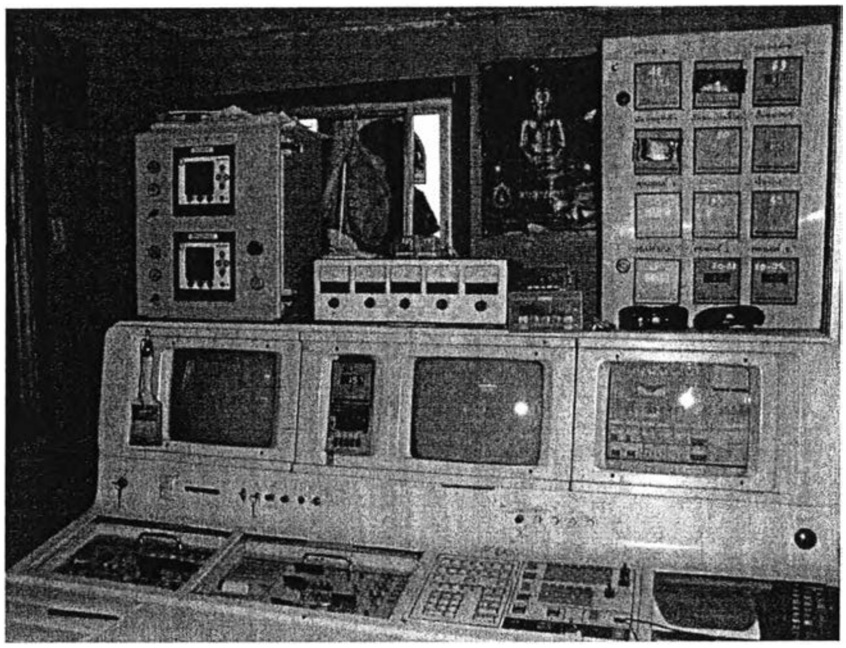
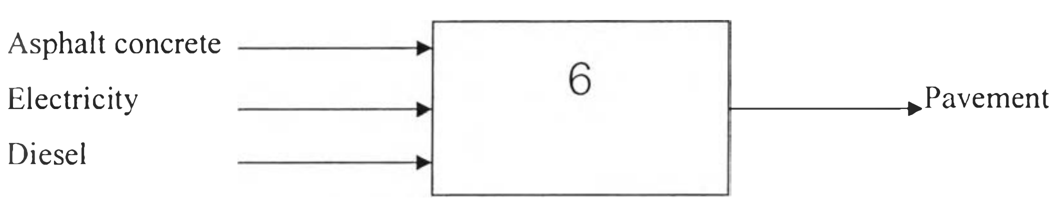


Figure 4.13 Controlled room

6. Track Load Out



After mixing, asphalt concrete is load out to truck to pavement and the distance between plant and paving is 37 kilometers.

4.1.1.1.2 Pavement Process

On Friday morning of November 2, my team visited Thaiwat Engineering Co .,Ltd (Bangbuatong) to collect the paving data at Chiangraknoi (เชียงรากน้อย). There are 6 Trailers and 4 trucks for this paving.

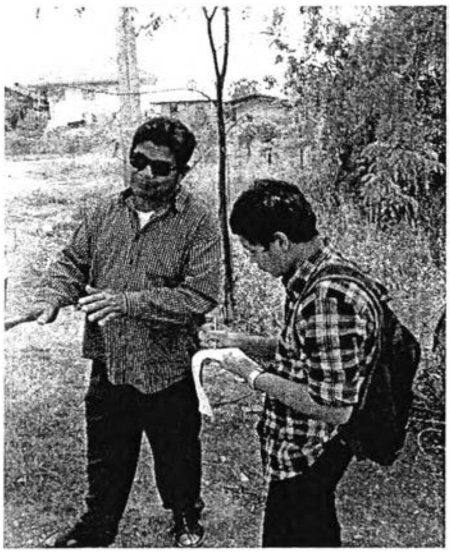


Figure 4.14 Interview Supervisor.

Figure 4.15 Interview Foreman.

This is the job of repairing the road which pave only wearing layer. Wearing which is covered with a thickness of 5 cm and a width of 10 meters and a distance of 1.1 km. Before the pavement of wearing layer, they will prepare the base layer by recycled truck. And shoveled the old mixed with Cement 3-4% and 2-3% water, and pour it back on the road in a single step and leave it for 7-15 days to make the Curing. When expired, Prime coat will be pave by a rubber CSS1 and leave 24 hours. In both steps, we did not see because they have prepared since last week. Then we started to get covered by paving of wearing layer.

1. Asphalt concrete trucks are carried mixed which temperature is about 150-160 °C from the plant. The site which is located about 37 km. Truck was parked and the car later pulled up next to a car that was first shown.

Figure 4.16 Truck for carrying asphalt concrete.

2. Asphalt concrete trucks pour hot-mixed asphalt into paver which was used to pave and 15 tons of weight. Paver and asphalt concrete truck moves with a speed of 7.28 m/s (From a distance of about 15 m and a timer for 2.06 minutes), the temperature of the asphalt concrete paving will start at about 145 ° C by using a thermometer to measure temperature. If the temperature is below 120 ° C, it cannot pave.

Figure 4.17 Thermometer to measure temperature.

Figure 4.18 Asphalt concrete truck pour hot-mixed asphalt into paver.

Because the road is paved lane by lane that is 5 meters, so the operators use pickax to equalize at edge joints. Moreover, they pave more a thickness of 25%, that is, if the specification is 5 cm thick, they will pave 6.25 cm. and it becomes to 5 cm after steamroller.

Figure 4.19 Equalize at edge joints.

3. After pave by paver, steel drum roller or Breakdown that weighs 9 tons use to compress the road. The steel wheels are lubricated with water for protecting asphalt concrete attached to the wheels seeing that the tank of water is the top of the wheel. Steel drum roller will be running all 2 path (1 patch = go + back) and have to use water 1000 Liters per 500 meters (estimate from foreman).

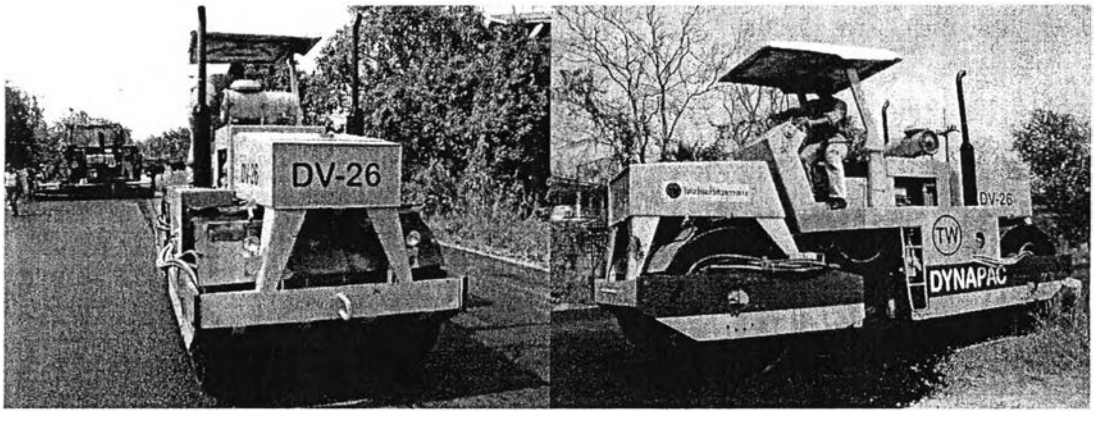


Figure 4.20 Steel drum rollers (DYNAPAC CS142).

4. After that, static pneumatic tried roller which has 9 wheels (4 wheels in front and 5 wheels in back) and 14 tons of weight continue to compress the road running all 14 path (1 patch = go + back). In generally, static pneumatic tried roller use water lubricating same as steel drum rollers but it is broken. So they use solar-oil for protecting asphalt concrete attached to the wheels and have to use solar/oil 10 Liters per 500 meters (estimate from foreman).

Figure 4.21 Static pneumatic tried roller (SAKAI TS200).

Between the pavements, the truck of carrying the water always park for adding water to steel drum rollers. The truck contains water 15,000 cubic meters of a day.

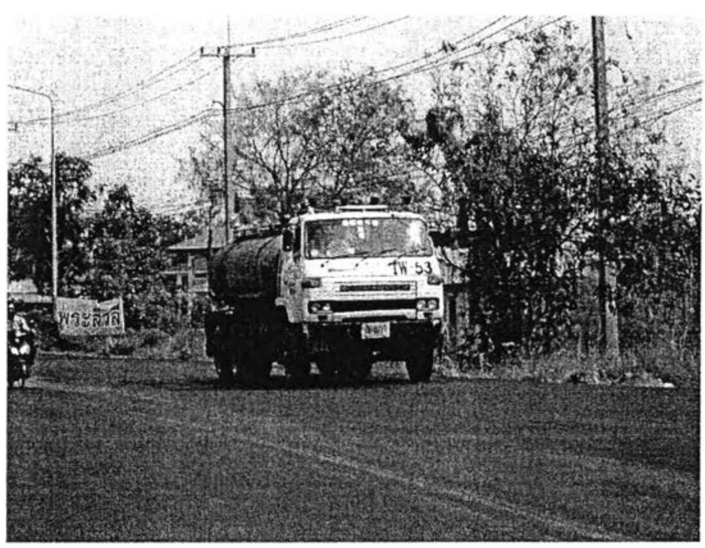


Figure 4.22 Truck for carrying the water.

4.1.1.2 Data Inventory

- Asphalt Binder

Asphalt binder is bought from PTT and Shell at Sriracha, Chonburi by 18-wheel truck which loads 25 tons and uses diesel fuel. Fuel consumption is about 2.4 liters of fuel per kilometer. Before applying, asphalt binder sample is tested the viscosity with flowing which should be more 120 seconds with testing cup. Asphalt binder is kept in five tanks. There are 2 tanks and 3 tanks containing 30 tons and 15 tons respectively.

We collect data from the control room. The computer set at 67.1 kg to produce 1 batch (1 batch = 1567.1 kg, 1500 kg of aggregate + 67.1 kg of asphalt binder) but asphalt binder is drop 68 kg at the real time.

- Aggregate

The plant orders from Siramitjacheon Co .,Ltd (โรงโม่หินศิลามิตรเจริญ (อู่ทอง) จำกัด) and Karnchanasirapan Co .,Ltd (โรงโม่หินกาญจนาศิลาภัณฑ์), Suphanburi. Aggregate has 4 sizes which are dust, 3/8 inches, 3/4 inches and 1/2 inches. The transportation uses 18-wheel truck which loads 25 tons and uses diesel fuel. Fuel consumption is about 2.4 liters of fuel per kilometer. Aggregate will be piled up and transported to 4 cold aggregate buckets with according size by tractor. The tractor will be used for transporting within the plant which consists of aggregate and sediment transferring. The tractor works by using diesel fuel and 500 tons of aggregate used about 80 liters (0.16 Litres / ton).

The data of the aggregate collect from the control room. The computer set 1500 kg to produce 1 batch (1 batch = 1567.1 kg, 1500 kg of aggregate + 67.1 kg of asphalt binder), which is proportional to the size of the job mix design. In this project uses of 700 kg of dust aggregate, 455 kg of 3/8 inches aggregate, 185 kg of 3/4 inches aggregate and 160 kg of 1/2 inches aggregate but the fact that the aggregate is dropped to exceed the 1500 kg about 0 to 2.4%.

- Pond Water

The plant will use the water from the pond behind the plant. Using pump discharge flow rate constant by 10 amperes current, 250 volts voltage and 2,500 watts of power. Water is used for the water trap dust arising from the production process and pulled in rollers for pavement.

The data of water is used to measure the flow rate of water because water is recycled which cannot find the exact amount of water used. The measurement of flow rate is pouring water in 15,000 liter tank along with a timer until the water in tank is full. From the calculation, the flow rate of water is 1,149.5 liters per minute or 19.11 liters per second.

Note that we would like to discuss evaporation water loss about 10%

- Fuel Oil

The plant orders from Shell Company in Sriracha, Chonburi by 10-wheel truck with 15,000 liters per each and use diesel fuel. The oil is used for burning aggregate to 160-170 ^{O}C temperature.

From asking, we have found that using 12 liters per one batch asphalt concrete.

- Hot Oil

Hot oil is used as a fuel for heat and control the temperature of the asphalt binder at 150 ^{O}C. The plant will be purchased from Shell at Sriracha, Chonburi by truck which used diesel as fuel. Then be stored in tanks at the plant which has a capacity of 600 liters.

Of inquiry found that the addition hot oil about 200 liters per year.

- Electricity

There are two meters which the large meter covers a total area and small meter is for the workers house.

The data is from making a note of the both meters and before-after production. Then subtract that value. Moreover electricity consumption within office and partial workers house will be eliminated for remaining electricity consumption in the production only. Electricity bill will help to calculate easier.

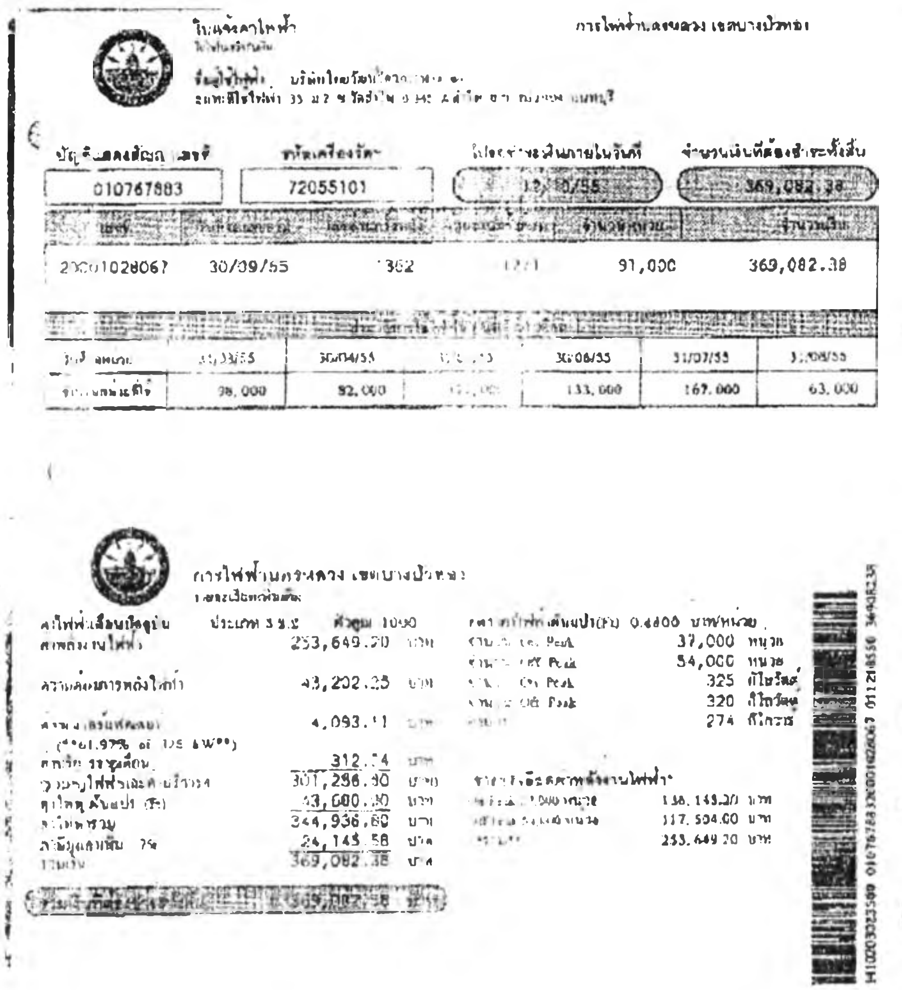


Figure 4.23 Electricity bill.

Table 4.1 Results of the inventory analysis of electricity for office

	Electric equipment	no.	Using rate (hour/day)	Power (Watt)	Unit
Meeting Room					
1	Bulb	6	3	15	0.27
2	Fluorescent	4	3	36	0.432
3	Air Conditioner	1	3	1200	3.6
Office					
1	PHILIPS 107 S1 Computer	1	15	500	7.5
2	Weighter	1	15	20	0.3
3	EPSON LQ-300-II Printer	1	15	60	0.9
4	Fluorescent	7	15	36	3.78
5	Screen Computer	2	15	330	9.9
6	CPU	2	15	150	4.5
7	loudspeaker	2	15	10	0.3
8	UPS	1	15	1200	18
9	EPSON Stylus Printer	1	15	60	0.9
10	Small Printer	1	15	4.5	0.0675
11	Photocopier	1	15	200	3
12	Fax	1	15	60	0.9
13	TP-LINK TD854W	1	15	1500	22.5
Toilet					
1	Long light bulb	2	2	36	0.144
Building					
1	Bulb	6	8	18	0.864
2	Freezer	1	8	150	1.2
3	Fan	2	8	60	0.96
4	Television	1	8	60	0.48
5	Refrigerator	1	8	120	0.96
6	Short light bulb		8	18	0
6 houses					
1	Short light bulb	36	8	18	5.184
2	Television	6	8	60	2.88
3	Refrigerator	6	8	120	5.76
4	Fan	12	8	60	5.76
				Total	101.0415
				1 month	30
					3,031.245

Table 4.2 Results of the inventory analysis of electricity

	August	July	June
Amount of hot-mixed asphalt production (Ton)	4,723	21,982	13,859
Electricity used total (unit)	63,000	167,000	133,000
Electricity for habitation within the plant (unit)	8,946.29	8,946.29	8,657.70
Electricity for office within the plant (unit)	3,132.30	3,132.30	3,031.26
Electricity for hot-mixed asphalt production (unit)	50,921.41	154,921.41	121,311.04
Electricity for hot-mixed asphalt production (unit/Ton)	10.78	7.05	8.75
Average electricity for hot-mixed asphalt production (unit/Ton)		**8.86**	

- Bitufresh

Bitufresh is used to adjust the flavor of the Asphalt binder and required that the addition of 1 liter bitufresh per 15 tons asphalt binder.

- Lubricant

Lubricant is used to lubricate machinery and required the addition of 1 kg per day (no matter how large or small it will be produced).

- Sediment

Dust is trapped with water. This will precipitate out. The plant will use a tractor for transporting to leave from the factory every day.

For the production of the Asphalt concrete 500 tons, sediment dust is about 5 tons.

- Emission

Emission is analyzed from Environmental Responsibility with accuracy measurement.

eVL

บริษัท เอ็นไวแล็บ จำกัด

Environmental responsibility with accuracy measurement

ANALYSIS REPORT

Project Name	:	โครงการตรวจวัดคุณภาพปล่องระบาย บริษัท ไทยวัฒน์ศวการทาง จำกัด (บางบัวทอง)			
Customer Name	:	บริษัท ดีเอเอม ไทย เอเจนซ์ จำกัด			
Address	:	59/7 หมู่ 4 ตำบลหนองไม้แดง อำเภอเมืองชลบุรี จังหวัดชลบุรี 20000			
Location	:	ปล่องระบายควัน	**Sampling By**	:	Envilab Co.,Ltd.
Sampling Date	:	21 August 2012	**Receive Date**	:	22 August 2012
Analytical Date	:	22-30 August 2012	**Report Date**	:	30 August 2012
Ref.No.	:	471-475/08/2012	**Reported No.**	:	2641/2012

Item	Unit	Analysis Method	ปล่องระบายควัน	Standard*
Time			14:00	
Diameter	m.		1.0	
Fuel			น้ำมันเตาเกรด A	
Temperature	°C	Thermocouple	49.2	
O_2 Content	%	Combustion Analyzer	16.8	
Moisture content	%	U.S. EPA Method 4	2.4	
Velocity	m/s	U.S. EPA Method 2	8.26	
Flow Rate (STD. Condition)	m^3/s	Calculated	5.81	
Total Suspended Particulate	mg/Nm^3	U.S. EPA Method 5	87.86	240
Sulfur dioxide (SO_2)	ppm	U.S. EPA Method 6	44.07	950
Oxides of Nitrogen (NO_x as NO_2)	ppm	U.S. EPA Method 7	162.73	200
Carbon monoxide (CO)	ppm	U.S. EPA Method 10	633.98	690
Opacity	%	Ringelmann Chart	5.21	10

Remark : * Notification of the Ministry of Industry (2006).
Concentration of air pollutants caculated at dry basis 25 °C 760 mm.Hg and 7% oxygen.

นายอัครเดช ปิ่นอารมณ์
ผู้อำนวยการห้องปฏิบัติการ
(เลขทะเบียน ว-118-ค-4686)
Sampling/Record/Analyze

นายอาคิต วิทยประภารัตน์
ผู้มีอำนาจลงนาม
(เลขทะเบียน ว-118-ค-2271)
Control

Figure 4.24 Analysis emission report.

4.1.1.2.1 Production Process

Table 4.3 Results of the inventory analysis of one ton asphalt concrete production

Input			Output		
Item	**Quantity**	**Unit**	**Item**	**Quantity**	**Unit**
Raw material			**Products**		
Asphalt binder	43	kg	asphalt concrete	1000	kg
Fine Aggregate	439	kg			
3/8 inches Aggregate	300	kg	**Waste**		
3/4 inches Aggregate	107	kg	Aggregate (off spec)	0.968	kg
1/2 inches Aggregate	122	kg	Sediment	10.10	kg
Pond water	688	Litres	**Waste emission**		
Electricity	9	units	Waste water	68.82	Litres
Grease	1.79	grams			
Bitufresh	0.00286	Litres	**Air emissions**		
Fuel			SO_2	66.92	ppm
Fuel Oil	8	Litres	NO_x	247.11	ppm
Hot oil	0.00123	Litres	CO	962.70	ppm

4.1.1.2.2 Transportation

In this study, data divide 7 parts of transportations which present emission based on one ton hot-mixed asphalt production at all.

Table 4.4 Emissions from transportation for asphalt binder

Transportation of Asphalt Binder					
Input Inventory			**Output Inventory**		
Description	**Unit**	**Amount**	**Description**	**Unit**	**Amount**
Resource			**Product**		
Diesel	kg	0.0735	Asphalt Binder	kg	43
			Emission to air		
			Carbon dioxide (CO_2)	g	274.41
			Carbon monoxide (CO)	g	1.2151
			Nitrogen oxides (NO_x)	g	3.2698
			Particulate matter (PM)	g	0.2454
			Hydrocarbons (HC)	g	0.2822
			Methane (CH_4)	g	0.0066
			Benzene (C_2H_6)	g	0.0053
			Toluene (C_7H_8)	g	0.0020
			Xylene (C_8H_{10})	g	0.0020
			Non – methane volatile organic compounds (NMVOCs)	g	0.0618
			Sulfur oxides (SO_x)	g	0.0500
			Nitrous Oxide (N_2O)	g	0.0092
			Cadmium	g	7.11E-07
			Copper	g	1.21E-04
			Chromium	g	3.55E-06
			Nickel	g	4.97E-06
			Selenium	g	7.11E-07
			Zinc	g	7.11E-05
			Lead	g	7.83E-09
			Mercury	g	1.42E-09

Table 4.5 Emissions from transportation for aggregate

Transportation of Aggregate					
Input Inventory			**Output Inventory**		
Description	**Unit**	**Amount**	**Description**	**Unit**	**Amount**
Resource			**Product**		
Diesel	kg	1.2437	Aggregate	kg	968
			Emission to air		
			Carbon dioxide (CO_2)	g	4643.157
			Carbon monoxide (CO)	g	20.561
			Nitrogen oxides (NO_x)	g	55.326
			Particulate matter (PM)	g	4.152
			Hydrocarbons (HC)	g	4.776
			Methane (CH_4)	g	0.111
			Benzene (C_2H_6)	g	0.089
			Toluene (C_7H_8)	g	0.033
			Xylene (C_8H_{10})	g	0.033
			Non – methane volatile organic compounds (NMVOCs)	g	1.046
			Sulfur oxides (SO_x)	g	0.846
			Nitrous Oxide (N_2O)	g	0.156
			Cadmium	g	1.20E-05
			Copper	g	2.05E-03
			Chromium	g	6.01E-05
			Nickel	g	8.42E-05
			Selenium	g	1.20E-05
			Zinc	g	1.20E-03
			Lead	g	1.32E-07
			Mercury	g	2.40E-08

Table 4.6 Emissions from transportation for fuel-oil

Transportation of Fuel-Oil					
Input Inventory			**Output Inventory**		
Description	**Unit**	**Amount**	**Description**	**Unit**	**Amount**
Resource			**Product**		
Diesel	kg	0.014	Fuel-Oil	kg	7.12
			Emission to air		
			Carbon dioxide (CO_2)	g	43.977
			Carbon monoxide (CO)	g	0.151
			Nitrogen oxides (NO_x)	g	0.453
			Particulate matter (PM)	g	0.034
			Hydrocarbons (HC)	g	0.039
			Methane (CH_4)	g	9.80E-04
			Benzene (C_2H_6)	g	7.47E-04
			Toluene (C_7H_8)	g	3.15E-04
			Xylene (C_8H_{10})	g	3.15E-04
			Non – methane volatile organic compounds (NMVOCs)	g	7.51E-02
			Sulfur oxides (SO_x)	g	9.48E-03
			Nitrous Oxide (N_2O)	g	1.74E-03
			Cadmium	g	1.35E-07
			Copper	g	2.30E-05
			Chromium	g	6.76E-07
			Nickel	g	9.47E-07
			Selenium	g	1.35E-07
			Zinc	g	1.35E-05
			Lead	g	1.49E-09
			Mercury	g	2.70E-10

Table 4.7 Emissions from transportation for hot-oil

Transportation of Hot-Oil					
Input Inventory			**Output Inventory**		
Description	**Unit**	**Amount**	**Description**	**Unit**	**Amount**
Resource			**Product**		
Diesel	kg	7E-06	Hot-Oil	kg	0.00107
			Emission to air		
			Carbon dioxide (CO_2)	g	0.0203
			Carbon monoxide (CO)	g	2.51E-04
			Nitrogen oxides (NO_x)	g	5.40E-05
			Particulate matter (PM)	g	1.69E-06
			Hydrocarbons (HC)	g	4.70E-05
			Methane (CH_4)	g	1.12E-06
			Benzene (C_2H_6)	g	8.96E-07
			Toluene (C_7H_8)	g	3.75E-07
			Xylene (C_8H_{10})	g	3.75E-07
			Non – methane volatile organic compounds (NMVOCs)	g	2.44E-05
			Sulfur oxides (SO_x)	g	4.64E-06
			Nitrous Oxide (N_2O)	g	8.31E-07
			Cadmium	g	6.63E-11
			Copper	g	1.13E-08
			Chromium	g	3.32E-10
			Nickel	g	4.64E-10
			Selenium	g	6.63E-11
			Zinc	g	6.63E-09
			Lead	g	7.30E-13
			Mercury	g	1.33E-13

Table 4.8 Emissions from transportation for grease

Transportation of Grease					
Input Inventory			**Output Inventory**		
Description	**Unit**	**Amount**	**Description**	**Unit**	**Amount**
Resource			**Product**		
Diesel	kg	1E-05	Grease	kg	0.00179
			Emission to air		
			Carbon dioxide (CO_2)	g	0.0341
			Carbon monoxide (CO)	g	0.0004
			Nitrogen oxides (NO_x)	g	9.12E-05
			Particulate matter (PM)	g	2.85E-06
			Hydrocarbons (HC)	g	7.89E-05
			Methane (CH_4)	g	1.89E-06
			Benzene (C_2H_6)	g	1.51E-06
			Toluene (C_7H_8)	g	6.30E-07
			Xylene (C_8H_{10})	g	6.30E-07
			Non – methane volatile organic compounds (NMVOCs)	g	4.11E-05
			Sulfur oxides (SO_x)	g	7.81E-06
			Nitrous Oxide (N_2O)	g	1.40E-06
			Cadmium	g	1.11E-10
			Copper	g	1.90E-08
			Chromium	g	5.59E-10
			Nickel	g	7.81E-10
			Selenium	g	1.11E-10
			Zinc	g	1.11E-08
			Lead	g	1.23E-12
			Mercury	g	2.23E-13

Table 4.9 Emissions from transportation for asphalt concrete

Transportation of Asphalt Concrete					
Input Inventory			**Output Inventory**		
Description	**Unit**	**Amount**	**Description**	**Unit**	**Amount**
Resource			**Product**		
Diesel	kg	0.5128	Asphalt Concrete	kg	1000
			Emission to air		
			Carbon dioxide (CO_2)	g	1607.65
			Carbon monoxide (CO)	g	5.509
			Nitrogen oxides (NO_x)	g	16.558
			Particulate matter (PM)	g	1.240
			Hydrocarbons (HC)	g	1.439
			Methane (CH_4)	g	0.033
			Benzene (C_2H_6)	g	0.027
			Toluene (C_7H_8)	g	0.012
			Xylene (C_8H_{10})	g	0.012
			Non – methane volatile organic compounds (NMVOCs)	g	2.745
			Sulfur oxides (SO_x)	g	0.348
			Nitrous Oxide (N_2O)	g	0.063
			Cadmium	g	4.96E-06
			Copper	g	8.40E-04
			Chromium	g	2.47E-05
			Nickel	g	3.46E-05
			Selenium	g	4.96E-06
			Zinc	g	4.96E-04
			Lead	g	5.44E-08
			Mercury	g	9.88E-09

Table 4.10 Emissions from transportation for water

Transportation of Water					
Input Inventory			**Output Inventory**		
Description	**Unit**	**Amount**	**Description**	**Unit**	**Amount**
Resource			**Product**		
Diesel	kg	0.0018	Water	kg	3.7
			Emission to air		
			Carbon dioxide (CO_2)	g	5.5267
			Carbon monoxide (CO)	g	0.0189
			Nitrogen oxides (NO_x)	g	0.0569
			Particulate matter (PM)	g	0.0043
			Hydrocarbons (HC)	g	0.0049
			Methane (CH_4)	g	0.0001
			Benzene (C_2H_6)	g	9.39E-05
			Toluene (C_7H_8)	g	3.96E-05
			Xylene (C_8H_{10})	g	3.96E-05
			Non – methane volatile organic compounds (NMVOCs)	g	9.43E-03
			Sulfur oxides (SO_x)	g	1.19E-03
			Nitrous Oxide (N_2O)	g	2.19E-04
			Cadmium	g	1.70E-08
			Copper	g	2.89E-06
			Chromium	g	8.50E-08
			Nickel	g	1.19E-07
			Selenium	g	1.70E-08
			Zinc	g	1.70E-06
			Lead	g	1.88E-10
			Mercury	g	3.40E-11

4.1.1.2.3 Paving Process

Table 4.11 Results of the inventory analysis of paving per one ton asphalt concrete production

Process	**Construction**		
	Paving	***Breakdown Rolling***	***Finish Rolling***
Time Used	0.0052 h	0.00103 h	0.035 h
Energy consumption (MJ)			
Fuel(Diesel)	5.79	0.2623	12.1641
Water used(Litres)			
Water used	-	4.5762	4.5762

4.1.1.2.4 Disposal Process

The waste management of this study has two different waste treatment scenarios: landfill and recycle. In this research, the inventory analysis of end of life phase involves the collection and computation of data to quantify relevant inputs and outputs of the system, the use of energy, and emissions to air. The inventory data were further analyzed by SimaPro 7.3 program with Eco-Indicator 95 method and CML 2 baseline 2000 method was used to compute energy demand and environmental impact potentials.

4.1.1.2.4.1 Transportation for Waste Collection

The transportation asphaly waste from pavement site to disposal site is approximately 37 km by using 10-wheel truck at full load 16 tons and go through all kind of hardships and difficulties condition.

Table 4.12 Emissions from transportation for waste collection

Transportation of Asphalt Concrete					
Input Inventory			Output Inventory		
Description	Unit	Amount	Description	Unit	Amount
Resource			Product		
Diesel	kg	0.5128	Asphalt Concrete	kg	990
			Emission to air		
			Carbon dioxide (CO_2)	g	1607.65
			Carbon monoxide (CO)	g	5.509
			Nitrogen oxides (NO_x)	g	16.558
			Particulate matter (PM)	g	1.240
			Hydrocarbons (HC)	g	1.439
			Methane (CH_4)	g	0.033
			Benzene (C_2H_6)	g	0.027
			Toluene (C_7H_8)	g	0.012
			Xylene (C_8H_{10})	g	0.012
			Non – methane volatile organic compounds (NMVOCs)	g	2.745
			Sulfur oxides (SO_x)	g	0.348
			Nitrous Oxide (N_2O)	g	0.063
			Cadmium	g	4.96E-06
			Copper	g	8.40E-04
			Chromium	g	2.47E-05
			Nickel	g	3.46E-05
			Selenium	g	4.96E-06
			Zinc	g	4.96E-04
			Lead	g	5.44E-08
			Mercury	g	9.88E-09

4.1.1.2.4.2 Landfill

In landfill, we use information from eco-invent data base with 1%loss. This study analyzed based on 1 ton asphalt concrete treated after service period of the road.

Table 4.13 Results of the inventory analysis of landfill based on one ton of asphalt waste.

Input			Output		
Item	Quantity	Unit	Item	Quantity	Unit
Raw material			**Products**		
Reclaimed asphalt pavement	1000	kg	Asphalt binder + aggregate	990	kg

4.1.1.2.4.3 Recycling

For recycling we use information from literatures. The recovery and processing of the recycled asphalt concrete require additional energy inputs. These inputs include the energy required to recover, load, and crush asphalt concrete (Levis, 2008); however, the GHG emissions associated with these additional energy inputs are outweighed by the GHG savings from the avoided raw material extraction for aggregate and crude oil, as well as the avoided asphalt binder production.

Table 4.14 Results of the inventory analysis of recycling scenario based on one ton of asphalt waste

Input			Output		
Item	Quantity	Unit	Item	Quantity	Unit
Raw material			**Products**		
Reclaimed asphalt pavement	1000	kg	Asphalt binder + aggregate	990	kg
Energy			**Waste**		
Power shovel	10.021	MJ	Asphalt binder + aggregate	10	kg
Motor grader	1.993	MJ			
Storage, crushing, screening	25	MJ			

4.1.1.3 Life Cycle Impact Assessment

After LCI for hot-mixed asphalt was completed, life cycle impact assessment (LCIA) could be analyzed for one ton of hot-mixed asphalt for relevant impact categories, using both impact assessment model CML 2 baseline 2000 and Eco-Indicator 95. Figure 4.25 illustrates a simple process diagram of hot-mixed asphalt production, which can be divided into 3 main unit processes: hot-mixed asphalt production (raw material + production), transportation and pavement. Figure 4.26 shows the greenhouse gas (GHG) emission in each unit process per ton of HMA production. It can be seen from this figure that raw material has the highest GHG impact among the four unit process of the overall hot-mixed asphalt production.

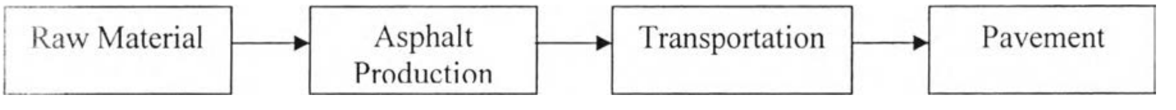


Figure 4.25 A Simple process diagram of asphalt production and usage.

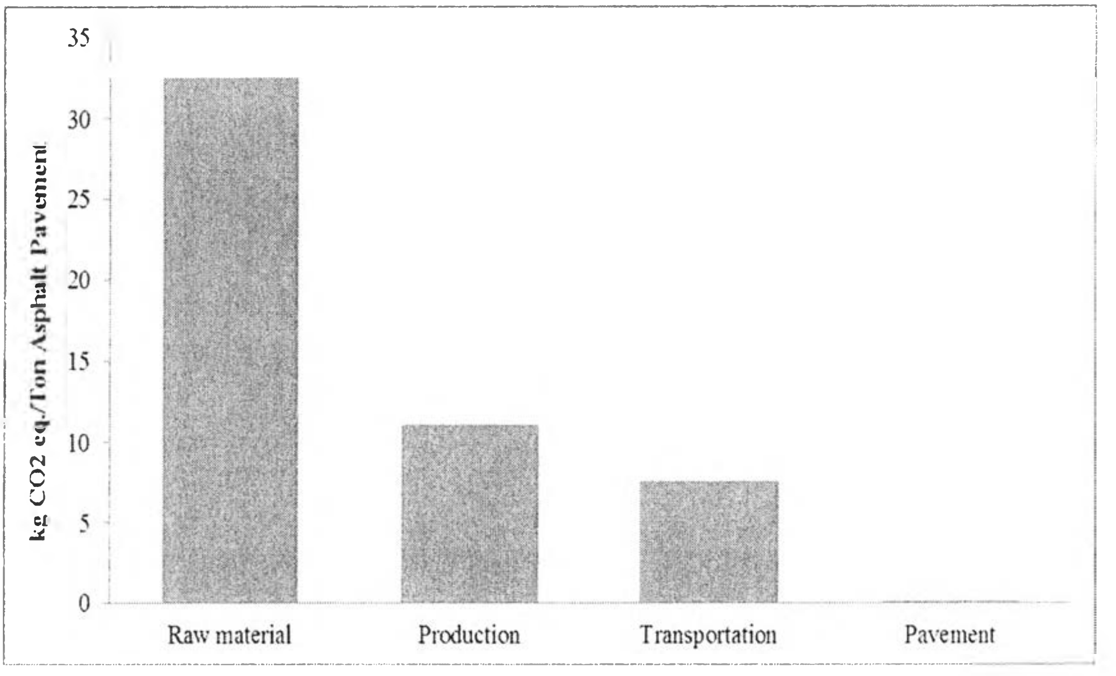


Figure 4.26 GHG emission of hot-mixed asphalt production for each unit process by CML 2 baseline 2000.

- Global Warming Potential (GWP)

GWP impact is represented by GHG emission as shown in Figure 4.26. From the figure, it can be seen that the most GHG emission in raw material is from bitumen because it include emission from crude oil.

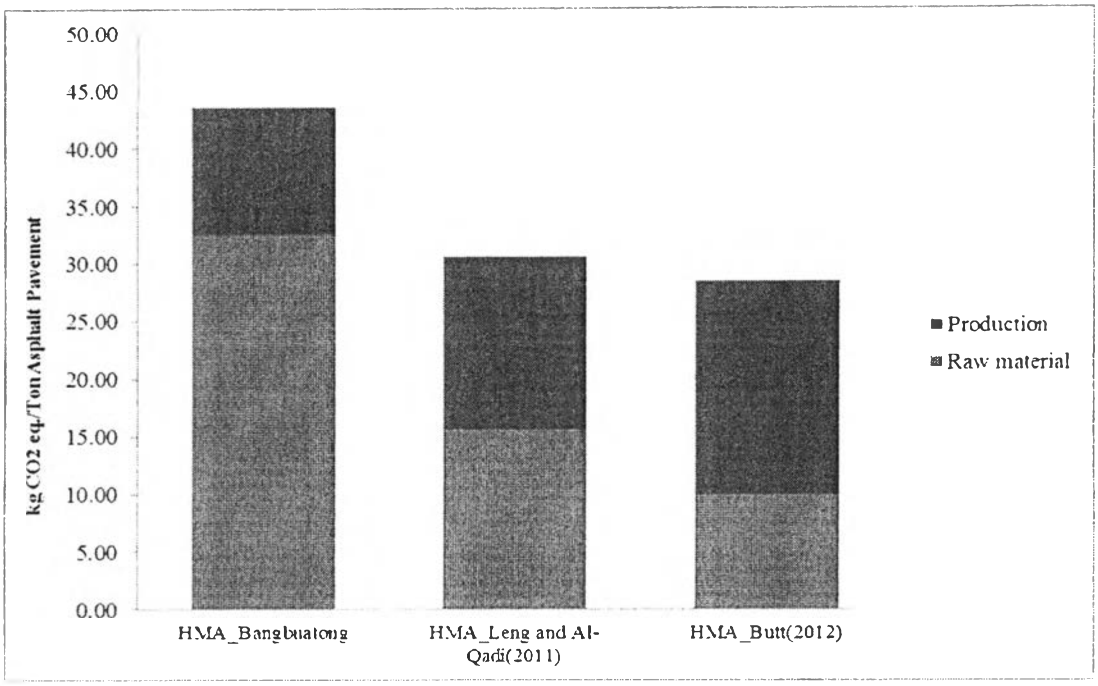


Figure 4.27 Comparison of GWP of production process between Bangbuatong plant, HMA_Leng and Al-Qadi(2011) and HMA_Butt (2012) by using CML 2 baseline 2000.

Leng and Al-Qadi (2011) presented the comparative life cycle assessment (LCA) between warm stone mastic asphalt (SMA) and conventional SMA. Specifically, the study evaluated and compared the life cycle environmental and economic performances of two mixtures: a warm SMA binder course mixture with a chemical additive and a control hot SMA binder course mixture. Both of these mixtures were utilized as part of a complete overlay project on the Veterans Memorial Expressway (I-355) near Chicago as part of the Illinois Tollway system. Moreover, Butt (2012) reported the selected pavement profile and materials were based on a commonly built Swedish pavement structure that is designed to have a service life time of 20 years. The pavement consisted of a 50 mm thick wearing course, binder course (different for different cases depending on the design) above an 80 mm base course and a 420 mm granular sub-base layer.

From Figure 4.27, it can be seen that Bangbuatong plant has shown to be the highest GWP which is equal to 43.64 kg CO_2 eq. / Ton of asphalt. The lowest GWP is HMA_Butt (2012) has shown the GWP 28.50 kg CO_2

eq. / Ton of asphalt. For HMA_Leng and Al-Qadi (2011) which is equal to 30.61 kg CO_2 eq. / Ton of asphalt.

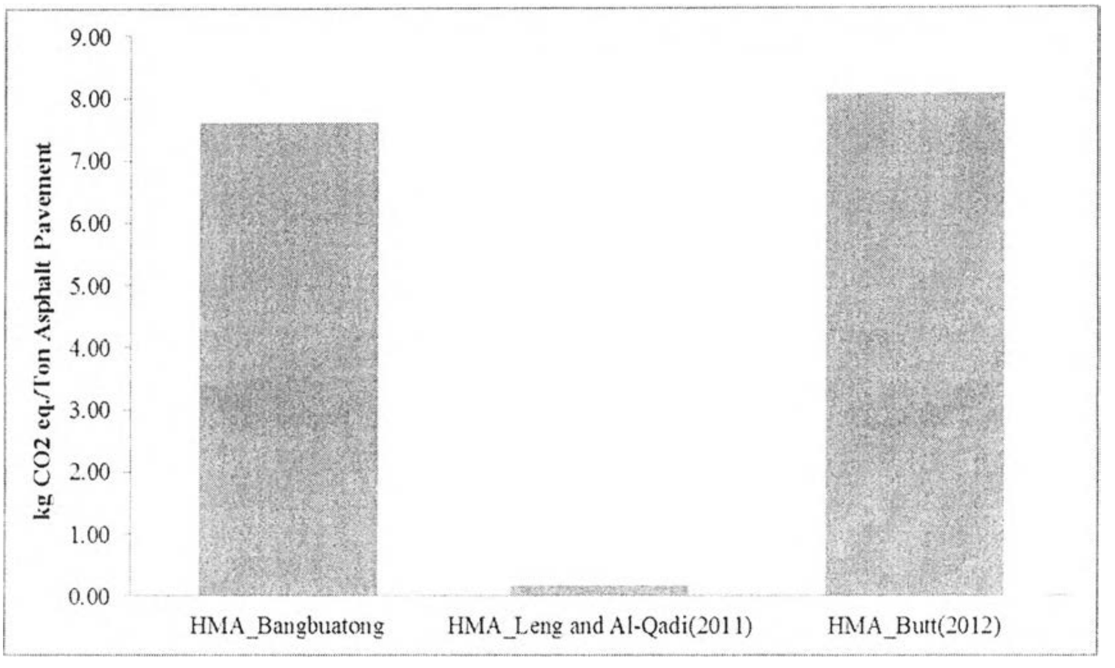


Figure 4.28 Comparison of GWP of transportation between Bangbuatong plant, HMA_Leng and Al-Qadi(2011) and HMA_Butt (2012) by using CML 2 baseline 2000.

From Figure 4.28, it can be seen that HMA_Butt (2012) has shown to be the highest GWP which is equal to 8.05 kg CO_2 eq. / Ton of asphalt. The lowest GWP is HMA_Leng and Al-Qadi(2011) which is equal to 0.168 kg CO_2 eq. / Ton of asphalt. For Bangbuatong plant has shown the GWP 7.607 kg CO_2 eq. / Ton of asphalt.

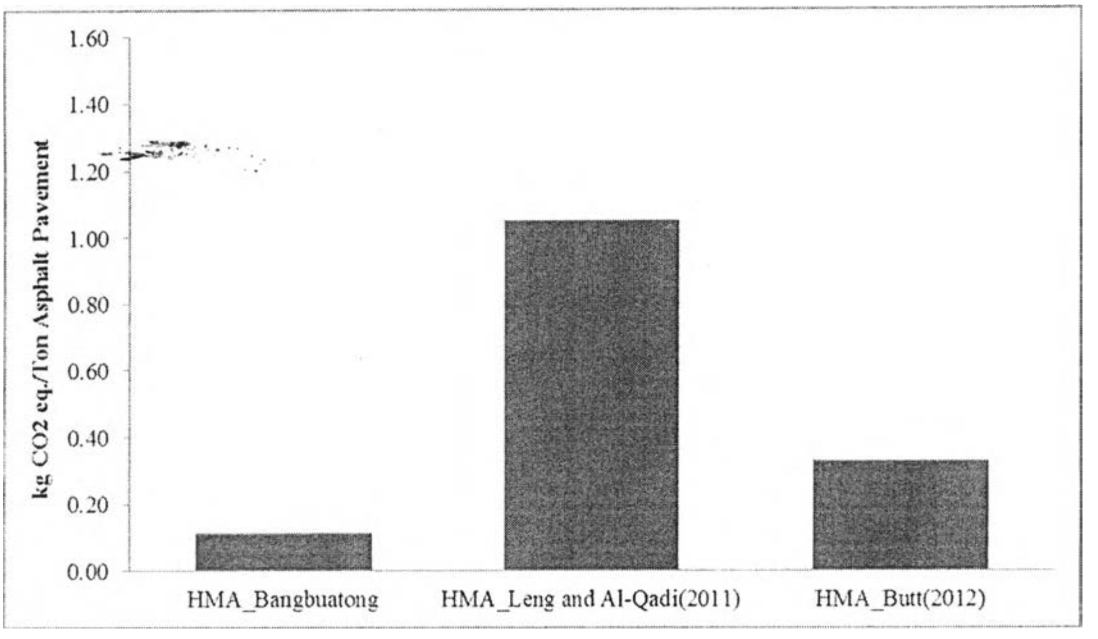


Figure 4.29 Comparison of GWP of paving process between Bangbuatong plant, HMA_Leng and Al-Qadi(2011) and HMA_Butt (2012) by using CML 2 baseline 2000.

From Figure 4.29, it can be seen that HMA_Leng and Al-Qadi(2011) has shown to be the highest GWP which is equal to 1.05 kg CO_2 eq. / Ton of asphalt. The lowest GWP is HMA_Butt (2012) which is equal to 0.11 kg CO_2 eq. / Ton of asphalt. For Bangbuatong plant has shown the GWP 0.33 kg CO_2 eq. / Ton of asphalt.

When the comparison to in all. The total CO_2 emission in Bungbuatong plant is the highest, follow by HMA_Butt (2012) and HMA_Leng and Al-Qadi(2011) is the slowest which are 51.36, 36.88 and 31.83 kg CO_2 eq. / Ton of asphalt respectively. It is speculated that the different countries made the various GHG emission and due to efficiency in the production of asphalt and uncertainty in primary data at each site.

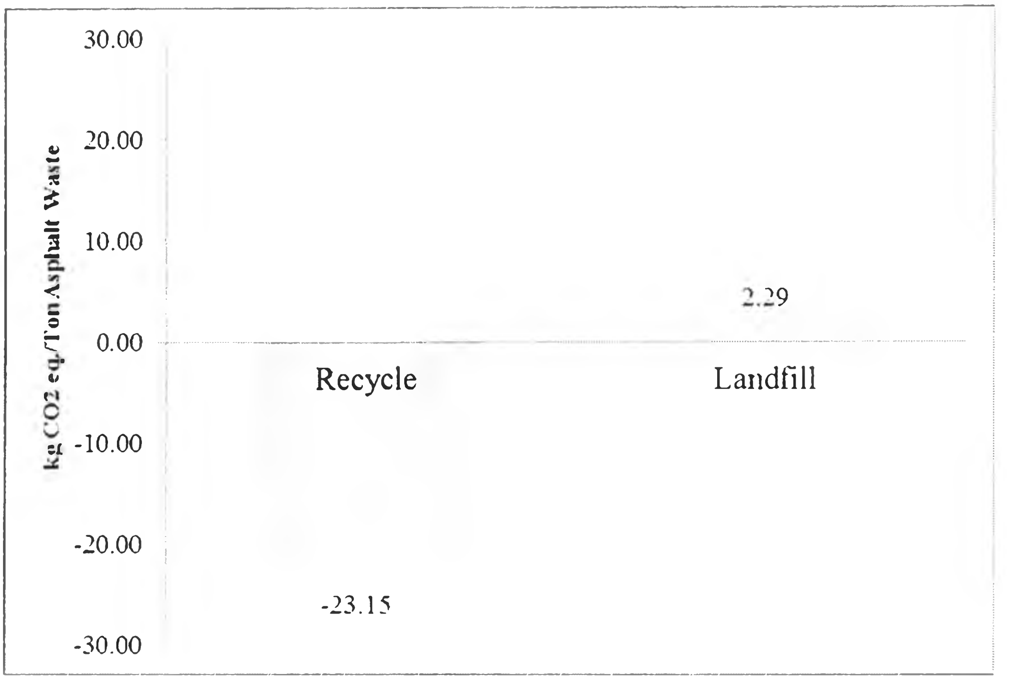


Figure 4.30 GWP of 100%Recycle and 100%Landfill technologies based on 1 ton asphalt treated.

Moreover, Figure 4.30 shows the GWP impact for the end of life phase which presents the results of two cases studied: recycle and landfill. Both cases were analyzed based on 1 ton asphalt concrete treated after service period of the road. The results showed an obvious benefit of recycle that the GWP of recycle technology is -23.15 kg CO2 eq./ton of asphalt treated compared to 2.29 kg CO2 eq./ton asphalt treated for landfill technology. This negative GWP would help significantly reduce the overall GHG emissions of asphalt as much as 45% of the total GHG emissions in its whole life cycle.

- Energy Resources

The data for energy resources were taken from Eco-Indicator 95 method.

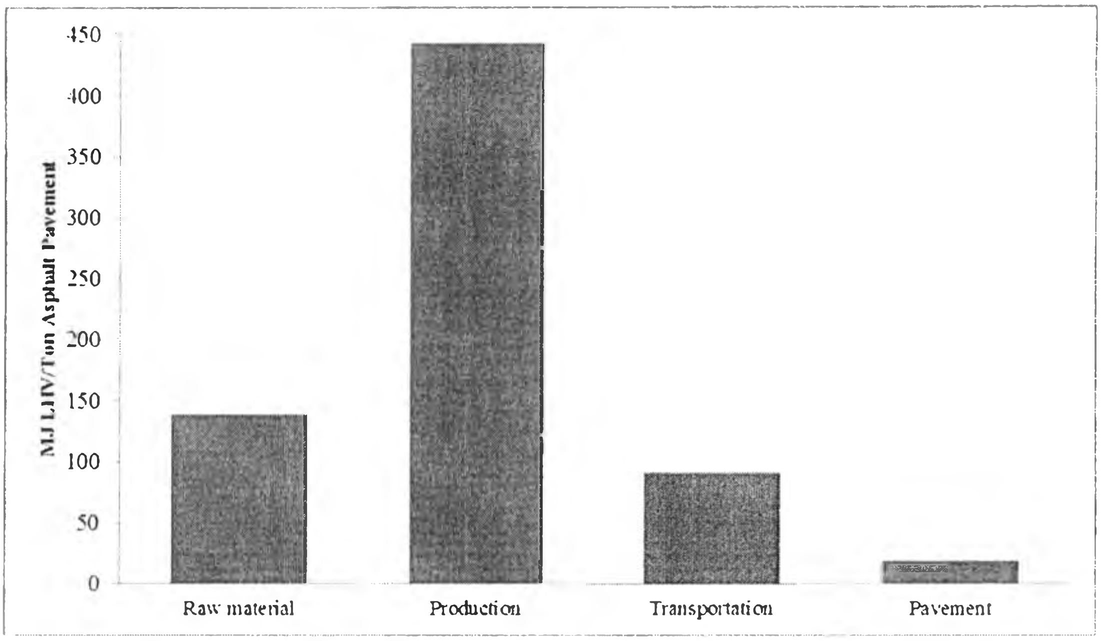


Figure 4.31 Energy resources of hot-mixed asphalt production for each unit process by using Eco-Indicator 95 method.

From Figure 4.31 shows the energy resources in each unit process per ton of HMA production. It can be seen from this figure that production has the highest energy impact among the four unit process of the overall hot-mixed asphalt production. Because embedded energy or feedstock energy of bitumen (i.e., heavy fuel oil) is not included in raw material. It could be considered as it is borrowed from the nature and returned without being used at end of life. The treatment is similar to several other studies such as Oers *et al.* (2002), a certain functional element from a natural resource which can be recycled and has an economical reserve is considered as borrowed.

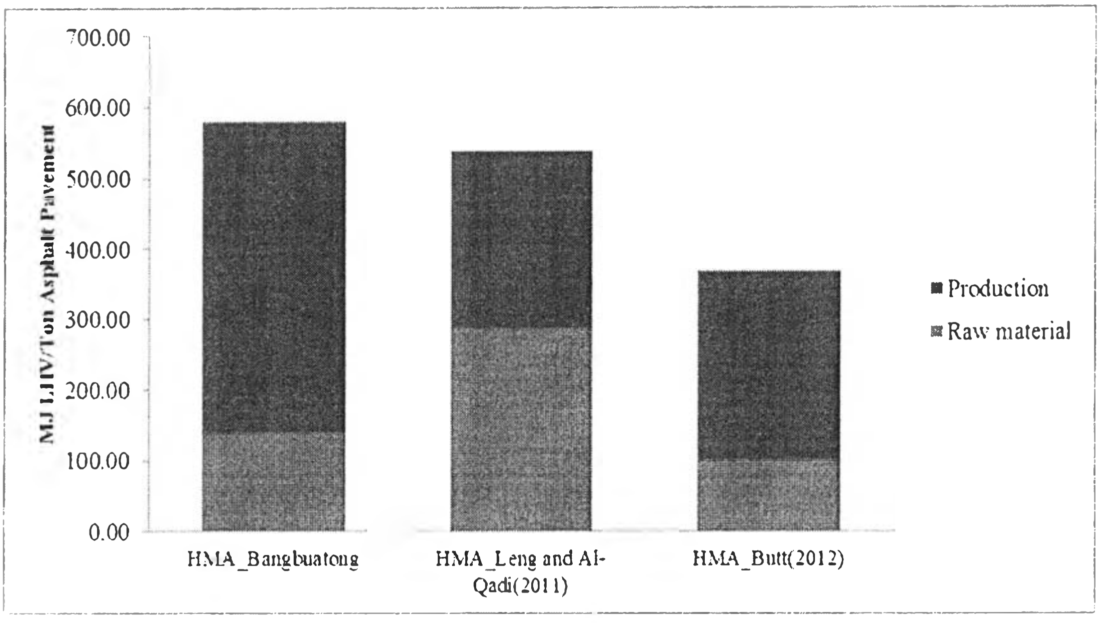


Figure 4.32 Comparison of energy resources of production process between Bangbuatong plant, HMA_Leng and Al-Qadi(2011) and HMA_Butt (2012) by using Eco-Indicator 95 method.

From Figure 4.32, it can be seen that Bangbuatong plant has shown to be the highest energy resources which is equal to 580.58 MJ LHV/ Ton of asphalt. The lowest energy resource is HMA_Butt (2012) HMA_Leng and Al-Qadi(2011) which is equal to 367.60 MJ LHV / Ton of asphalt. For has shown the energy resources 537.60 MJ LHV. / Ton of asphalt.

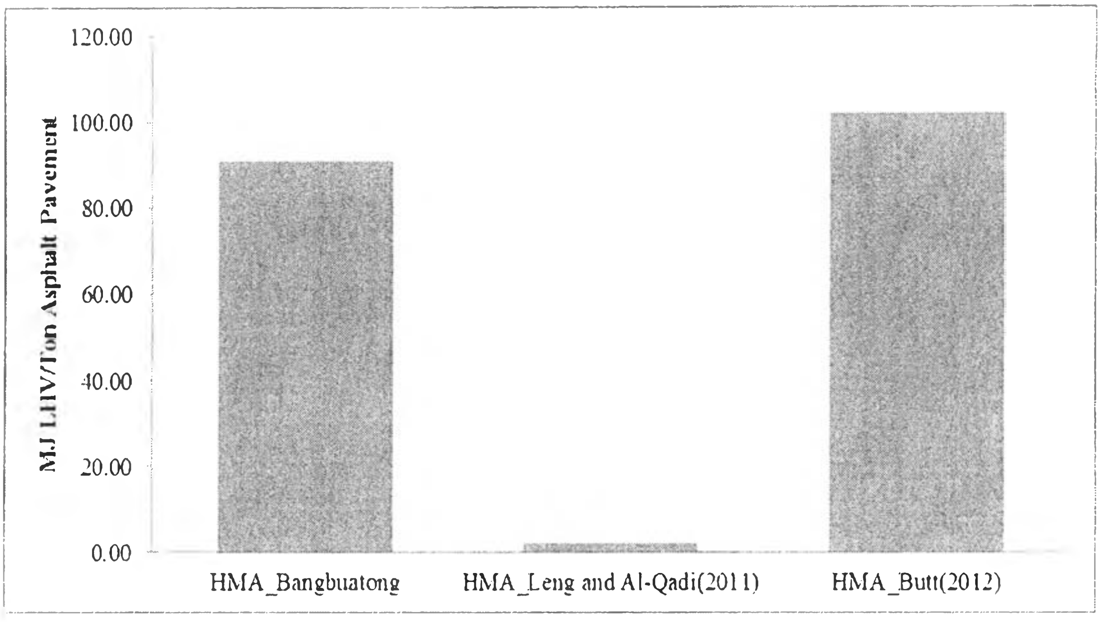


Figure 4.33 Comparison of energy resources of transportation between Bangbuatong plant, HMA_Leng and Al-Qadi (2011) and HMA_Butt (2012) by using Eco-Indicator 95 method.

From Figure 4.33, it can be seen that HMA_Butt (2012) has shown to be the highest energy resources which is equal to 101.93 MJ LHV/ Ton of asphalt. The lowest energy resource is HMA_Leng and Al-Qadi (2011) plant which is equal to 2.28 MJ LHV / Ton of asphalt. For Bangbuatong has shown the energy resources 90.99 MJ LHV. / Ton of asphalt.

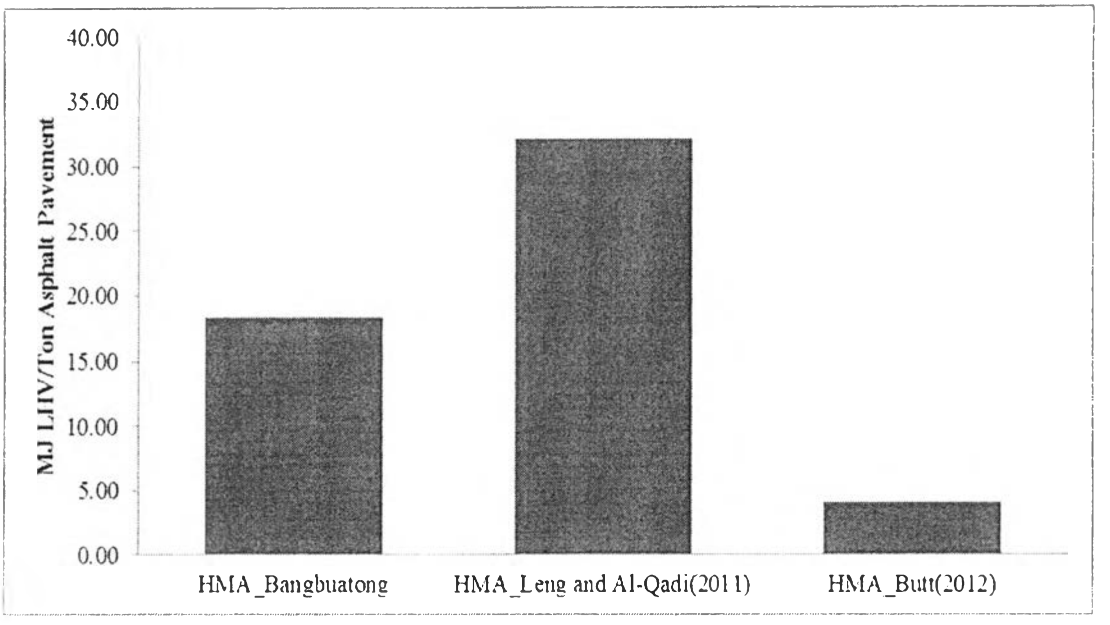


Figure 4.34 Comparison of energy resources of paving process between Bangbuatong plant, HMA_Leng and Al-Qadi (2011) and HMA_Butt (2012) by using Eco-Indicator 95 method

From Figure 4.34, it can be seen that HMA_Leng and Al-Qadi (2011) has shown to be the highest energy resources which is equal to 32.06 MJ LHV/ Ton of asphalt. The lowest energy resource is HMA_Butt (2012) which is equal to 4.10 MJ LHV / Ton of asphalt. For Bangbuatong plant has shown the energy resources 18.32 MJ LHV. / Ton of asphalt.

When the comparison to in all. The total energy resources in Bungbuatong plant is the highest, follow by HMA_Leng and Al-Qadi(2011) and HMA_Butt (2012) is the slowest which are 689.89, 571.94 and 473.63 MJ LHV/ Ton of asphalt respectively. Similar to GHG emission, it is speculated that the different countries made the various GHG emission and due to efficiency in the production of asphalt and uncertainty in primary data at each site.

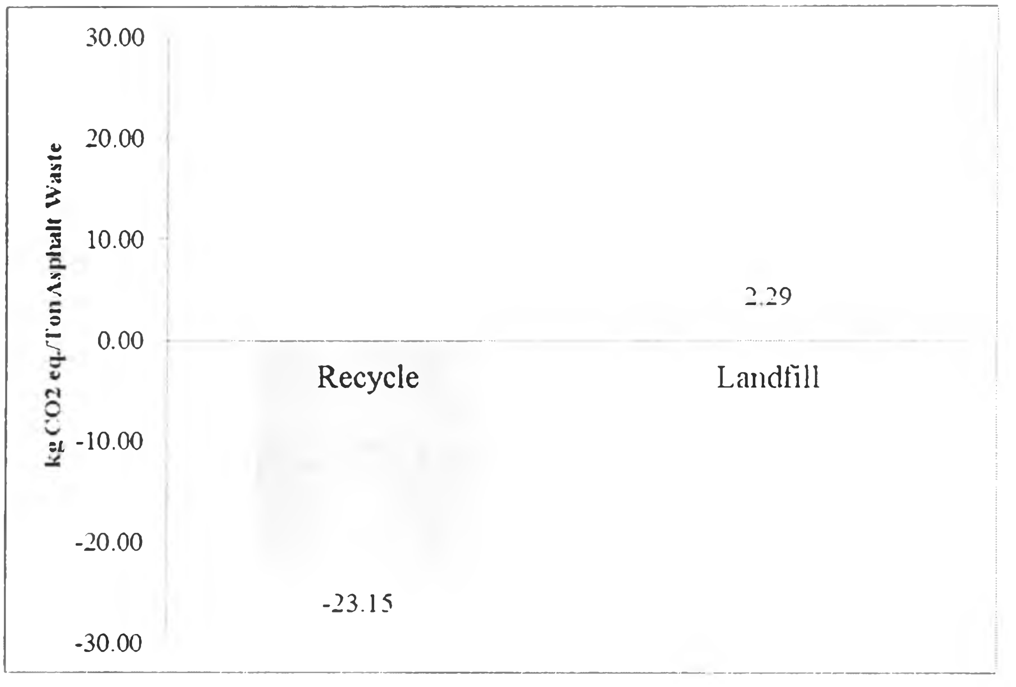


Figure 4.35 Energy input per 1 ton asphalt concrete treated by 100%recycle and 100%landfill after service period.

Moreover, Figure 4.35 shows the energy resources for the end of life phase which presents the results of two cases studied: recycle and landfill. Both cases were analyzed based on 1 ton asphalt concrete treated after service period of the road. The results showed an obvious benefit of recycle that the energy input of recycle technology is -16.93 MJ LHV/ ton of asphalt treated compared to 30.97 MJ LHV/ ton asphalt treated for landfill technology. This negative energy resource would help reduce the overall energy input of asphalt in its whole life cycle, but the impact might not be significant as its value is only about 2.5% of the total energy input.

4.2 Warm-Mixed Asphalt

4.2.1 Description Sites of Data Collection

4.2.1.1 Process of Thaiwat Engineering Co .,Ltd (Sriracha)

4.2.1.1.1 Production process

In the Production process, there are 6 main steps as illustrated in Figure 4.34.

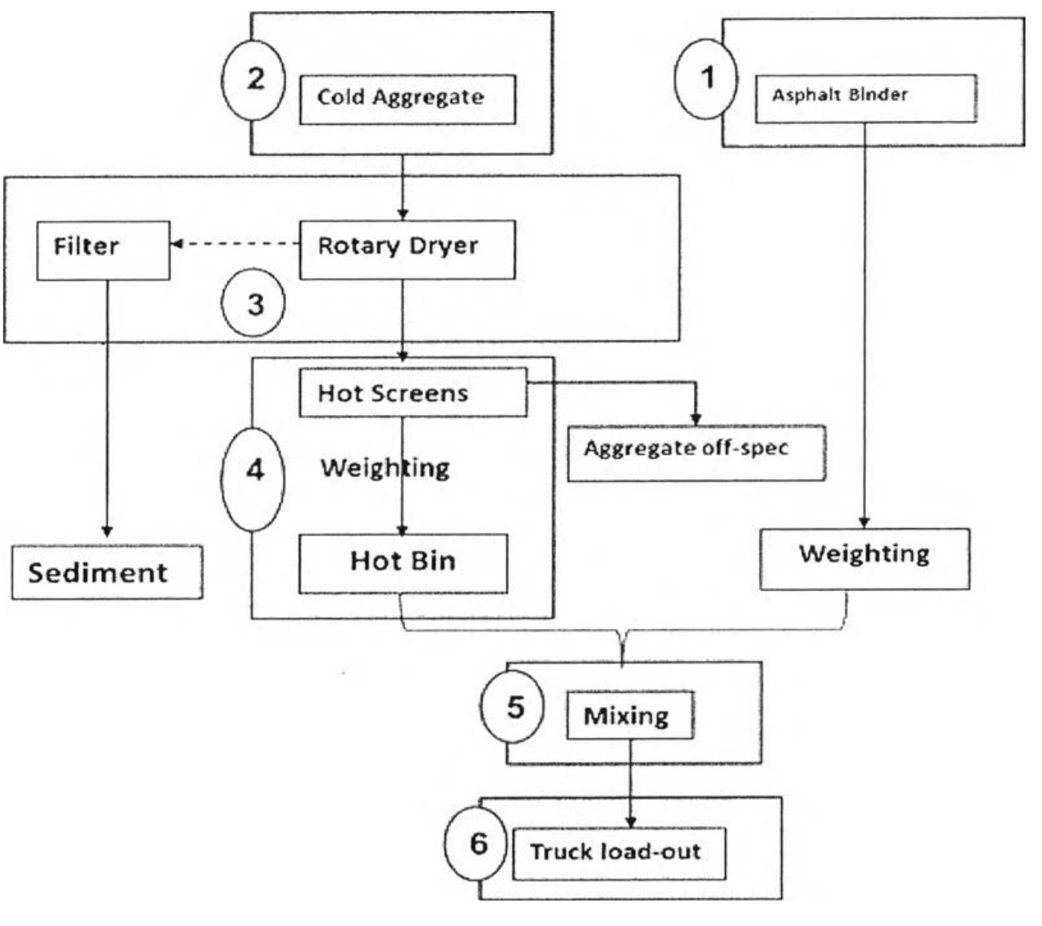
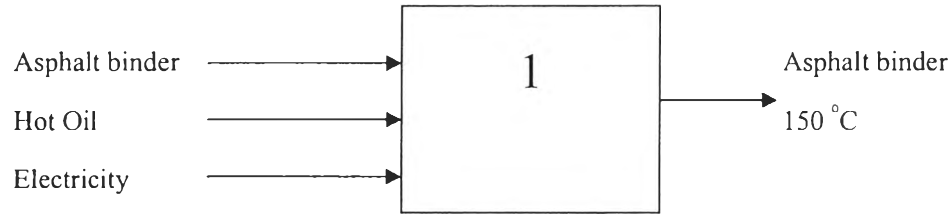


Figure 4.36 The hot-mixed asphalt production of Thaiwat Engineering Co .,Ltd (Sriracha).

1. Asphalt Binder



The plant keeps asphalt binder in storage tank with heating at 150 °C by electricity. So asphalt binder is pumped from a heated storage tank to an asphalt bucket, where it is weighed to achieve the desired aggregate-to-asphalt. Hot-oil is for keeping temperature at 150 °C and is circulated system.

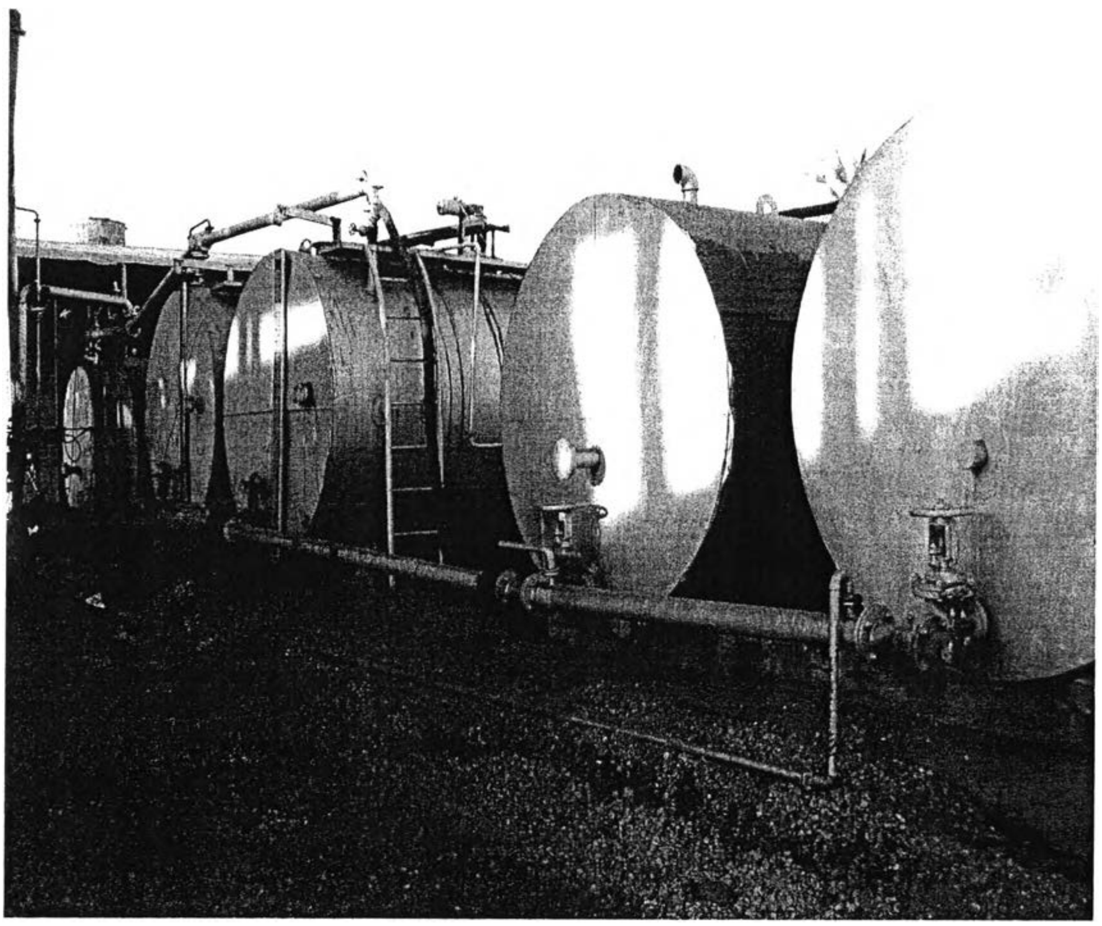
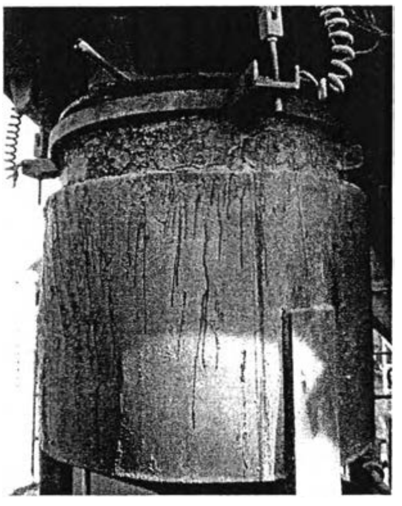


Figure 4.37 Asphalt binders in storage tank.



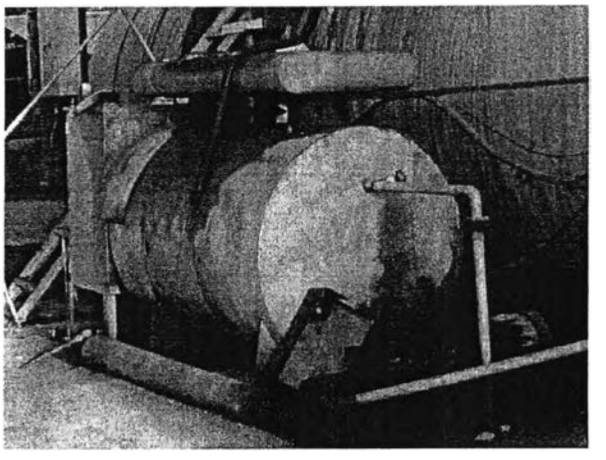
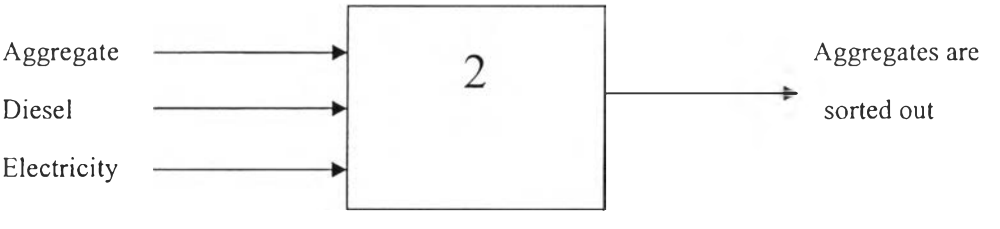


Figure 4.38 Asphalt binders bucket. **Figure 4.39** Hot oil storage tank.

2. Aggregate Preparation



There are 4 aggregate sizes which are fine aggregate, 3/8 inches aggregate, ¾ inches aggregate and ½ inches aggregate. They are piled up and transported to 4 cold aggregate buckets by tractor. Then the aggregate is transported into a rotary dryer.

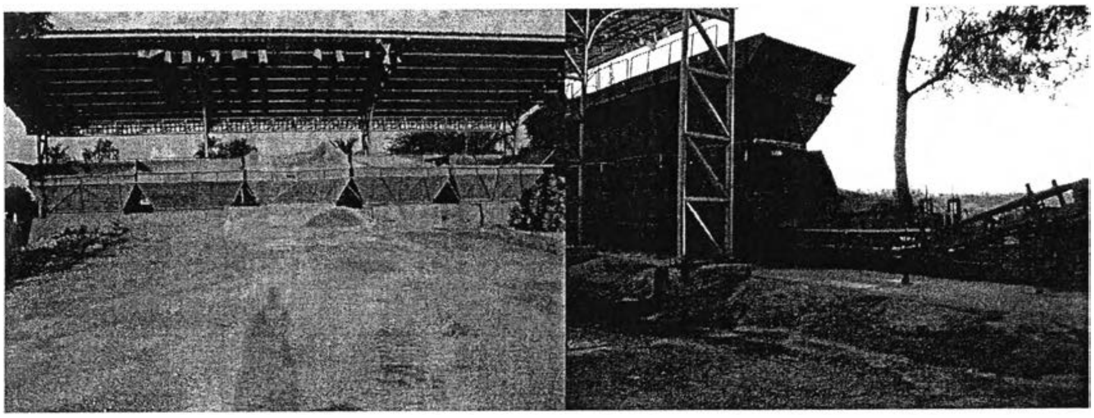
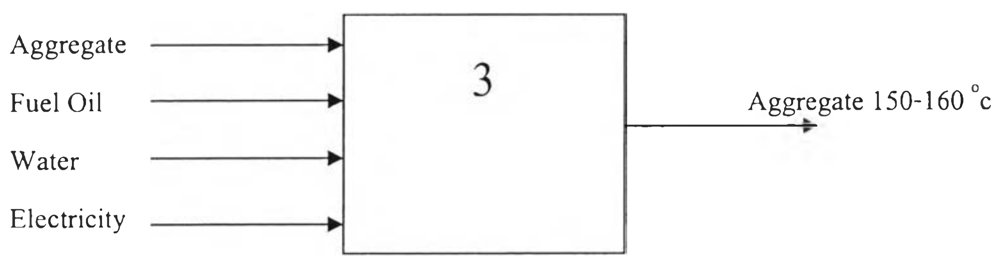


Figure 4.40 Cold aggregate tank and transporting to rotary dryer.

3. Rotary Dryer



Rotary Dryer is for driving away moisture and burning aggregates with fuel oil to 150-160 °C.

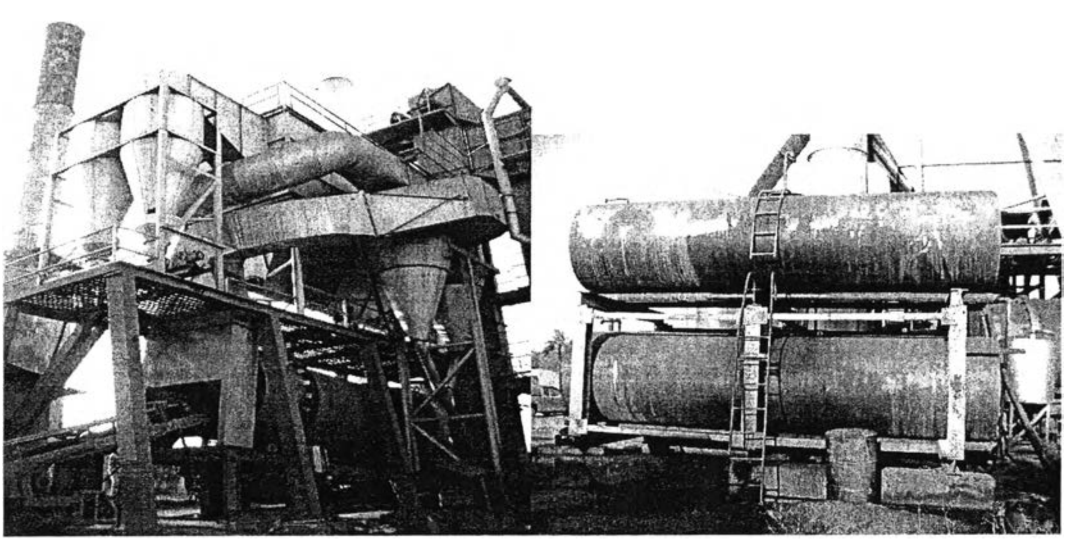


Figure 4.41 Rotary dryer system and fuel oil storage.

There are the dusts abundantly in burning process so the plant use filters which contain bag filters for trapping the going down dusts to be sediment.

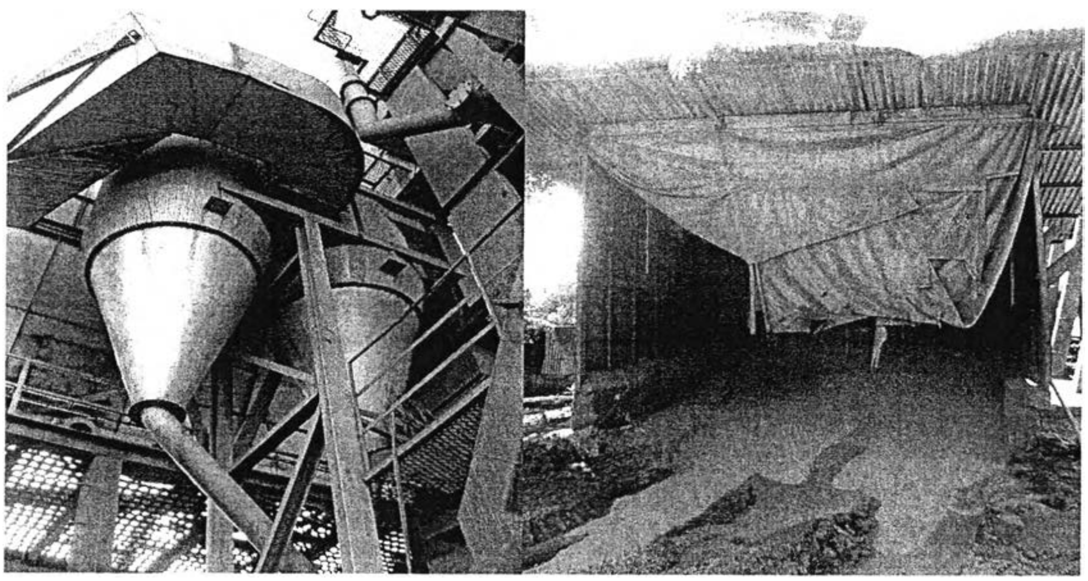
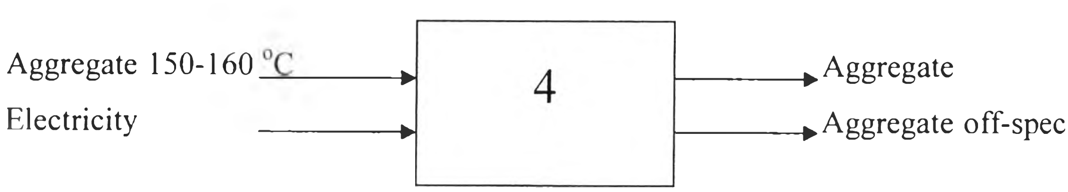


Figure 4.42 Trapping the dust and piling up of sediment.

4. Weighting



After burning aggregates, they are transferred to hot screen according to size. There is aggregates off-spec about 5-6%. The proportionate aggregates are kept at hot bin which for waiting to weighting and mixing with asphalt binder.

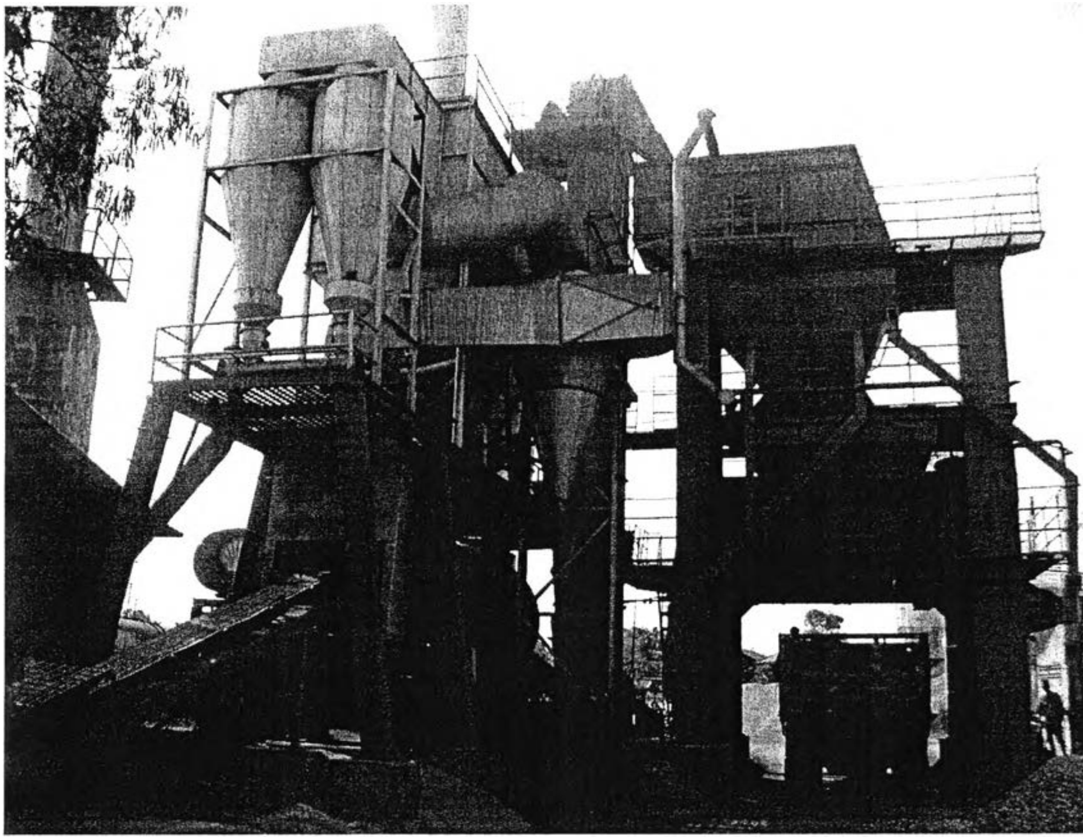
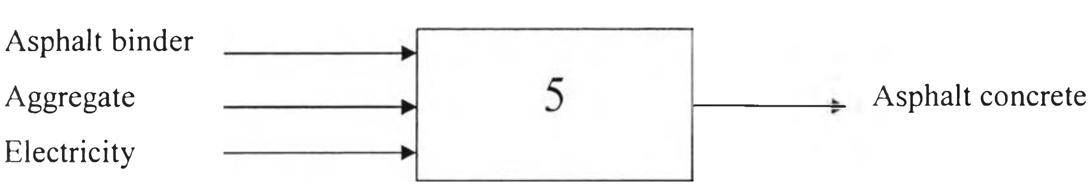


Figure 4.43 Hot-mixed asphalt plant.

5. Mixing



The asphalt binder and aggregates which is prepared are transferred to weight and mix. The mixing use about 45 seconds and all processes are controlled automatically in controlled room.

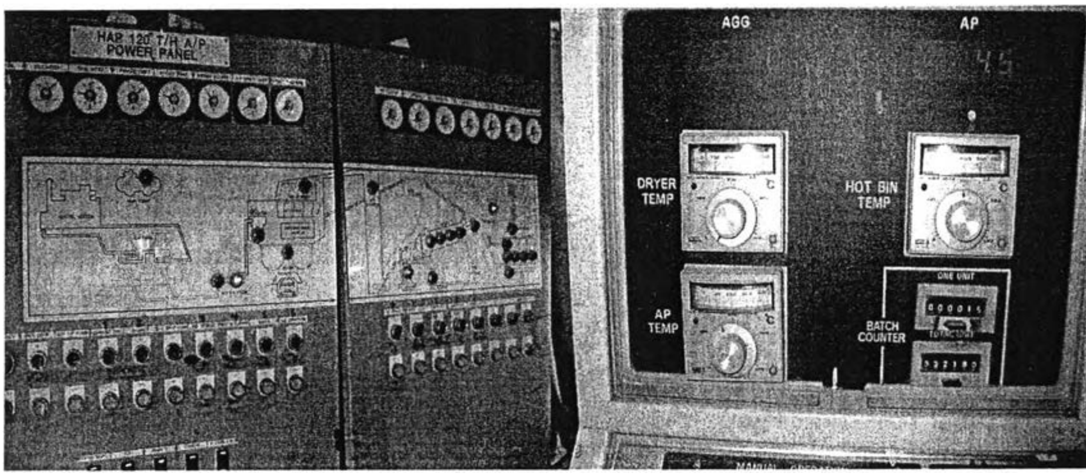
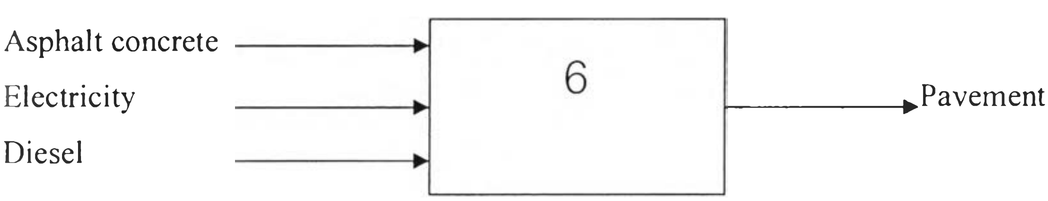


Figure 4.44 Controlled room.

6. Track Load Out



After mixing, asphalt concrete is load out to truck to pavement.

4.2.1.1.2 Pavement Process

On Monday afternoon of December 24, my team visited Thaiwat Engineering Co .,Ltd (Sriracha) to collect the paving data at Thai-oil.

This is the job of repairing the road which pave only wearing layer. Asphalt concrete trucks are carried mixed which temperature is about 130 °C from the plant. The site which is located about 25 km. Truck was parked and the car later pulled up next to a car that was first shown.

1. Asphalt concrete trucks pour hot-mixed asphalt into paver which was used to pave and heat asphalt concrete more than 120° C. The temperature of the asphalt concrete paving will start at about 125 ° C by using a thermometer to measure temperature.

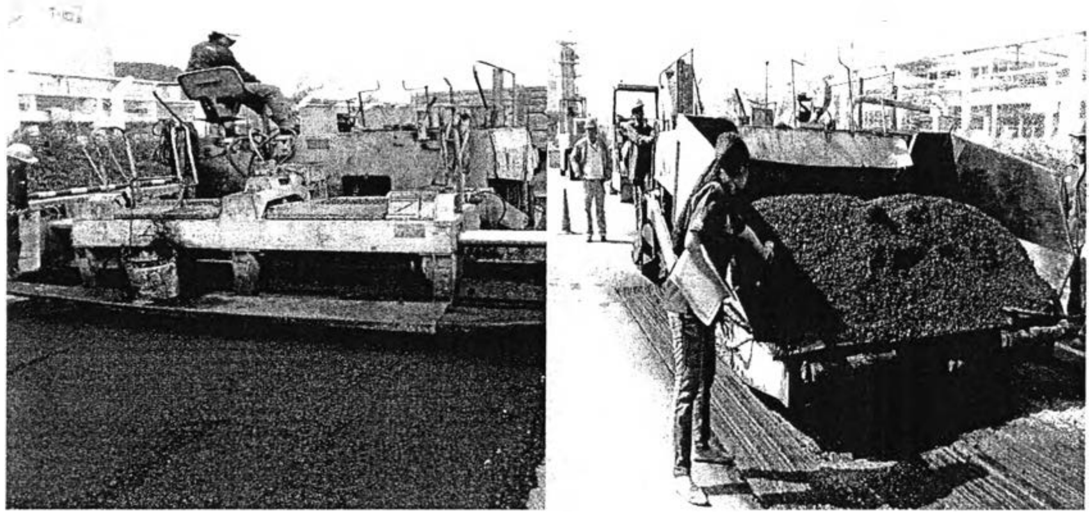


Figure 4.45 Asphalt concrete in paver.

Because the road is paved lane by lane so the operators use pickax to equalize at edge joints.

Figure 4.46 Equalize at edge joints.

2. After pave by paver, steel drum roller or Breakdown that use to compress the road. The steel wheels are lubricated with water for protecting asphalt concrete attached to the wheels. Steel drum roller will be running all 5 path (1 patch = go + back) in 3.30 minutes.

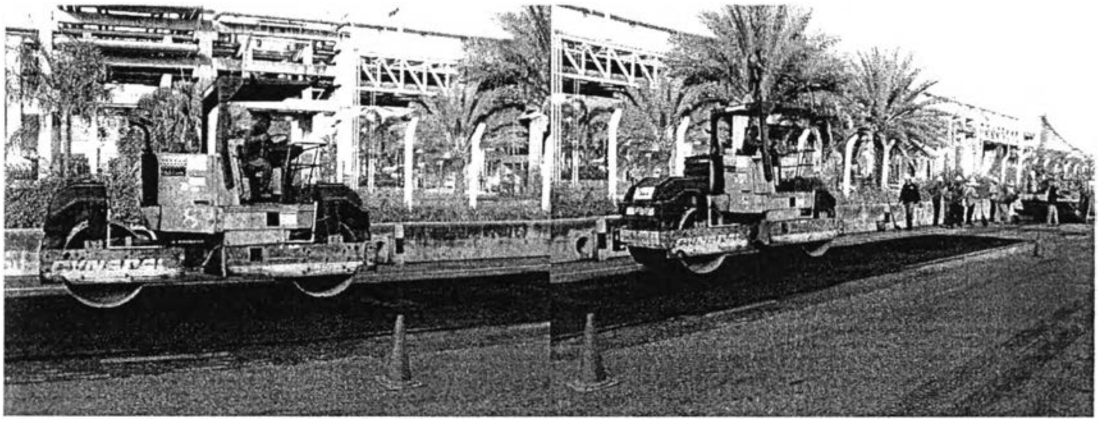


Figure 4.47 Steel drum rollers (DYNAPAC CC211).

3. After that, static pneumatic tried roller which has 9 wheels (4 wheels in front and 5 wheels in back) continue to compress the road running all 25 path (1 patch = go + back) in 23 minutes. In generally, they use solar-oil about 30-40 litres/day (estimate from foreman).

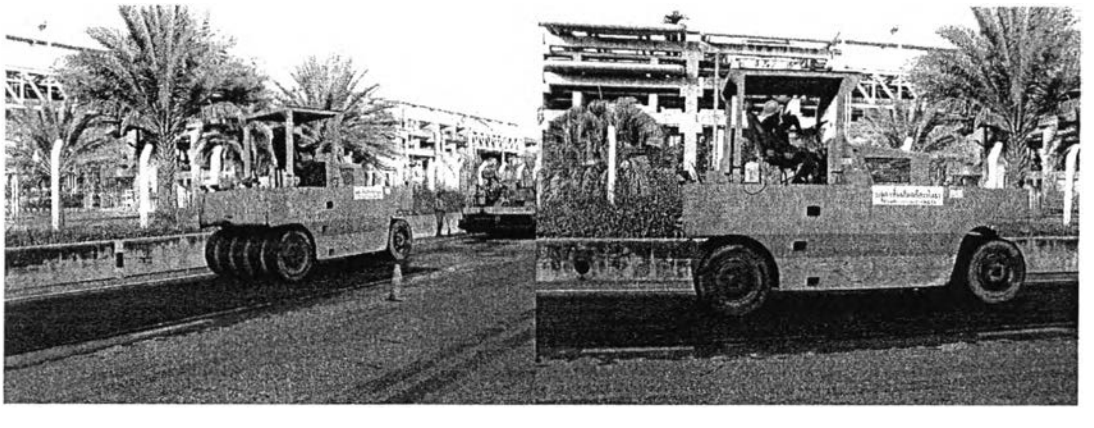


Figure 4.48 Static pneumatic tried roller (SAKAI TS200).

4.2.1.2 Data Inventory

- Asphalt Binder

Asphalt binder comes from warehouse at Pathumthani by 18-wheel truck which loads 25 tons and uses diesel fuel. Fuel consumption is about 2.4 liters of fuel per kilometer.

We collect data from the control room. The computer set at 73 kg to produce 1 batch (1 batch = 1523 kg, 1450 kg of aggregate + 73 kg of asphalt binder).

- Aggregate

The plant orders from Siramitjacheon Co .,Ltd. Aggregate has 4 sizes which are fine, 3/8 inches, 3/4 inches and 1/2 inches. The transportation uses 18-wheel truck which loads 25 tons and uses diesel fuel. Fuel consumption is about 2.4 liters of fuel per kilometer. Aggregate will be piled and transported to 4 cold aggregate buckets to according size by tractor.

The data of the aggregate collect from the control room. The computer set 1500 kg to produce 1 batch (1 batch = 1523 kg, 1450 kg of aggregate + 73 kg of asphalt binder), which is proportional to the size of the Job mix design. In general uses of 705 kg of fine aggregate, 345 kg of 3/8 inches aggregate, 190 kg of 3/4 inches aggregate and 210 kg of 1/2 inches aggregate.

- Fuel Oil

The plant orders from warehouse at Pathumthani by 10-wheel truck with 15,000 liters per each and use diesel fuel. The oil is used for burning aggregate to 160-170 ^{O}C temperature.

From asking, we have found that using 7-8 liters per one batch.

- Hot Oil

Hot oil is used as a fuel for heat and control the temperature of the asphalt binder at 150 ^{O}C. The plant will be purchased by truck which used diesel as fuel. Of inquiry found that the addition hot oil about 300 liters per 3 months.

- Electricity

The data is from bill and number of asphalt production.

- Lubricant

Lubricant is used to lubricate machinery and required the addition of 3 kg per day, no matter how large or small it will be produced.

- Sediment

Dust is trapped with air bag. This will precipitate out. The plant will use a tractor for lapping to leave the factory.

For the production of the Asphalt concrete, sediment dust is about 500-1000 kg/day.

Table 4.12 Results of the inventory analysis of one ton asphalt concrete production

Input			**Output**		
Item	Quantity	Unit	Item	Quantity	Unit
Raw material			**Products**		
Asphalt binder	54	kg	asphalt concrete	1000	kg
Dust rock	491	kg			
3/8 inches Rock	240	kg	**Waste**		
3/4 inches Rock	132	kg	Aggregate (off spec)	58.20106	kg
1/2 inches Rock	146	kg	Sediment	6.01154	kg
Electricity	7.05	units			
Grease	24.05	grams	**Air emissions**		
Fuel			SO_2		ppm
Fuel Oil	5	Litres	NO_x		ppm
Hot oil	0.00523	Litres	CO		ppm

But we cannot gain acceptance the actual warm-mixed asphalt data from asphalt industry at the time of this study so we use basis of calculation from any research similar to our research for using in the according and comparison to the information that we have received from real site.

4.2.1.2.1 Basis of Calculation

Kristjansdottir *et al.* (2007) and Olard, Héritier and Beduneau (2008) published details of energy input calculations for a typical hot mix and mixes with the same aggregate grading manufactured by three versions of the LEA processes. The same methodology will be used to compare energy inputs for different energy saving processes. For this purpose, the specific heats of the various components are required. Different aggregates and bitumen have different specific heats, and specific heats of water and bitumen vary with temperature. Representative values will be used (Table 4.15).

Table 4.15 Representative specific heats of asphalt component

Material	Notation	Specific heat (kJ/kg °c)
Aggregate	Cagg	0.85
Water (10-100°C)	C_{H2O}	4.191
Steam	C_{vap}	1.85
Bitumen at T°C	$C_{bit}(T)$	$1.779 + 1.967\times10^{-3}T$ (Pfeiffer 1950)
Paraffin wax	C_w	2.9
Slaked lime ($Ca(OH)_2$)	C_{lime}	1.2

It follows from the data above that the heat required to raise a kilogram of bitumen from temperature T_1 to temperature T_2 is given by

$$Q_{bit}(T_1, T_2) = \int_{T_1}^{T_2} C_{bit}(T)dT$$

$$= 1.779 (T_2-T_1) + 9.835\times10^{-4} (T_2 - T_1)^2 \text{ kJ/kg}$$

In addition to the above data we require for damp aggregate heated above 100°C the latent heat of vaporization of water:

$$L_{vap} = 2270 \text{ kJ/kg}$$

In cases where paraffin wax is present and heated above its fusion range, we need to account for the heat of fusion:

$$L_{fus} = 220 \text{ kJ/kg}$$

The calculation is based on the production of 1 ton of mixed asphalt. Energy input is divided into two types of energy usage: fuel oil and electricity. Bitumen is heated by using electricity whereas aggregates are heated by using fuel oil. Total energy input is a sum of both.

Hot-mixed asphalt : The total heat required for the bitumen = 10.142 MJ
The total heat required for the aggregate = 177.808 MJ
The heat input for one ton is therefore = 187.95 MJ

Warm-mixed asphalt : The total heat required for the bitumen = 9.835
The total heat required for the aggregate = 160.88 MJ
The heat input for one ton is therefore = 170.712 MJ

As seen above, the decrease in energy required for heating bitumen is 0.307 MJ which is equivalent to a decrease in electricity required to heat bitumen in case of warm-mixed asphalt of 0.085 kWh or 0.085 units. Moreover, the decrease in energy required for heating aggregates is 16.928 MJ which is equivalent to a decrease in fuel oil used to heat aggregates in case of warm-mixed asphalt of 0.397 kg or 0.45 L.

To quantify the energy and emission benefits of WMA, Lecomte *et al.* (2007) measured the energy consumption and emission at a plant producing a warm asphalt mixture and a conventional asphalt mixture in Italy. They found by reducing the mixing temperature from 356 to 257 °F (180 to 125 °C), the percentage reductions of various emission flows, as shown in the second column of Table 4.18 , were also measured. Due to the unavailability of the plant-measured energy consumptions and emissions, this analysis assumed that the reductions of the energy consumption and emission are proportional to the temperature reduction. In this study, the control HMA was mixed at 160 °C, while the WMA was mixed at 140 °C. Therefore, the reductions in emissions shown in the last column in Table 4.14 were obtained and incorporated into a life cycle inventory that describes emission of the WMA mixture.

Table 4.16 Emission Reduction

Emission Flow	Emission Reduction (180°C to 125°C)	Emission Reduction (160°C to 140°C)
SO_x	25%	**9.09%**
NO_x	60%	**21.82%**
CO_2	35%	**6.36%**
CO	8%	**2.91%**
Particles	28%	**5.09%**
VOC	83%	**15.09%**

4.2.1.2.2 Production Process

Table 4.17 Results of the inventory analysis of one ton WMA production

Input			**Output**		
Item	Quantity	Unit	Item	Quantity	Unit
Raw material			**Products**		
Asphalt binder	[redacted]	kg	asphalt concrete	1000	kg
Fine Aggregate	442.92	kg			
3/8 inches Aggregate	302.51	kg	**Waste**		
3/4 inches Aggregate	107.86	kg	Aggregate (off spec)	9.7647	kg
1/2 inches Aggregate	123.18	kg	Sediment	10.1010	kg
Sasobit	[redacted]	kg	**Water emission**		
Pond water	756.76	Litres	Vapor	68.796	Litres
Electricity	[redacted]	units			
Bitufresh	0.0029	Litres	**Air emissions**		
Grease	1.79	grams	SO_2	67.503	grams
Fuel			NO_x	249.256	grams
Fuel Oil	[redacted]	Litres	CO	971.076	grams
Hot oil	0.00123	Litres	Suspended Particulate	2.359	grams

4.2.1.2.3 Transportation

From assumptions in methodology (3.2.2), they conclude that GWP and energy sources of transportation in warm-mixed asphalt are equal to hot-mixed asphalt.

4.2.1.2.4 Paving Process

From assumptions in methodology (3.2.2), they conclude that GWP and energy sources of pavement in warm-mixed asphalt are equal to hot-mixed asphalt.

4.2.1.3 Impact Assessment

- Global Warming Potential (GWP)

GWP impact is represented by GHG emission as shown in Figure 4.49. From the figure, it can be seen that the most GHG emission in raw material is from bitumen because it include emission from crude oil. The second highest GHG emission is production, follow by transportation and pavement is the lowest.

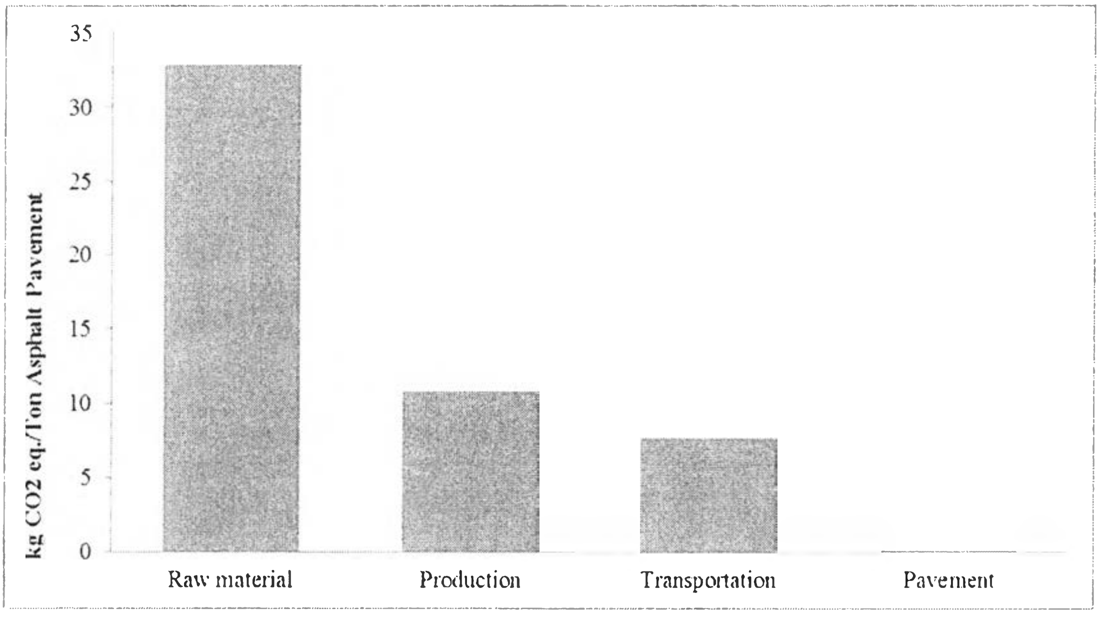


Figure 4.49 GHG emission of warm-mixed asphalt production for each unit process by CML 2 baseline 2000.

From Figure 4.50, HMA_Butt (2012) presented the selected pavement profile and materials were based on a commonly built Swedish pavement structure that is designed to have a service life time of 20 years. The pavement consisted of a 50 mm thick wearing course, binder course (different for different cases depending on the design) above an 80 mm base course and a 420 mm granular sub-base layer but in case was based on modification of the bitumen by adding 4% wax to the bitumen.

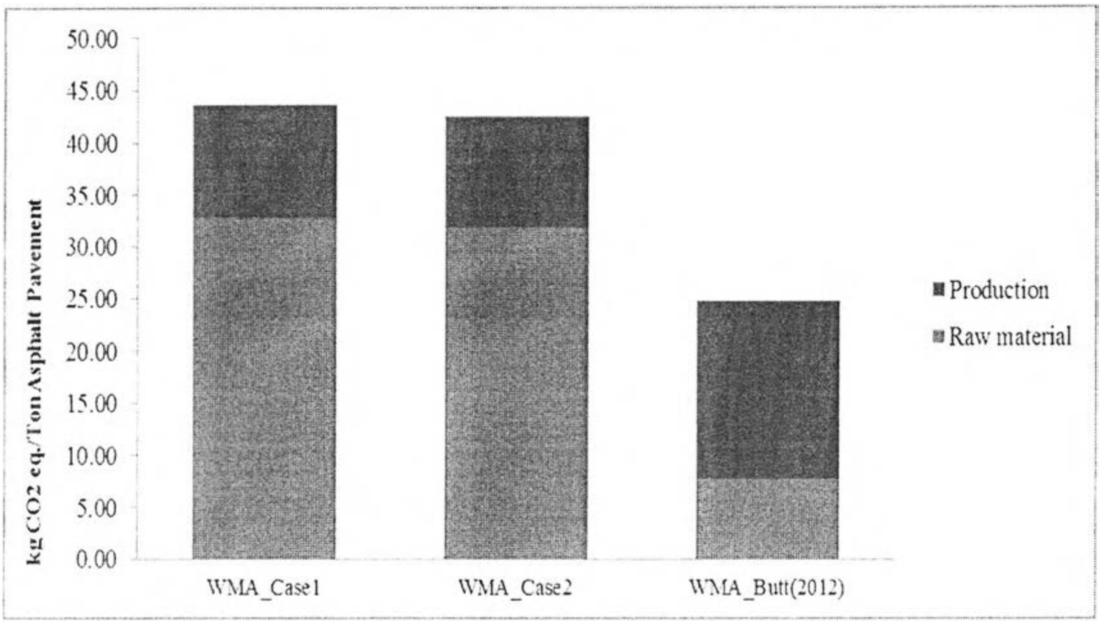


Figure 4.50 Comparison of GWP of production process between WMA from calculation and WMA_Butt (2012) by using CML 2 baseline 2000.

In addition, the results obtained in this study are compared to those of other studies. It should be noted that in our study WMA results are divided into 2 cases since we do not have actual energy and environmental profile of the additive, Sasobit.

In Case 1, paraffin wax is used as a representative for Sasobit.

In Case 2, the energy and environmental footprints of Sasobit are excluded in the analysis.

From Figure 4.50, it can be seen that WMA_Case1 has shown to be the highest GWP which is equal to 43.70 kg CO_2 eq. / Ton of asphalt. The lowest GWP is WMA_Butt (2012) which is equal to 24.74 kg CO_2 eq. /

Ton of asphalt. For WMA_Case2 which is equal to 42.59 kg CO_2 eq. / Ton of asphalt.

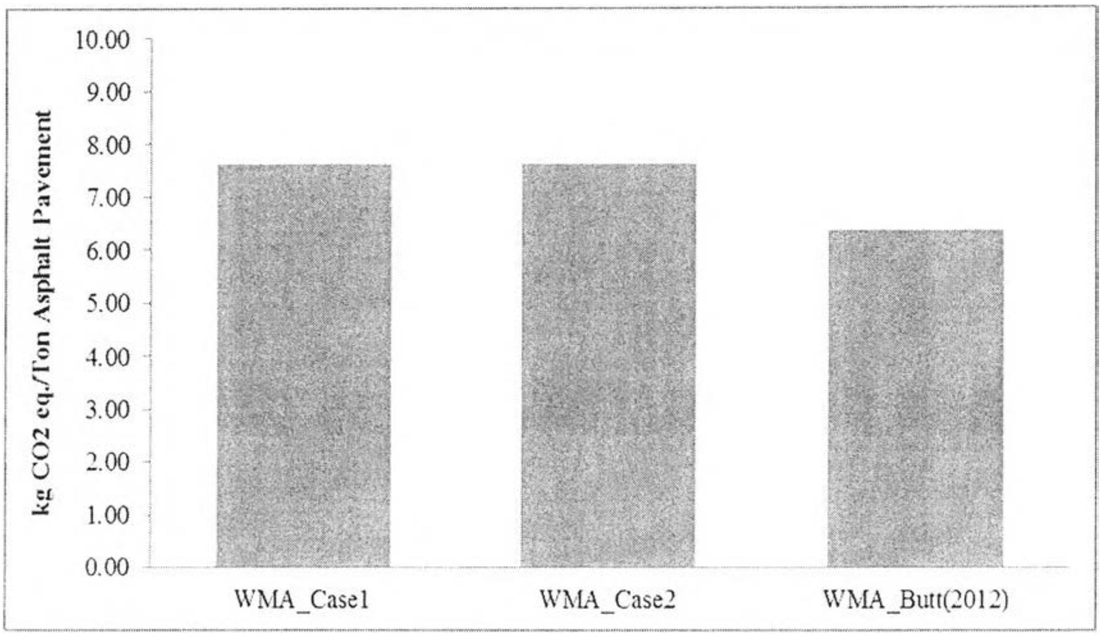


Figure 4.51 Comparison of GWP of transportation between WMA from calculation and WMA_Butt (2012) by using CML 2 baseline 2000.

From Figure 4.51, it can be seen that WMA_Case1 and WMA_Case2 have shown to be the highest GWP which is equal to 7.62 kg CO_2 eq. / Ton of asphalt. The lowest GWP is WMA_Butt (2012) which is equal to 6.37 kg CO_2 eq. / Ton of asphalt.

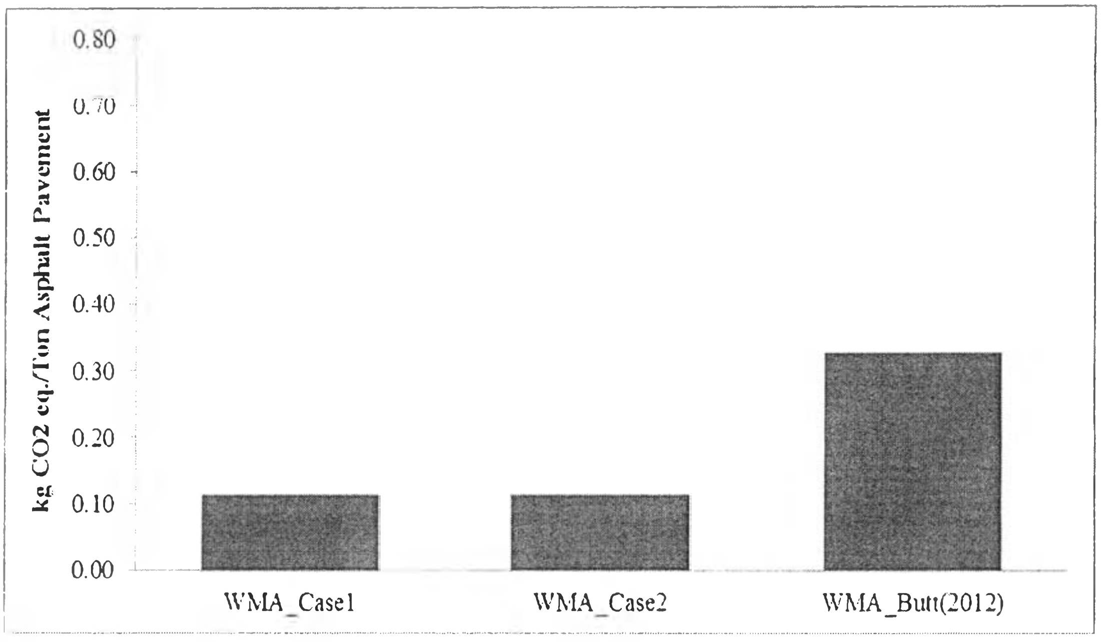


Figure 4.52 Comparison of GWP of paving process between WMA from calculation and WMA_Butt (2012) by using CML 2 baseline 2000.

From Figure 4.52, it can be seen that WMA_Butt (2012) has shown to be the highest GWP which is equal to 0.33 kg CO_2 eq. / Ton of asphalt. The lowest GWP is WMA_Case1 and WMA_Case2 which are equal to 0.11 kg CO_2 eq. / Ton of asphalt.

When the comparison to in all. The total CO_2 emission in WMA_Case1 is the highest, follow by WMA_Case2 and WMA_Butt (2012) is the lowest which are 51.44, 50.33 and 31.44 kg CO_2 eq. / Ton of asphalt respectively. WMA shows slightly better performance but the benefit is not significant (~5%). Because we use basis of calculation from literature; it may be not good enough for real case.

- Energy Resources

The data for energy resources were taken from Eco-Indicator 95 method.

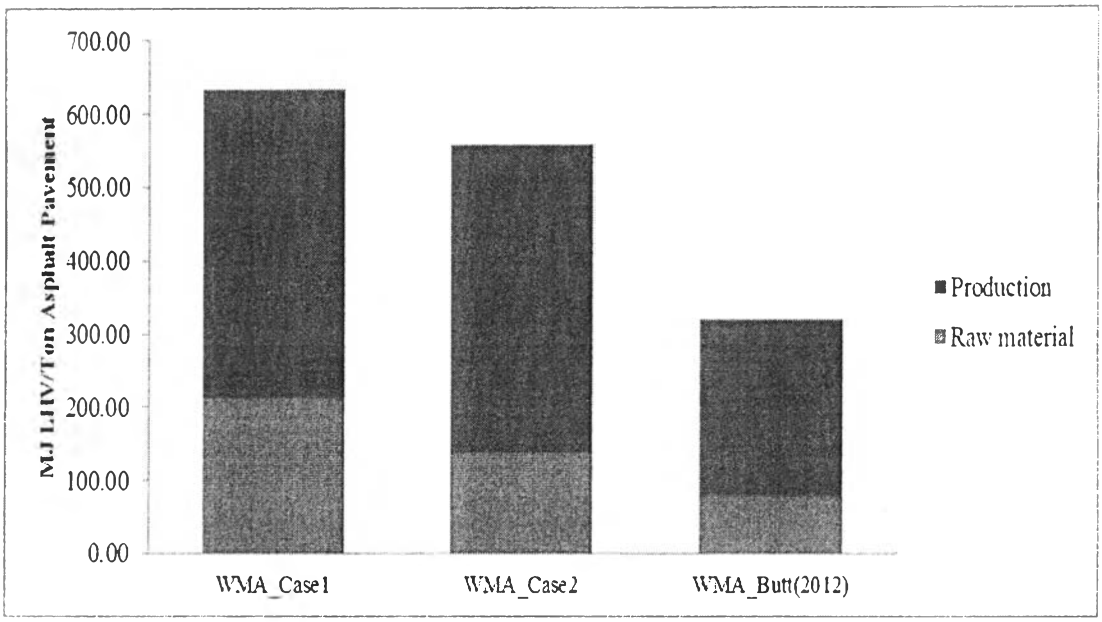


Figure 4.53 Comparison of energy resources of production process between WMA from calculation and WMA_Butt (2012) by using Eco-Indicator 95 method.

From Figure 4.53, it can be seen that WMA_Case1 has shown to be the highest energy resources which is equal to 633.94 MJ LHV/ Ton of asphalt. The lowest energy resource is WMA_Butt (2012) which is equal to 319.72 MJ LHV / Ton of asphalt. For WMA_Case2 which is equal to 558.25 MJ LHV / Ton of asphalt.

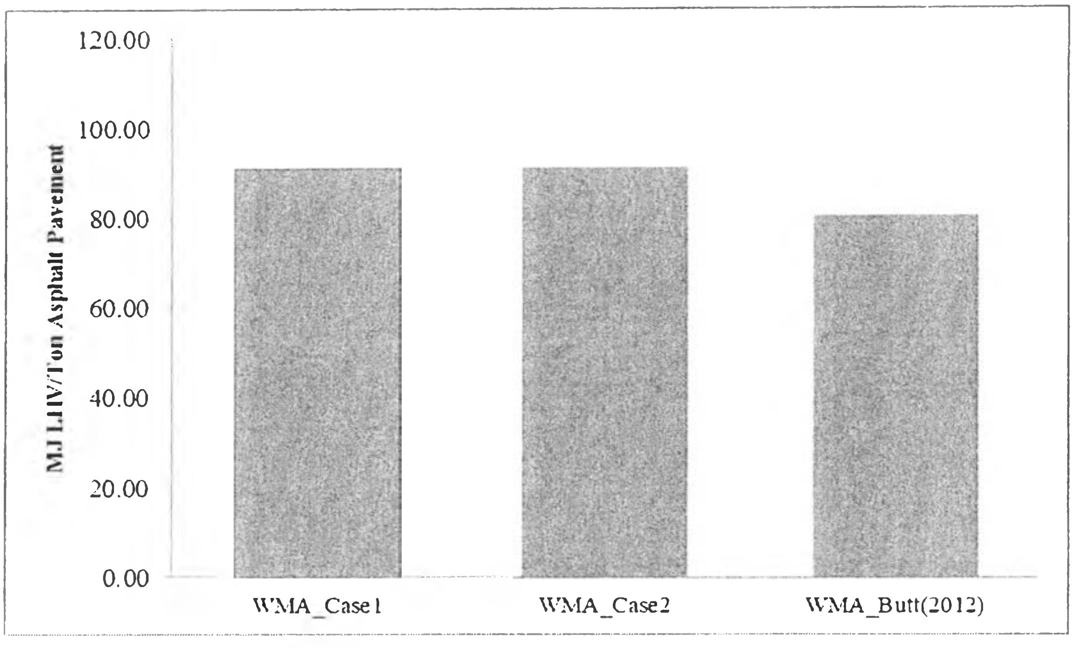


Figure 4.54 Comparison of energy resources of transportation between WMA from calculation and WMA_Butt (2012) by using Eco-Indicator 95 method.

From Figure 4.54, it can be seen that WMA_Case1 and WMA_Case2 have shown to be the highest energy resources which is equal to 91.24 MJ LHV/ Ton of asphalt. The lowest energy resource is WMA_Butt (2012) which is equal to 80.55 MJ LHV / Ton of asphalt.

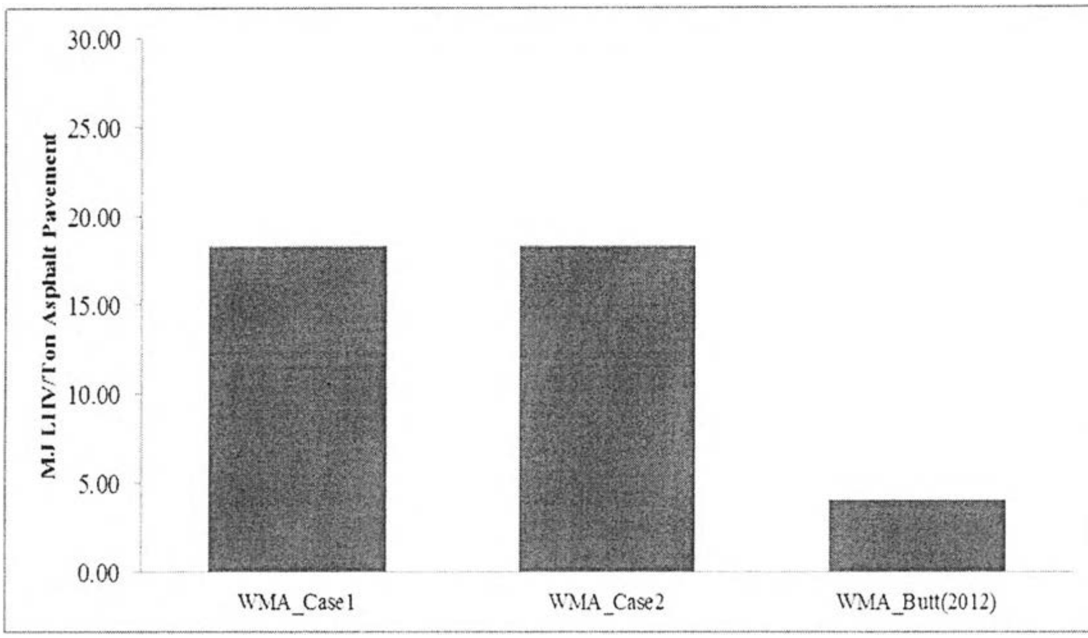


Figure 4.55 Comparison of energy resources of paving process between WMA from calculation and WMA_Butt (2012) by using Eco-Indicator 95 method.

From Figure 4.55, it can be seen that and WMA_Case2 have shown to be the highest energy resources which is equal to 18.32 MJ LHV/ Ton of asphalt. The lowest energy resource is WMA_Butt (2012) which is equal to 4.10 MJ LHV / Ton of asphalt.

When the comparison to in all. The total energy resources in WMA_Case1 is the highest, follow by WMA_Case2 and HMA_Butt (2012) is the slowest which are 743.50, 667.81 and 404.37 MJ LHV/ Ton of asphalt respectively. Similar to GHG emission, WMA shows slightly better performance but the benefit is not significant (~5%). Because we use basis of calculation from literature; it may be not good enough for real case.

4.3 Comparison Between Hot-Mixed Asphalt and Warm-Mixed Asphalt

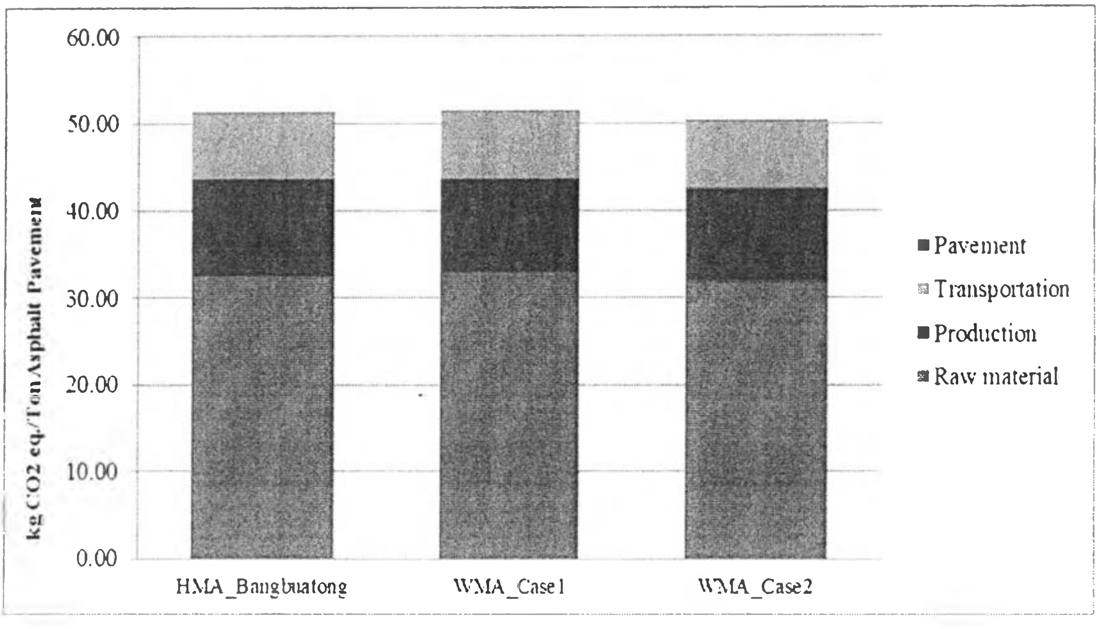


Figure 4.56 Comparison of GWP between HMA from Bangbuatong plant and WMA from calculation by CML 2 baseline 2000.

From Figure 4.56, it can be seen that the GWP of warm-mixed asphalt in case 2 decrease about 1.03 kg CO_2 eq. / Ton of asphalt but in case 1 increase about 0.08 kg CO_2 eq. / Ton of asphalt. WMA shows slightly better performance but the benefit is not significant (~5%).

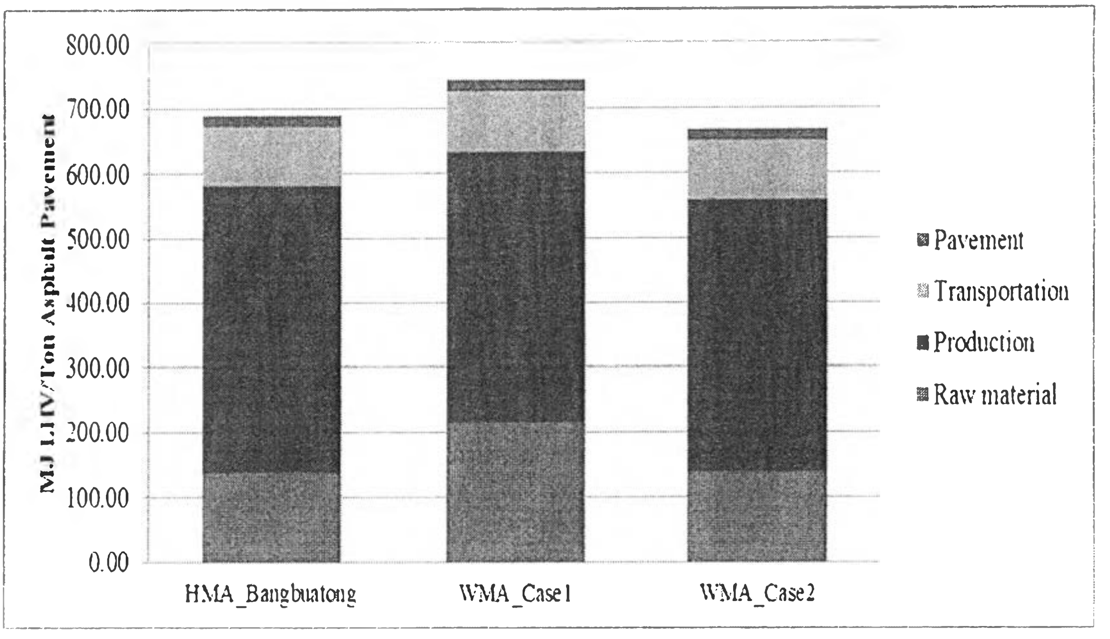


Figure 4.57 Comparison of energy resource between HMA from bangbuatong plant and WMA from calculation by using Eco-Indicator 95 method.

From Figure 4.57, it can be seen that the energy source of warm-mixed asphalt in case 2 decrease about 22.08 MJ LHV / Ton of asphalt but in case 1 increase about 53.61 MJ LHV/ Ton of asphalt.

So, warm-mixed asphalt in case 2 has shown to have benefits in both GHG emission and energy consumption as compared to HMA, but the percent decrease is only in the range of 2-3%. But GHG emission and energy consumption of warm-mixed asphalt in case 1 are increased because we cannot find truly the inventory of sasobit production but we know paraffin is the main component in sasobit. Therefore, the energy and emission are calculated using paraffin instead sasobit. This may result in a higher value.

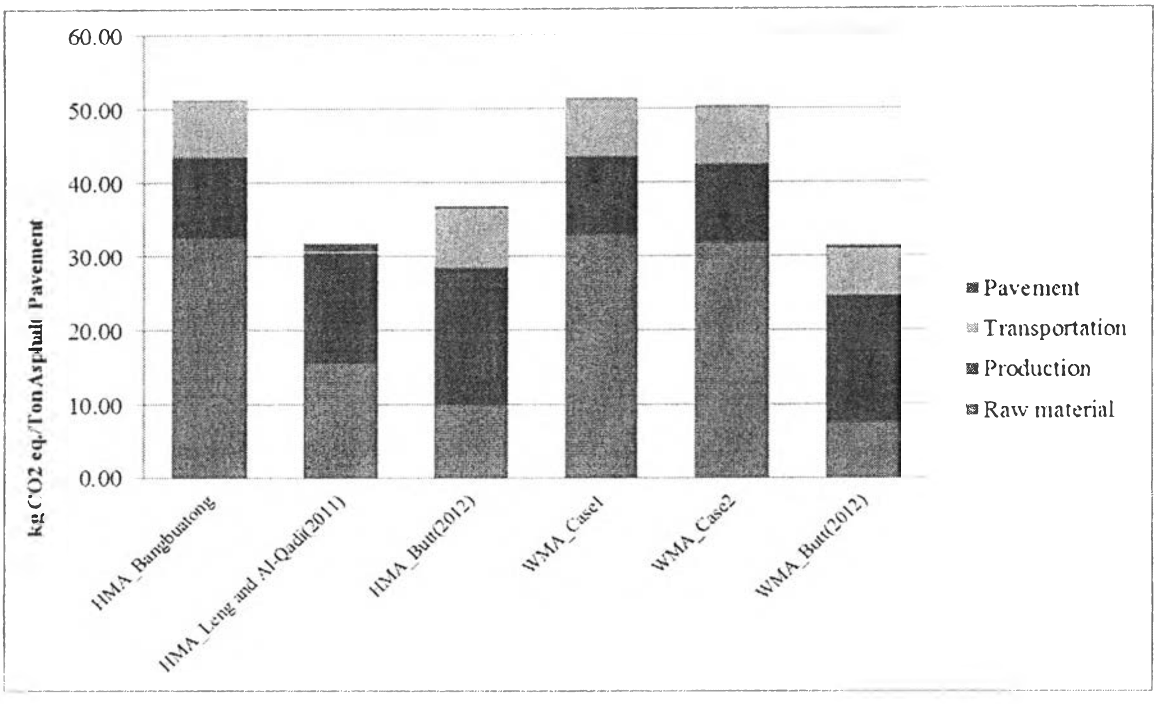


Figure 4.58 Comparison of GWP between HMA from Bangbuatong plant ,WMA from calculation and other studies by CML 2 baseline 2000.

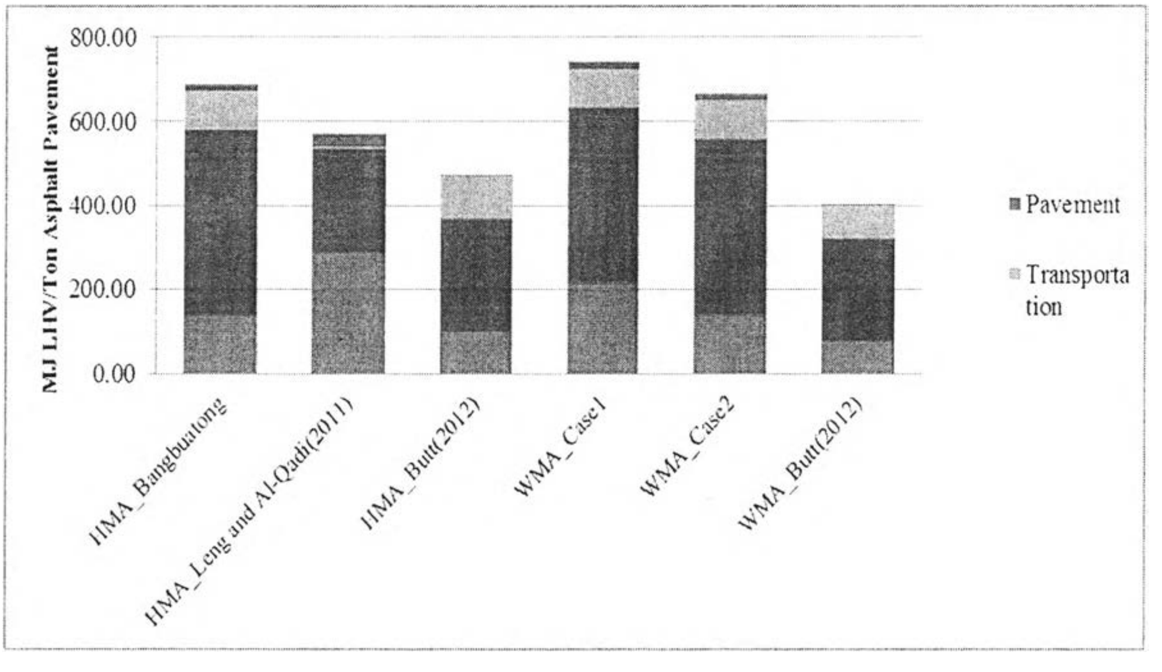


Figure 4.59 Comparison of energy resource between HMA from bangbuatong plant ,WMA from calculation and other studies by using Eco-Indicator 95 method.

From Figure 4.58 and Figure 4.59, when comparing to other studies, the energy and environmental performance of HMA and WMA in Thailand is not as good as observed in other countries which is speculated to be due to lower efficiency in the asphalt production and high uncertainty of the data.

4.4 Energy and Environmental Benefits of Warm-Mixed Asphalt

From Figure 4.56 and Figure 4.57, if use warm-mixed asphalt in case 2 for calculation, the GWP of hot-mixed asphalt and warm-mixed asphalt is 51.36 and 50.33 kg CO2 eq./Ton asphalt concrete, the energy consumption of hot-mixed asphalt and warm-mixed asphalt is 689.89 and 667.81 MJ LHV / Ton of asphalt. Moreover, 1 functional unit of 1 km length, 3.5 width 5 cm thickness is equal to 849.8 ton hot-mixed asphalt and 848.05 ton warm-mixed asphalt. So the GHG emission and energy consumption of warm-mixed asphalt as compare to hot-mixd asphalt is decreased about 963.37 kg per functional unit and 19,932 MJ LHV per functional unit.