CHAPTER III
METHODOLOGY

3.1 Materials and Equipment

3.1.1 Equipment

- Notebook computer (Pentium IV, RAM 2 GB, Window 7 and Microsoft Office 2010)

3.1.2 Software

- SimaPro version 7.3

3.2 Experimental Procedures

3.2.1 Goal and Scope Definition

3.2.1.1 Objectives

- Study and review the background of warm-mixed asphalt from stage of raw material, production, transportation, paving, usage and recycling including their environmental impact and energy consumption through LCA technique.
- Specify intention or purpose of use and scope of the study.
- Contact manufacturers/companies to explain about the importance and scope of this work and ask for their corporations.
- Develop the process and flow diagrams.
- Design data templates and distribute to the company for collecting data as shown in Table 3.1.

3.2.1.2 Formulate and Specify Goal of The LCA Study

- The goal of this LCA study is to assess the environmental impacts of warm mix asphalt. The collected inventory data will be compiled by using SimaPro 7.3 software and the environmental impacts of warm mix asphalt will be evaluated using Eco-Indicator 95 and CML 2 baseline 2000.

Table 3.1 Template of data collection for production of mixed asphalt

Production of Asphalt							
Input Inventory				**Output Inventory**			
Description	**Unit**	**Amount**	**Remark**	**Description**	**Unit**	**Amount**	**Remark**
Resources				***Products***			
Asphalt	kg			Asphalt binder	kg		
Additive	kg			....			
...				....			
Utilities				***Emissions***			
Electricity	kWh			CO_2	kg		
...				....			
...				....			

3.2.1.3 System Boundaries and Scopes

- Define system boundary of the study and make assumptions based on the objectives and scope.
- The system boundary used in this study covers all processes in the entire life cycle of the production and usage of asphalt including four distinct stages: provision of asphalt (raw material), asphalt production, apply paving, and maintenance, demolition or recycling as shown in Figure 3.1 and 3.2 below.
- Evaluate the end-of-life scenario (see Table 3.2) which really use in Thailand as business as usual (BAU) and suggest the possible scenario that can be implemented for environmental friendly in the future.

3.2.1.4 Functional Unit

- Identify functional unit of the study.
- In this study, the functional unit is 1 ton for production stage and 2 lane road, 7 meter wide, 1 kilometer long and 5 centimeter thick for pavement and end-of-life stage of applied paving by HMA and WMA.

Table 3.2 The expected scenarios for assessing end-of-life sessions

Conditions/Scenarios	1	2	3	4
Cold in-place recycling	**90%**	**60%**	**50%**	**40%**
Hot in-place recycling	**1%**	**40%**	**25%**	**30%**
Hot in-plant recycling	**0%**	**0%**	**25%**	**30%**
Landfill	**9%**	**0%**	**0%**	**0%**

* Business as usual case (The data come from talking with PTT public company limited and civil engineering Chulalongkorn University researcher).

3.2.2 <u>Inventory Analysis (LCI)</u>

- Collect both numerical and qualitative data for all activities based on the system boundary concerning all energy inputs, raw materials, chemicals, utilities, and emissions in each process. Table 3.3 and 3.4 show the inventory data and acquirement of the data.
- Quantify the flow of material and energy as well as environmental load attributable to each stage of product's life cycle based on the functional unit.
- The result of the inventory analysis is the inventory table which is a list of all inputs and outputs per functional unit.
- Define environmental impact category in term of:
  - Global warming potential

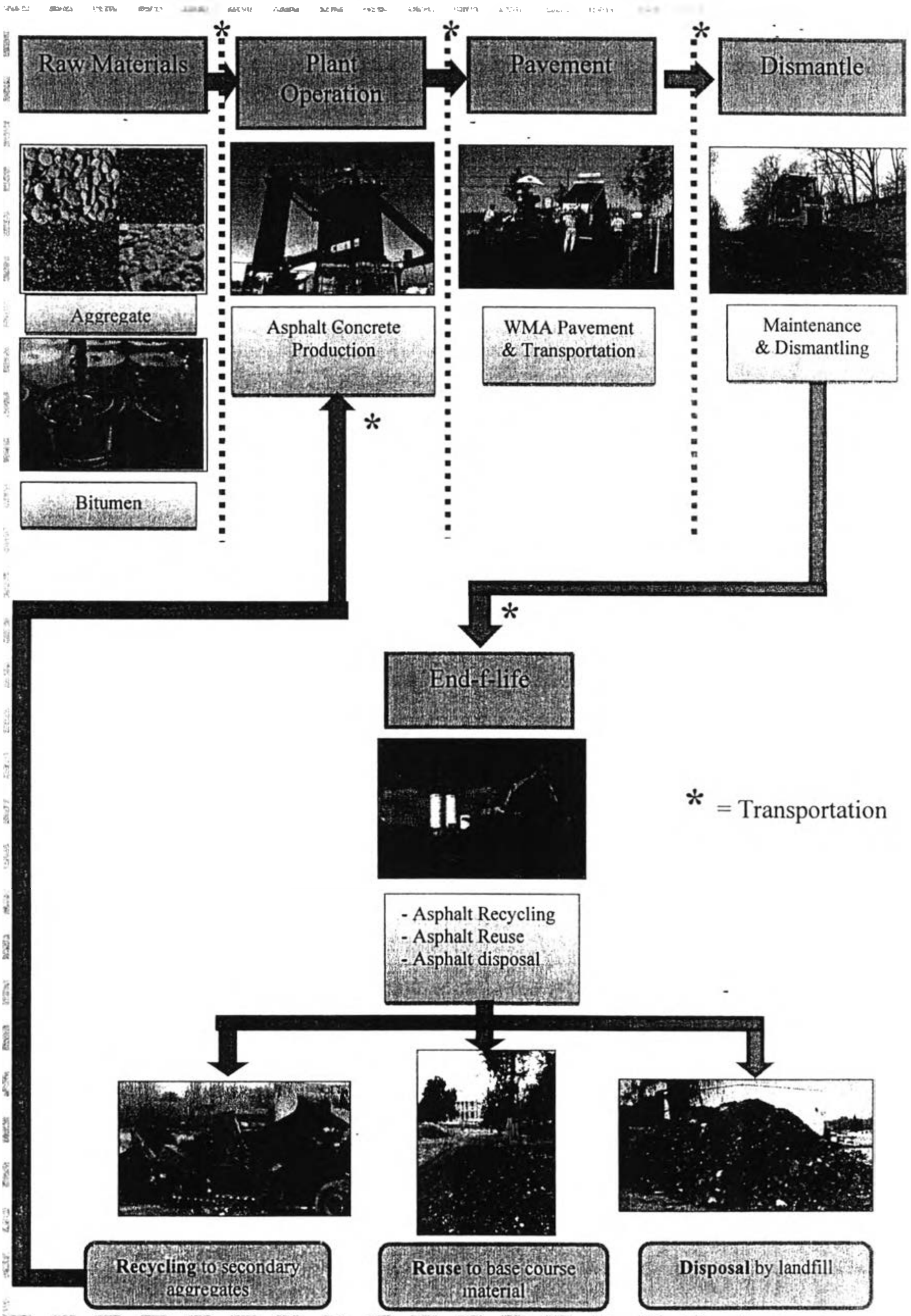

Figure 3.1 System boundary of research.

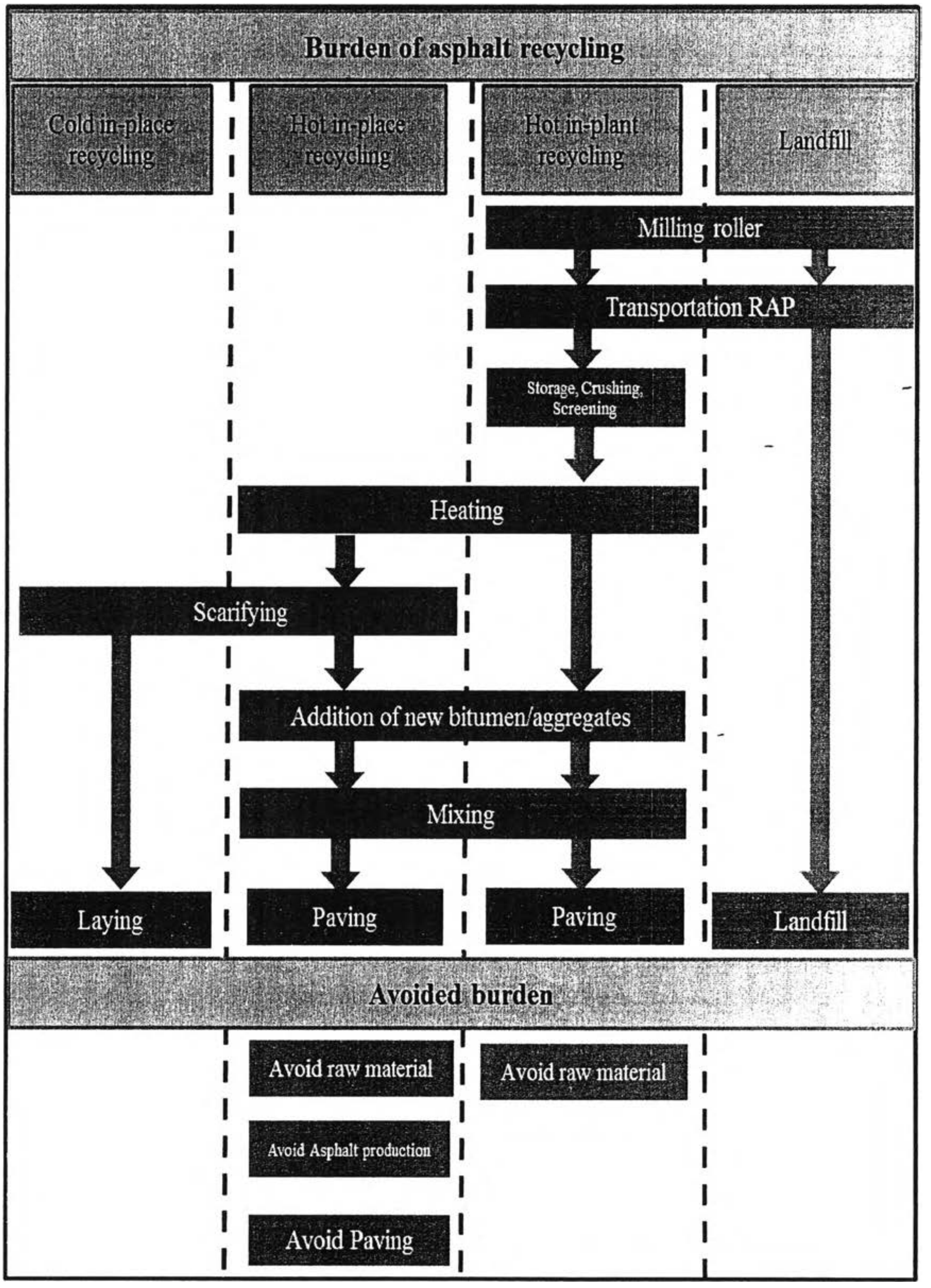

Figure 3.2 System boundary of research focus on each end-of-life processes.

Table 3.3 Source of data

Phase	Process	Type of Data	Data Source
Raw Materials		Secondary Data	Ecoinvent
Transportation	Transporting by truck	Primary Data (From Phase I)	Thaiwat Engineering Co., Ltd (Bangbuatong and Sriracha)
Asphalt Production	Hot-Mixed Asphalt Production	Primary Data (From Phase I)	Thaiwat Engineering Co., Ltd (Bangbuatong)
Pavement	Hot-Mixed Asphalt Paving	Hybrid* (From Phase I)	Thaiwat Engineering Co., Ltd (Bangbuatong)
End of life	Hot in-plant recycling	Secondary Data	Literature
	Hot in-place recycling	Secondary Data	Literature
	Cold in-place recycling	Secondary Data	Literature
	Landfill	Secondary Data	ETH-ESU 96 Systems processes

*Combination of primary and secondary data.

- Compute impact potentials based on the LCI results by compiling data in the LCA commercial program named SimaPro version 7.3 with Eco-indicator 95 and CML 2 Baseline 2000 methods and then analyzing the overall process in both energy and environmental aspects.

3.2.3 *Impact Assessment (LCIA)*

- Define environmental impact category in term of:
  - Global warming potential
- Compute impact potentials based on the LCI results by compiling data in the LCA commercial program named SimaPro version 7.0 with Eco-indicator 95 and CML 2 Baseline 2000 methods and then analyzing the overall process in both energy and environmental aspects.
  - Energy efficiency will be expressed in terms of Net Energy Ratio (NER defined as a ratio of life cycle energy input/energy output of warm mix asphalt).
  - Global warming potential (GWP as kg CO_2 equivalent) will be evaluated.

3.2.4 Interpretation and Reporting

- Compare the results with the NER and GWP of conventional hot mix asphalt and warm mix asphalt.
- Evaluate opportunities to reduce energy, material inputs, or environmental impacts for each stage of the product's life cycle.
- Analyze the improvement, in which recommendations are made based on the results of the inventory analysis and impact assessment stages.

Table 3.4 Sources of Data for Calculation

Phase	Source of Data Collection	Database for Environmental Profile
Raw Material		
Bitumen	Secondary Data	Ecoinvent
Aggregate	Secondary Data	Ecoinvent
Transportation		
Transportation of raw material, asphalt production and pavement	Primary Data	Thai LCI Database
Asphalt Concrete Production		
Hot-Mixed Asphalt Production		
Fuel	Primary Data	Ecoinvent
Electricity	Primary Data	Thai LCI Database
water	Primary Data	Ecoinvent
Grease	Primary Data	Ecoinvent
Waste	Primary Data	Ecoinvent
Water Emission	Primary Data	Ecoinvent
Air Emission	Primary Data	Ecoinvent
Bitufresh	Primary Data	Ecoinvent
Pavement		
Hot-Mixed Asphalt Paving		
Paving		
- Time/Distance	Primary Data	Ecoinvent
- Specification and fuel consumption of paver	Secondary Data	Ecoinvent
Breakdown rolling		
- Time/Distance	Primary Data	Ecoinvent
- Specification and fuel consumption of breakdown	Secondary Data	Ecoinvent
Finish rolling		
- Time/Distance	Primary Data	Ecoinvent
- Specification and fuel consumption of the roller	Secondary Data	Ecoinvent
End of life		
Hot in-plant recycling		
Dismantle	Secondary Data	IDEMAT 2001
Transportation RAP	Primary Data	Thai LCI Database
Storage, Crushing, Screening	Secondary Data	Ecoinvent
Avoid - raw material	Secondary Data	Ecoinvent
Hot in-place recycling		
Scarifying, paving, compaction	Secondary Data	IDEMAT 2001
Propane for Heating and mixing	Secondary Data	Franklin USA 98
Avoid - raw material	Secondary Data	Ecoinvent
Avoid - Asphalt production	Secondary Data	Ecoinvent
Avoid - Paving	Secondary Data	Ecoinvent
Cold in-place recycling		
Scarifying, paving, compaction	Secondary Data	IDEMAT 2001
Landfill		
Dismantle	Secondary Data	IDEMAT 2001
Transportation RAP	Primary Data	Thai LCI Database
Landfill	Secondary Data	ETH-ESU 96 Systems processes

3.3 Assumptions and Limitations

3.3.1 Assumptions and Limitations of Raw Material and Production

- The asphalt production process is followed by Standard Drawings for Highway Construction.
- Amount of aggregates used and air emission generated in hot-mixed production and warm-mixed production are assumed to be the same.
- Amount of asphalt binder in hot-mixed production equals amount of asphalt binder including Sasobit additive in warm-mixed production.
- Hot oil consumption in the production process is constant and the same for both HMA and WMA.
- Ambient temperature is estimated from average temperature of Thailand which is 25°C.
- Equipment for production processes are not included in this study.
- As limited by data provider, the data for asphalt production, raw materials used and electricity consumption are based on 3 months (June, July and August). The embedded energy or feedstock energy of bitumen in asphalt is not included in this study as it could be considered as it is borrowed from the nature and returned without being used at end of life (Oers et al., 2002). The value of this embedded energy is treated as heavy fuel oil (HFO). In addition, it is assumed that pavement step for both HMA and WMA is the same in terms of process, energy and utility usage. For WMA, due to the unavailability of completed primary data at the asphalt plant, calculations based on Kristjansdottir et al. (2007), Olard, Héritier and Beduneau (2008) and Lecomte et al. (2007) were used in this study for the reduction in energy consumption and emissions of raw material stage.

3.3.2 Assumptions and Limitations of Pavement

- The asphalt pavement process is followed by Standard Drawings for Highway Construction
- Thickness and area of hot-mixed pavement and warm-mixed pavement are the same.

- Specifications of machines/equipment for paver, breakdown and static pneumatic rolling used in hot-mixed pavement and warm-mixed pavement are the same.
- Equipment for production and pavement processes are not included in this study.

3.3.3 Assumptions and Limitations of Transportation

- Transport distances for material transportation of hot-mixed pavement and warm-mixed pavement are the same.
- Transport distances from RAP site to asphalt plant and landfill site both HMA and WMA is 50 km.

3.3.4 Assumptions and Limitations of End-of-life

- Road age for HMA pavement and WMA pavement are the same.
- Equipment for end-of-life processes apart from end-of-life machine are not included in this study.
- No waste both residue and air emission in dismantle process, hot in-place, hot in-plant, and cold in-place recycling, and landfill process.
- Efficiency and specifications of milling machine, cold in-place recycling machine and hot in-place recycling machine in hot-mixed and warm-mixed asphalt recycling are the same.
- In Thailand the abandon asphalt was assumed as landfill burden
- Method that was used to evaluate landfill process of HMA and WMA is the same.
- RAP ratios for hot in-place, hot in-plant, cold in-place recycling and landfill processes are consisting of aggregate (94%) and bitumen (6%). For WMA, It consists of 3% additive in bitumen. (Miliutenko et al., 2013).