Chapter2

Principle and literature review

2.1 Life Cycle Assessment Methodology

White et al., 1993 and Elkington et al., 1993 has reviewed LCA is an environmental management tool increasingly used to predict and compare the environmental impacts of a product or service, 'from cradle to grave' (P. White et al., 1995).

LCA is defined by Vigon et al., 1993 as "an evaluation of the environmental effects associated with any given activity from the initial gathering of raw material from the earth until the point at which all residuals are returned to the earth (Paul L. Bishop, 2000).

The Society of environment Toxicology and Chemistry (SETAC) has provided LCA guidelines for LCA definition as "a tool that can be used to evaluate the environmental effects of a product, process, or activity. The LCA methodology has four components: Goal definition and scoping, Life Cycle Inventory (LCI), impact assessment, and improvement assessment" (Curran, M.A., 1996).

SETAC has defined the LCA process as "An objective process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and material usage and environmental releases to assess the impact of those energy and material uses and releases on the environments, and to evaluate and implement opportunities to effect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing, transportation, and distribution; use/re-use/maintenance; recycling; and final disposal" (Graedal, T.E., 1998).

The LCA procedure is standardized by ISO (Cascio, J., 1996), which defines LCA as "a technique for assessing the environmental aspects and potential impacts associated with a product, by

- compiling an inventory for relevant inputs and outputs of a product system;
- evaluating the potential impacts associated with those inputs and outputs;
- interpreting the results of the inventory and impact assessment phases in relation to the objectives of the study" (European environment agency, 1997).

The LCA methodology has four components: goal and scope definition, inventory analysis, impact assessment, and interpretation. A full life cycle assessment includes each of these four components and the life cycle assessment framework is shown in Fig. 2.1 (Curran, M.A., 1996).

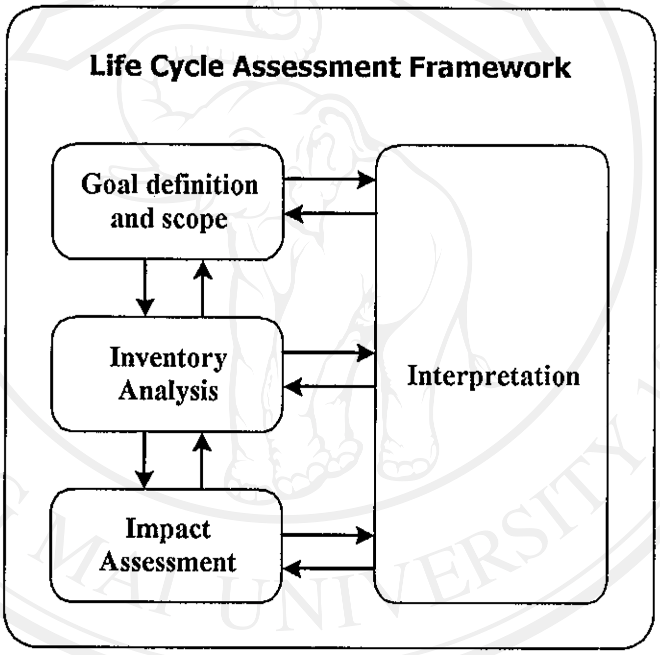

Figure 2.1 Life cycle assessment framework-phases of an LCA (Source: ISO, 1997)

2.1.1 Goal and scope definition

Establishing goals and scope of the assessment, is the first phase in LCA and an important step containing the main issue as follows:

2.1.1.1 Goal

The goals of the LCA study should be included the purpose for carrying out the study, the intended applications, the intended audience, the initial data quality objectives, and the type of critical review that will be conducted for LCA (Ritchie, I. and Hayes, W., 1998).

2.1.1.2 Scope

The scope of LCA is set the borders of the assessment. It should be included background information for the product, process or activity being evaluated, boundaries of the study, method of impact assessment, data requirements, assumptions, and limitations of the study. Therefore, the scope of the study may need to be modified while the study is being conducted as additional information is collected (Ritchie, I. and Hayes, W. 1998 and European environment agency, 1997).

2.1.1.3 Functional unit

The main purpose for a functional unit is to provide a reference to which input and output data are normalized. Defining the subject of the study, the functional unit should be large sufficiently to simplify calculation and detailed sufficiently to enable the identification of relevant differences (European environment agency, 1997 and Curran, M.A., 1996).

2.1.1.4 System boundaries

The system boundaries is defined the processes/operations i.e., manufacturing, transportation, and waste management, and the inputs and outputs to be taken into account in the LCA (European environment agency, 1997).

2.1.1.5 Quality of the data

Data quality used in the Life Cycle Impact (LCI) is reflected with the quality of the final LCA study. Thus requirement of initial data quality should be established to define as time-related coverage, geographical coverage and technology coverage (European environment agency, 1997).

2.1.1.6 Critical review

The purpose of critical review process is to ensure the quality of the LCA. The review can be internal review, external review or interested parties.

2.1.2 Inventory Analysis

Conducting the inventory analysis, is the second stage and the core of the LCA system. The LCI is a process for quantifying the resource use, energy use, air emissions, waterborne effluents, solid waste, and other environmental releases associated with throughout the life cycle of a product, process, or activity being evaluated. For a product life cycle, the analysis involves all steps in the life cycle of each component of the product being studied which all relevant data is collected, measured and organized (Kolluru, R.V. 1994 and USEPA, 2001). The level of accuracy and detail of the collected data is reflected throughout the LCA process. This relationship between the inputs and outputs and the six stages of a life cycle inventory is illustrated in Fig. 2.2 as described:

- raw materials acquisition
- manufacturing, processing, and formation
- distribution and transportation
- use/reuse and maintenance
- recycle and
- waste management

The result of an inventory analysis is a list containing the quantities of pollutants released to the environment and the amount of energy and material consumed.

The balancing of LCI methodology is used material and energy for each operation within the system and for the whole life-cycle system. The three major types of LCI decisions should be taken: (1) allocation of inputs and outputs from an industrial operation to the various products produced, (2) analysis of recycling systems, and (3) reporting of energy that is embodied in products entering or existing the LCI system (Curran, M.A., 1996).

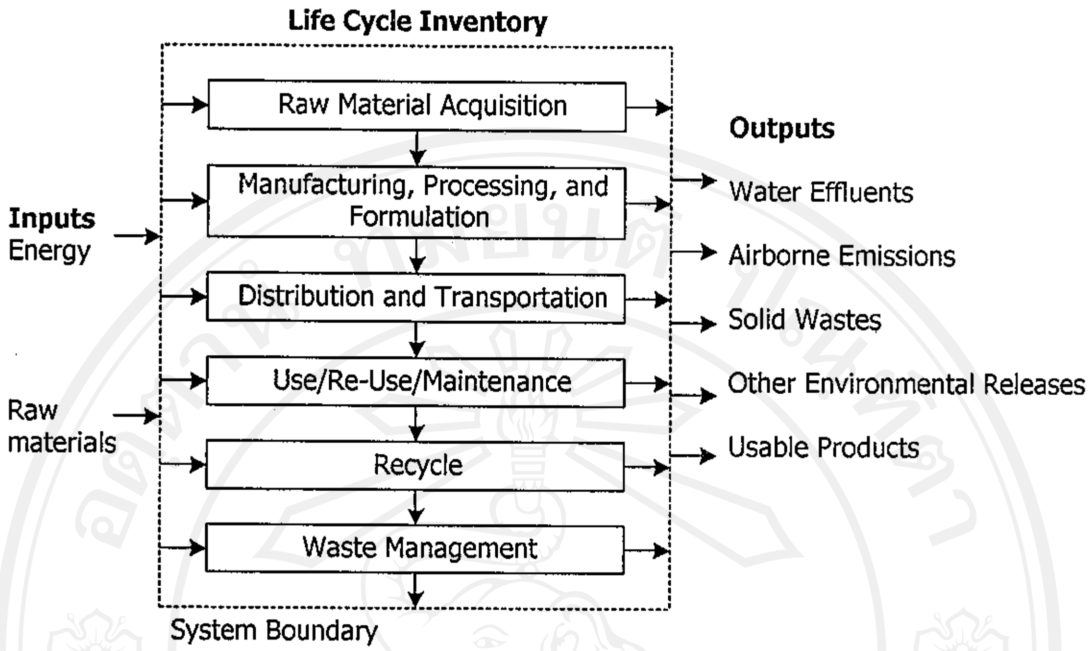

Figure 2.2 Life cycle inventories account for material use, energy use, wastes, emissions, and co-products over all of a product's life cycle (Allen, D.T. and Shonnard D.R., 2002.).

When co-products arise in LCI, these processes are become the complexities. Co-product allocation is considered for the inputs and outputs of a manufacturing facility for the processes. Almost the allocation of material use, energy use, and emission among co-products is based on mass. Other methods of co-product allocation is included use of the mass of dry solids, stoichiometry, heat of reaction, and economic value (Allen, D.T. and Shonnard D.R. 2002 and Curran, M.A., 1996).

The framework of LCI analysis and assessment perform the quality of data are used and combined 2 guidance documents as Life-Cycle Assessment: Inventory Guidelines and Principle (1993) and EPA published Guidelines for Assessing the Quality of Life-Cycle Inventory Analysis (1995) and some parts is modified from Curran M.A.. Inventory can be split up into 4 basis parts to perform LCI study: (1) develop a process flowchart; (2) develop an LCI data collection plan; (3) gather data and create a computer model; (4) analyze and report the study results; and (5) interpret the results and draw conclusions.

2.1.2.1 Develop a process flowchart

A process flowchart is the gathering and processing of the environmental interventions and forms a qualitative graphical representation of all relevant processes during the life cycle of a product, process or activity. The main goal of the process flowchart is created an overview of the inputs and outputs to a process or system. The process flowchart is started with the manufacturing process of main product and adds the previous and following stages i.e., resources, components, waste. Unit processes inside of the system boundary is linked together to form a complete life cycle picture of the required inputs and outputs (material and energy) to the system. Some processes can be combined for easily handled depending on the concentration that generates the largest environmental impact or goal definition (Curran, M.A., 1996).

The more complex the flow diagram, is more accuracy and utility of the results. However the increased complexity data is consumed more time for collecting and analyzing data (USEPA, 2001).

2.1.2.2 Develop an LCI Data Collection Plan

Data collection is often the most work intensive part of a LCA, especially site specific data. Therefore many cases use average data from the literature or data from trade organization.

During the data collection stage required information is gathered by questionnaire or checklist. These are valuable tools for ensuring completeness, accuracy, and consistency to meet the needs of a specific LCI. The relevant data specifies the necessary data source to complete the LCI is planed to ensure that the quality and accuracy of data meet the study's goals (European Environment Agency. 1997 and USEPA, 2001).

Defining the required data sources and types prior to data collection helps to reduce costs and the time required collecting the data. Sources of information are included;

- standard documents or other literature
- journals, papers, books, and patents
- internal information on processes in industry

- government documents, reports and databases
- related/previous life cycle inventory studies
- published databases
- trade associations

2.1.2.3 Gather data and create a computer model

This step consists of finding and filling in the flow diagram and worksheets with numerical data. Therefore, the system boundaries or data quality goals of the study need to be modified based on data availability.

Data collection efforts involve a combination of research, site-visits and direct contact with experts that generate large quantities of data. A computer modeling can be done by spreadsheets or software usage. An electronic database or spreadsheet can be useful to hold and manipulate the data. But an alternative to developing a computer model, it may be more cost effective to buy commercially available LCA software package.

Another method to reduce data collection time and resources is to obtain non-site specific inventory data. Several organizations have developed databases specifically for LCA that contain some of the basic data commonly needed in constructing a LCI.

2.1.2.4 Analyze and report the study results

Now that the data has been collected and organized into one format, the accuracy of the results must be verified and sufficient to support the purposes for performing the LCA as defined in section 2.2.1. The LCI result is analyzed and reported for environmental release, as detailed below; (USEPA, 2001)

a) Atmospheric emissions

LCI results typically are listed 30 to 40 different air emissions, including carbon dioxide as well as substances classified as pollutants. Some of the most commonly reported atmospheric emissions are particulate, nitrogen oxides, hydrocarbons, sulfur oxides, and carbon monoxide.

b) Wastewater discharge

Typically LCI results are listed more than 20 different waterborne releases. Some of the most commonly reported wastewater are Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), suspended solids (SS), dissolved solids, iron, chromium, acid, and ammonia.

c) Solid wastes

Solid wastes are solid outputs from the system that are sent to landfills or disposed in some way that has a potentially detrimental effect on the environment. Industrial wastes are generated during the manufacturing of the product are sometimes overlooked. Industrial solid wastes are included wastewater treatment sludge; solids collected in air pollution control devices; trim or waste materials from manufacturing operations.

2.1.2.5 Interpret the results and draw conclusions

The LCI study will be summarized the specific product, process, or activity being analyzed. LCI results will list resources used into the amount of energy and materials consumed, and environmental release to the air, water, and land containing the quantities of pollutants.

Therefore, it is important to thoroughly describe the methodology used in the analysis, define the systems analyzed and the boundaries and all assumptions made in performing the inventory analysis.

2.1.3 Impact assessment

Conducting the impact assessment, the third stage of LCA, is a technical quantitative and/or qualitative process to evaluate potential human health and environmental impacts of the environmental resources and releases identified during the LCI. The process for Life Cycle Impact Assess (LCIA) production generally consists of three stages: classification, characterization, and valuation. Classification is the assignment of LCI results to impact categories. Characterization is the process of developing conversion models to translate and combine LCI results into representative indicators of impacts to human and ecological health. Valuation is the assignment of relative values or weights to different impacts, allowing integration across all impact categories (Curran, M.A., 1996 and USEPA, 2001).

The final step in LCIA, valuation, consists of weighing the results of the characterization step. In general, the weighting method includes activities i.e., identifying the reflect of goals, determining weights to place on impacts and applying weights to impact indicators. Thus, the highest environmental impact categories is important and given more attention more than the impact categories of least concern. A aggregating values obtained from the evaluations of different impact categories is accumulated to a single environmental impact score (Allen, D.T. and Shonnard D.R. 2002. and USEPA, 2001).

LCA will be provided real benefits to the decision-making process but it needs to provide information on a range of relevant environmental issues. In conventional LCA, any required information, without weighing, can not be excluded, and will create a lengthy list of inventory parameters. Therefore, it is a time consuming and highly expensive to collect data. In addition to the above problems the important inventory data may not be available because it is not in any recorded measure or report.

According to the standard, ISO 14042 offers some suggestions in these cases for internal and non-comparative LCA that is the optional elements of normalization, grouping, and weighting that might help to resolve these problems. However, both grouping and weighting are based on value choices. Whereas grouping is the sorting and ranking of potential impact categories according to importance, weighting uses quantitative factors, eventually leading to a single score.

In some cases, the most appropriate method for doing simple, understandable and comparable format is to use an eco-indicator. The eco-indicators have been developed and used in Europe for a decade. Some of the strategies for valuating LCIA approaches have been employed such as Ecopoint, EPS, Ecological scarcities, CML, Eco-indicator 95 and Eco-indicator 99. (Grant, T. 2000., and Ritchie, I. and Hayes, W. 1998)

2.1.4 EPS default method

The LCA approach is standardized by ISO which defines LCA as a technique for assessing the environmental aspects and potential impacts associated with a product including ISO 14041, 14042 and 14043 standards (European Environment Agency. 1997). The EPS rules and terminology are described in agreement with the ISO framework (Steen, B. 1999). Furthermore it contains a specified methodology, the EPS default method, which is the approach of this study. The EPS default method follow the ISO standard 14042 and contains detail as follows:

- selection of impact categories and category indicators
- assignment of emissions and resources to impact categories (Classification)
- characterization
- weighting
- a database with characterization factors and weighting factors which are multiplied to give indices

The Fig. 2.3 is shown the outline of relation between the LCA concept, ISO framework, EPS system and the EPS system default method.

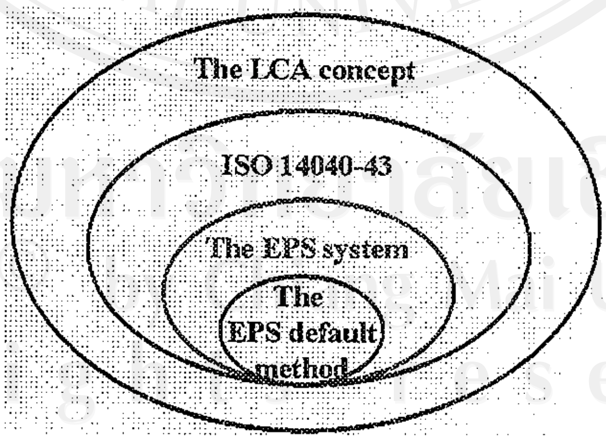

Figure 2.3 Relation between LCA concept, ISO standard framework, EPS system and EPS default method (Steen, B. 1999).

The development of the EPS system is started during 1989, to meet the requirements of the product continual improvement process (Steen, B. 1999). The EPS method is an ecological scoring system of assessing environmental impacts on technical, ecological, and socioeconomic systems. This method combines characterization and weighing factors for emissions and resource depletion, as weight indices, into single values for each inventory element. Impact categories for this system are identified from five safeguarded subjects including biodiversity, human health, ecological health, resource, and aesthetics. The basic method describes a product life cycle in term of materials, processes and evaluates emissions by means of willingness to pay (WTP) for protecting the safeguard subjects (Steen, B. 1999).

In the EPS system, environmental indices are multiplied by the appropriate quantity of raw materials used or emission released to arrive at ELU, which can then be added together to arrive at an overall ELU for the subject of the life-cycle study (Allen, D.T. and Shonnard D.R. 2002). The measure is expressed in ELU, as given by Eq. 1.1.

$$ELU = \sum_i \sum_s (ELU / kg)_i M_{i,s} \qquad \text{(Eq. 1.1)}$$

Where i indicate the type of material, s the life stage, and M is the mass of material i at life stage s (Graedel, T.E. 1998).

The LCA application with the EPS default approach is a way of handling the conflict. It can be summed up with one recommendation of which product alternative is preferred and realize the fact that there may be several answers (Steen, B. 1999). Using a default weighting and valuation method helps in finding for interested inventory data. If data is not available, a rough estimation is considered better than just leaving a data gap. In the EPS default method, the weighting is still made through valuation. There is only one weight indicator, as only one value for the total environmental impact is requested (Steen, B. 1999).

2.1.5 Interpretation

Life cycle interpretation is the last phase of the LCA process which is a systematic evaluation of the needs and opportunities to reduce the environmental burden associated with energy and raw materials use and waste emissions throughout the whole life cycle of a product process or activity. This technique is to identify, quantify, check, and evaluate information from the results of the LCI and the LCIA to communicate them effectively. Otherwise this analysis may include improvements and alterations of a product or process is often the driver for a given study, such as changes in product design, raw materials use, industrial processing, consumer use, and waste management (Kolluru, R.V. 1994).

The International Organization for Standardization (ISO) has defined the following two objectives of life cycle interpretation;

a) Analyze results, reach conclusions, explain limitations and provide recommendations based on the findings of the preceding phases of the LCA and to report the results of the life cycle interpretation in a transparent manner.

b) Provide a readily understandable, complete, and consistent presentation of the results of an LCA study, in accordance with the goal and scope of the study (ISO 1998b).

Refer to the ISO draft standard provided steps to conduct a life cycle interpretation are identified and discussed into 3 steps as detail below:

2.1.5.1 Identify Significant Issues

The first step of the life cycle interpretation phase involves reviewing information from the first three phases of the LCA process in order to identify the data elements that contribute most to the results of both the LCI and LCIA for each product, process or service, otherwise known as "significant issues" (Curran M.A.). Significant issues can be included as following;

- inventory parameters like energy use, emissions, waste, etc.
- impact category indicators like resource use, emissions, waste, etc.

- essential contributions for life cycle stages to LCI or LCIA results such as individual unit processes or groups of processes (e.g., transportation, energy production).

2.1.5.2 Evaluate the Completeness, Sensitivity, and Consistency of the Data

The results from these first steps are used to evaluate the completeness, sensitivity, and consistency of the LCA study in evaluation step. These steps establish the credibility and reliability of the results of the LCA. This is accomplished by completing the following tasks to ensure that products/processes are fairly compared at each technique that summarized below:

a) Completeness Check

Examining the completeness of the study to ensure that all relevant information and data needed for the interpretation are available and complete. The result of this effort will be a checklist indicating that the results for each product/process are complete and reflective of the stated goals and scope of the LCA study.

b) Sensitivity Check

Assessing the sensitivity of the significant data elements influence the results greatly and its ability to confidently draw comparative conclusions. A sensitivity check can be performed on the significant issues using these common techniques for data quality analysis i.e.; Gravity Analysis (Identifies the data that has the greatest contribution on the impact indicator results); Uncertainty Analysis (Describes the variability of the LCIA data to determine the significance of the impact indicator results); and Sensitivity Analysis (Measures the extent that changes in the LCI results and characterization models affect the impact indicator results).

c) Consistency Check

Evaluating the consistency used to set system boundaries, collect data, make assumptions, and allocate data to impact categories for each alternative. Verification and documentation of the study is completed as intended at the conclusion increases confidence in the final results.

2.1.5.3 Draw Conclusions and Recommendations

The objective of this step is to interpret the results of the life cycle impact assessment to determine which product/process has the overall supreme impact to human health and the environment with the highest score as defined by the goal and scope of the study.

2.2 Life Cycle Assessment of WWTP

Wastewater streams contain a variety of contaminants. The most serious issues are heavy metals. These contaminants are not only toxic to most living systems (even low concentrations), but they may interfere with conventional biological treatments. Although, there are many treatment processes (See Appendix B), which have developed their methods and techniques to follow regulations. Therefore, LCA can help to evaluate some environmental aspects and identify improving opportunities in environmental management and sustainable development. However, most previous investigations of LCA have been focused on the assessment of products. Only a few have concerned processes, especially the wastewater treatments process (Sengupta, A.K. and Lancaster, Pa. 1995 and Zhang, Z. and Wilson, F. 2002).

The EPS have used a number of industrial evaluations; for example, cables, refrigerators, printed electronic circuits, gasoline, packaging materials and car parts (Steen, B. and Wendel, A. 2001, Reine, K. and Steen, B. 1999, Steen, B. 2001, Erixon, M. 1999 and Amatayakul, W. and Ramnas, O. 2001).

2.2.1 Electronic products WWTP

The electric and electronic industries have been a leading sector of industrial growth and economic dynamism around the world for decades. They are regarded as "clean" industries, compared with heavy industries such as the steel and processing industries. However, the fast development of the electric and electronic manufacturing has caused a wide spread use and consequently a mass production of electronic products. This has forced the concerned businesses to adapt a more environmentally sustainable production in electric and electronic industries. Even though electronics manufacturing in Southeast Asia has become more interesting, leading firms have undertaken efforts to improve environmental performance (Erixon, M. 1999, Ritchie, I. and Hayes, W. 1998).

Theory of wastewater treatment for Electronic products is very important to the understanding of how to achieve the effluential standard (Ritchie, I. and Hayes, W. 1998).

2.2.2 Wastewater collection system

Wastewater is produced from various equipment and processed within the electronics manufacturer. This system is segregated based on its characteristics and components, divided into four categories, and treated via different treatment processes, i.e., rinse water recycled process (T1), heavy metal treatment process (T2), gold recovery process (T3) and batch treatment and neutralization process (T4). They will then be pumped to a proper treatment process within the Wastewater Treatment Plant. The wastewater treatment plant is required to treat all wastewater generated from the production process in order to meet the standard for discharged effluent of the Industrial Estate Authority of Thailand (IEAT). These diagram is shown on Fig. 2.4.

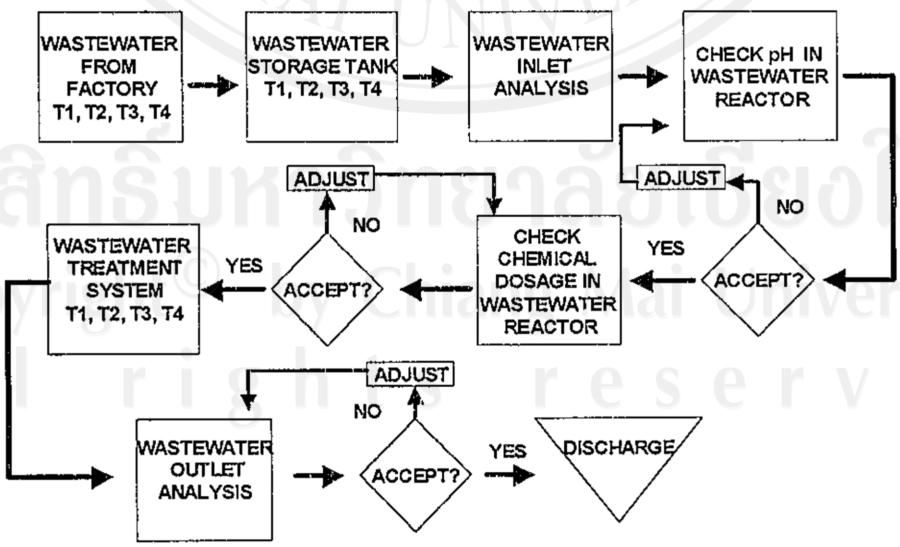

Figure 2.4 Process flowchart of WWTP

Each process should be suitable for treating each particular type of wastewater. The process description of each treatment process is as follows:

2.2.3 Rinse water recycled process (T1)

The slightly contaminated De-ionized (DI) rinse water from the production process will be treated via Reverse Osmosis (RO) membrane. The rinse water tank will receive the wastewater from production then pump to filtrate suspended solids with a multimedia filter and follow with a carbon filter to eliminate chlorine, which effects the RO membrane life cycle.

The main treatment is the RO system that separates wastewater from product water resulting in RO water. The other concentrated water is rejected water which is later drained. This system is controlled by a conductivity meter to measure water quality. The treated water is stored at a RO storage tank. The RO water supply pump is controlled by a level switch that is disinfected by an ultraviolet unit for disinfecting process and used as recycled water for the production process.

2.2.4 Heavy metal treatment process (T2)

All rinse water and chemicals used, containing heavy metal i.e., nickel, copper and lead in the production process, is treated by chemical addition and flocculation methods in order to separate heavy metals from wastewater.

In this system, coagulant chemicals are added into wastewater. Caustic soda is added by a pH controller, which is bed via inline piping. The static mixer is an inline mixer type, which is used to mix chemical and wastewater together. The chemical reaction occurs during the inline piping before going to the flocculation tank. Polymer is added into the flocculator; then, the wastewater flow is passed through the clarifier. This equipment can separate clear water and sludge by plate baffle. The settle sludge is collected at the sludge tank and pumped to a filter press. The diluted water will then be neutralized prior to discharge.

2.2.5 Gold recovery process (T3)

All rinsed water containing gold, in the production process, is treated by the use of ion exchange resin, used to absorb gold in the wastewater. The gold waste tank collects all wastewater from piping. Then, the gold rinse feed pump transfers wastewater into the treatment process. All gold rinse wastewater is filtered by micron filter to remove solids, which have periodic changes of micron filters by pressure gauge checking. This is followed by a pH adjustment process which neutralizes the gold rinse solution to extend the life time of the ion exchange resin. The ion exchange resin is the heart of the recycling process. Duration the adsorption process, the wastewater is passed through anionic resin and activated carbon. Diluted water is neutralized prior to discharge. Their gold containing absorbents are recovered by suppliers from outside the factory.

2.2.6 Batch treatment and neutralization process (T4)

Dumped chemicals containing other heavy metals, such as nickle, include concentrated rinse water and wastewater from other treatment processes are treated by chemical addition and flocculation method. The precipitation process involves adding chemicals at a controlled rate to the wastewater within the reactor tank which will adjusted the pH to 10.5, followed by mixing. The sedimentation process is to remove the precipitate by polyelectrolyte solution adding at flocculation tank. The flocculated wastewater overflows and within the plate settling tank. The settled sludge is fed to the sludge treatment system i.e., Filter press. While the clear water is filtrated by sand filter tank to remove solids and particles that cannot be removed by flocculation; further treated by Neutralization process. The dry sludge is collected for further disposal while the filtrated wastewater is drained to the Neutralization process. Dilute rinsed water and clear water from other wastewater treatment processes is collected into the neutralization tank and neutralized with hydrochloric acid prior to discharge or to further reuse.

2.2.7 Sludge treatment

Solid precipitate is generated by the addition of appropriate chemicals for heavy metal removal from the wastewater. The chemical sludge is to be dewatered by filter press, and disposed at landfill.

2.3 Waste minimization

Due to the increasing volume of complex electric and electronic products including many and often rare materials, the environment is being affected in various ways. Thus, an increasing number of firms have sought and obtained ISO 14001 and other certifications for environmental management. There are also economical benefits in minimizing the waste deposits and the exploitation of resources; as well as, the reusing and recycling of electric and electronic devices. In fact, global competitiveness in the industry will depend on its ability to minimize waste, enhance productivity, minimize material costs, and minimize the use of hazardous material due to regulatory costs and the high cost of waste disposal (Erixon, M. 1999).

Waste management is becoming increasingly more burdensome in terms of time, resources, and costs. Of particular concern to their business are listed as issues below:

- strict limits for discharging process wastewater to the sewer
- cost of wastewater treatment to meet those limits
- regulatory requirements for hazardous waste management
- cost of managing and disposing of hazardous wastes

Waste management can help to address these problems and reduce the burden of waste management on business.

Definition of waste minimization is described by EPA with two terms of this hierarchy as follows (Long, R.B. 1995 and Henry, F. 1990):

a) Source reduction is the reduction or elimination of hazardous waste at the source, usually within a process. Measurement of source reduction includes process modifications, feedstock substitutions, feedstock purity improvements, housekeeping and management practice changes, increases in the efficiency of equipment, and recycling within a process.

b) Recycling and recovery is the use or reuse of hazardous waste as an effective substitute for a commercial product or as an ingredient or feedstock in an industrial process. It includes the reclamation of useful constituent fractions within a waste material or the removal or contaminants from a waste to allow it to be reused.

The four basic incentives for motivating industry to establish and drive a waste minimization program include: (1) the real cost and economics associated with generating and managing waste;(2) corporate policies, procedures, and waste reduction goals;(3) the understanding that waste minimization will improve a company's environmental position by reducing risk, improving public support, and better utilizing natural resources; and (4) legal requirements (Bishop, P.L. 2000).

The principle ways to adopt waste minimization is source reduction, recycling and recovery, treatment and disposal. Techniques for implementing waste minimization's various methods is shows within Fig. 2.4

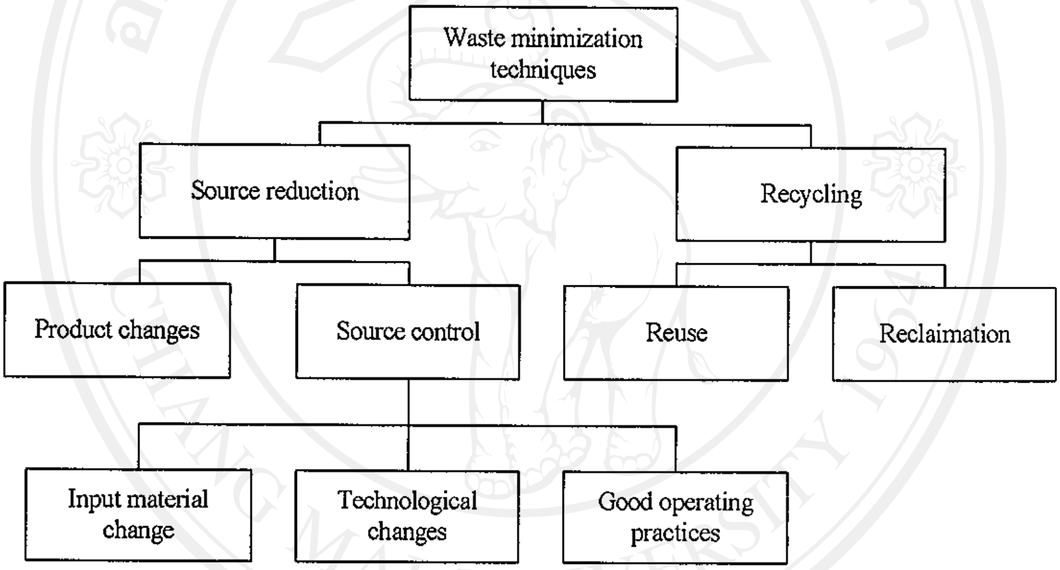

Figure 2.5 Overview of waste minimization techniques (Rhyner, C.R. et al., 1995).

These techniques range from low or no cost method to major equipment modifications requiring large capital investment and these general methods are described as below (Hazardous Waste Reduction Program. 1989);

a) process and equipment modification
   - redesign or replace equipment in order generate less waste
   - changes in operating condition, such as flow rates, temperature, pressure, residence times.
   - implement energy and water conservation programs

b) input material changes

- o material substitution or replacing a hazardous substance used in a process with a non-hazardous or less hazardous substance.
- o material purification involves input or feed materials in order to avoid the introduction of inert or impurities into the process.

c) improved operating and housekeeping practices

- o improve material tracking and inventory practice
- o improve material usage, handling and storage
- o improve scheduling
- o recordkeeping
- o preventive maintenance
- o spill and leak prevention
- o waste segregation
- o employee education and training
- o cost accounting practices

d) Recycling

- o direct use and reuse involves the return of waste material
- o reclamation or recovery of valuable material from a hazardous waste

The actions that can be initiated to implement minimization of hazardous waste techniques are:

- Segregate hazardous waste
- Monitor inventory
- Investigate material substitution
- Modify processes
- Change product design
- Investigate waste exchanges
- Investigate recycling opportunities

2.4 Environmental problems overview of WWTP

From a plant walk-through in the WWTP by observing, asking and checking, found the major impacts are explained below:

2.4.1 Water pollution

The level of nickel in the effluent exceeds the standard. The possible sources of nickel-laden solution contaminates the wastewater : spills from the rinsing tank, spills from the electroplating operations and discharges of spent nickel solution that go into the wastewater flow. The spill problems are fixed and improved with the intention of controlling their operation which reduces some of the nickel contamination in the wastewater.

Otherwise, the main wastewater treatment need to verify, identify and measure relevant parameters for minimizing the contained discharges.

2.4.2 High chemical consumption

Typical problems for chemical precipitation, include improper chemical addition rates, improper handling and storage of hazardous materials. The most common problem with pH adjustment is due to alkaline wastewater in heavy metal precipitation and the neutralization process. Continuous treatment is recommended with the addition of acids and bases delivered in two or more stages with pH control in each stage to spread out the approach at the endpoint. The optimum pH is not the same for all metals in wastewater containing a mixture of metals; therefore, a compromise pH may need to be determined by jar tests to get adequate effluent quality. Otherwise, the jar test can be used to find a satisfactory combination for proper settling of a wastewater. (Ritchie, I. and Hayes, W., 1998, Ritchie, I. and Hayes, W., 1998. and Long, R.B., 1995.)

2.4.3 High energy consumption

The area of WWTP is limited to a small space. Thus, it is designed within a 3 floor level, which creates high electricity consumption for pump shooting wastewater and sludge.

2.4.4 Air pollution

The source of air pollution problems are chemicals from pH adjustments which release vaporized acids and bases in to the air.

2.4.5 Sludge management

Sludge produced from wastewater treatment is typically hazardous waste. The sludge produces many problems; such as, high volumes and the cost of handling and disposal. The dewatering devices can not support the large volume generated. Thus, the remaining sludge is collected into clarifier, spills and leaks from the sludge effects wastewater quality.

2.5 Literature review

Reine and Agneta (1999) illustrated the use of an EPS system as an environmental management tool to clarify a life cycle perspective and compared a Volvo environmental concept truck (ECT) and a conventional truck (FL6), which focused on environmental loads such as emissions and natural resource depletion. The truck life cycle assessment dealed with the environmental load per transported quantity and distance (e.g. load/tonkm). Consideration to both truck alternatives had approximately the same loading capacity and the relation to distance covered. The result of this study found the direct and indirect load caused by primary production was larger for the ECT than for the FL6, because of higher resource values for rare metals used in batteries and electronics. Direct and indirect effects from the truck usage phase were mainly due to emissions and fuel consumption. The uncertainty used for analysis to calculate by using estimations of uncertainties in all input data and using a Monte Carlo method. The diagram shows 80% probability of ECT was environmentally preferable and 20% probability that it was better than the ECT.

Bengtsson et. al. (1998) have been developed a new data model to handle information relevant to site-specific life cycle assessments (LCA), which was orientated towards GIS-representations of three generalized subsystems; technical, environmental and the social subsystem. For all three systems important differences, attributable to geographical locations could be determined. The high level data model was expressed as relations between different entities using the entity relationship (ER) modeling language. An existing LCA database, SPINE (which was already used by several companies for decision support in product development) could be utilized due to the structure of the databases geographical support. SPINE is a relational database structure designed for storing LCA data. The structure was used to implement LCA database at many different locations, both for large database and as storage device for LCA analysis software.

Carlson and Tillman (1998) have developed a data model and a database format for LCA data called SPINE. SPINE allowed for reuse of data through the storage of data on an arbitrary level of aggregation, i.e.- a whole life cycle (flow model of connected processes), which might be stored and data for single processes that may be retrieved and incorporated into another life cycle. SPINE was implemented as relational database, such as MS access, Oracle, and Sybase. Commercial LCA calculation software were available; however, the programs were limited in that they did not implement the full potential of the SPINE model.

Baumann (1998) studied the introduction of LCA to industry. The results found a need for better distinguishing between: Life cycle accounting and life cycle assessment, and the latter used for analysis of consequences and LCA procedure and LCA model. Otherwise, LCA was, to a great extent, used for learning, but not so much for direct decision support.

Karlsson (1998) studied the role of LCA in sustainable business development and tended to focus on the negative externalities per functional unit (the functional unit represents mostly positive internalities). Otherwise, the result was discussed on eco-efficiency and eco-effectiveness. The latter representing the overall environmental consequences, such as seen by LCA (and the EPS system) tend to make products more attractive and consequently increase the market volume. The net result could, therefore, be an increased burden on the environment.

Steen and Wendel (2001) studied how LCA and the EPS system were introduced into two Swedish companies. The EPS system used for product development did not have a central LCA function and had difficulties in understanding the background of the system. The ISO standards development for LCA was a great help for the EPS system framework.

Renzoni and Germain purposed a study to determine the environmental impacts arising from water production, water transportation to the customer and wastewater treatment. The study was used EI99 to focus on the main differences between a collective wastewater treatment plant and several small wastewater treatment plants for a small rural community. The functional wastewater treatment of a community of 11,000 inhabitants which had a functional unit is 1 m^3 of water. The life cycle of this plant included construction and operation of the plant and the whole sewer network. Electricity and chemicals consumed during operation of the wastewater treatment plant were taken into account. The result of inventory analysis found that sewer construction was a great part of major atmospheric pollutants and centralized wastewater treatment was responsible for atmospheric emissions from chemical production. Unfortunately, a number of water pollutants, such as, BOD, COD and N-tot were actually not taken into account by EI99. This was the problem that would be solved in a future part of the study.

The option of impact categories according to ISO 14042 on life cycle impact assessment (LCIA) was particularly difficult for global organizations, as they had to consider a wide range of values. Thus, employment of weighting was considered to simplify LCIA outputs. ISO 14042 offered some suggestions in these cases. According to the standard, for internal and non-comparative LCAs, there were the optional elements of normalization, grouping, and weighting that might help to resolve these kinds of dilemmas. However, both grouping and weighting were based on value choices. Whereas grouping was the sorting and ranking of potential impact categories according to importance, weighting used quantitative factors leading to a single score in the end (River, S., 1998).

Rydh and Karlstrom (2002) had studied the evaluation of environmental impact of recycling portable nickel-cadmium (NiCd) batteries in Sweden by using LCI, to identify significant potential environmental impact of their life cycle. The sensitivity of the NiCd battery system had been evaluated by varying recycling rates and emissions for landfilled metal. Inventory data included manufacturing, collection, recycling, waste incineration and landfill. The result of their study found the primary energy use and emission of CO_2 were most significant in battery manufacturing.

Seppala and et. al. (2002) studied LCA as a tool for management of environmental issues in the finished metal industry to give general view of the use of materials and energy, emission and environmental impacts, and to identify important areas of environmental protection. The impact assessment method for inventory data was DAIA (Decision Analysis Impact Assessment). It helped to increase level of environmental protection in the Finish metals industry.

Zhang and Wilson (2002) analyzed the environmental impacts of WWTP and identify opportunities for environmental performance improvement which partially considered LCA for material and energy consumption. The result showed that 70% of energy consumption occurred during the operation phase.

Zhang and Wilson (2002) used LCA analysis of multi-stage flash (MSF) and reverse osmosis (RO) desalination processes to evaluate and compare their environmental impacts for construction and operation phase only. In this study the material usage and the energy consumption were compared, then calculated to the percentage of their usages per each plant. A result of their comparison of energy consumption concluded that both operation and construction phase of MSF was higher than RO.

Friedrich (2002) is study compared the environmental burdens of portable water production between conventional method and membrane filtration technology which used GaBi 3 software considering to 3 stages of construction, operation and decommissioning. The comparison result showed the operation stage to be the most energy and material intensive stage in the life cycle. The conventional method had a higher mass consumption, but the membrane method was higher in energy consumption.

Mario and Federica (2001) applied LCA methodology to drinking and wastewater treatment system's of Bologna, Italy, which calculated inventory and impact assessment by TEAM 3.0 software. It can be concluded that the main energy consumption was related to drinking water treatment and was due to electrical energy used for pumping water. The reduction of energy consumption could improve the environmental performance.

Pillay, Friedrich and Buckley (2002) assessed the environmental impacts associated with the production of recycled water and highlighted the process contributing the most impact by using GaBI 3 software. These studies were considered within 2 phases; the construction and operation phase was showed the majority of the environmental burden for producing industrial water was the consumption of electricity in the operation of the plant.

Prek (2003) considered the occurring problem in the LCA and proposed the alternative method as Eco-indicator, which used a weighing method to analyze and assess the environmental impact of energy-producing technologies. The environmental impact was evaluated by Eco-indicator 99 methodology, which calculated heat production as emission data. It found that the step in the production was contributed with the largest environmental impact.

Amatayakul and Ramnas (2001) assessed and compared the environmental impacts occurring in the LCA's catalytic converter and environmental benefits in terms of atmospheric emissions reduction from the exhaust pipe by three weighting methods comparison. The impact assessment method in this study was EPS, Environmental Theme (ET) and Eco-scarcity method. The two of the three weighting methods indicated that the main environmental impacts were resource depletion, waste generation and air emission at the car exhaust pipe.

Suh and Rousseaux (2002) used LCA as a tool for evaluating the resource consumption, pollutant emissions and their consequent environmental impacts of alternative wastewater sewage sludge treatment scenarios. Their impact assessment method used SETAC/CML and found the combination of anaerobic digestion and land application, was most environmentally friendly for less emission and consumption of energy.

In Thailand, there are LCA studies, not only LCA of electricity grid mixes, rotary compressor, steel production, refinery production, audiocassette tapes, paperboard packaging, colored grout for ceramic tile, shrimp production, Mae Moh Coal-Fired power plant, but also LCI data for power plant, refrigerants, HDPE bottle, electronic products, Portland cement and PS and ABS. Almost these researches are studied by SimaPro 5, which uses as the data processing tool to summarize and recalculate all resources use and emissions to the environmental impact. Some thesis were discussed in detail as below:

Srituhla (2001) studied the assessment of the environmental impact emission in the whole life cycle of shrimp production by using Sima Pro model for calculating the impact emission. The results showed environmental impact emission that produced from one tone of shrimp production and the majority sources of impact were growing process and preparation process.

Sukasame (2001) studied to minimize resource consumption, energy consumption and impact assessment categories resulting from one ton of CGCT (Color Grout for Ceramic Tile) which analyzed by Sima Pro 4 software. The interpretation showed that major source of contribution was from white cement. After that redesign of CGCT was conducted in the CGCT factory and found that improvements of up to 10% of the overall impact assessment and energy consumption reduction.

The LCA study of the Mae Moh coal-fired power plant in Thailand evaluated the environmental burdens by identifying and qualifying energy and material used and waste released to the environment by using Numerical Eco-Load total standardization (NETS). The most serious environmental problem in this study was the Acidification (Sampattagul, S. et.al., 2003).

The purpose of LCA of paperboard packaging produced in Thailand assessed the environmental impacts arising throughout the life cycle of paperboard packaging produced, used, and disposed in Thailand and further identifying improvement options to reduce environmental impacts. The result of using SimaPro 5 for this study showed that the most important process to environmental impacts was landfill (Ongmongkolkul, A. 2001).

Lohsomboon (2002) conducted the LCA of two models of audiocassette tapes in order to identify significant environmental methods for improving production and product, which compare with two studied models. This study used SimaPro 5 as database software to enhance the company's green productivity activities through LCA. The result from this study showed that new model was less environmental impact than the existing model, especially ozone layer depletion.