LIFE CYCLE ASSESSMENT OF END OF LIFE STRATEGIES FOR WASTE FROM PETROLEUM PRODUCTION

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A Thesis Submitted in Partial Fulfilment of the Requirements
for the Degree of Master of Science
The Petroleum and Petrochemical College, Chulalongkorn University
in Academic Partnership with
The University of Michigan, The University of Oklahoma,
Case Western Reserve University, and Institut Français du Pétrole
2018

Thesis Title: Life Cycle Assessment of End of Life Strategies for Waste from Petroleum Production

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Program: Petroleum Technology

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ABSTRACT

5973018063 Petroleum Technology Program
Nuntawat Urairat: Life Cycle Assessment of End of Life Strategies for Waste from Petroleum Production
Thesis Advisors: Dr. Ampira Charoensaeng and Asst. Prof. Manit Nithitanakul 117 pp.
Keywords: Environmental impacts/ Petroleum refinery wastes/ Material flow analysis (MFA)/ Life cycle assessment (LCA)

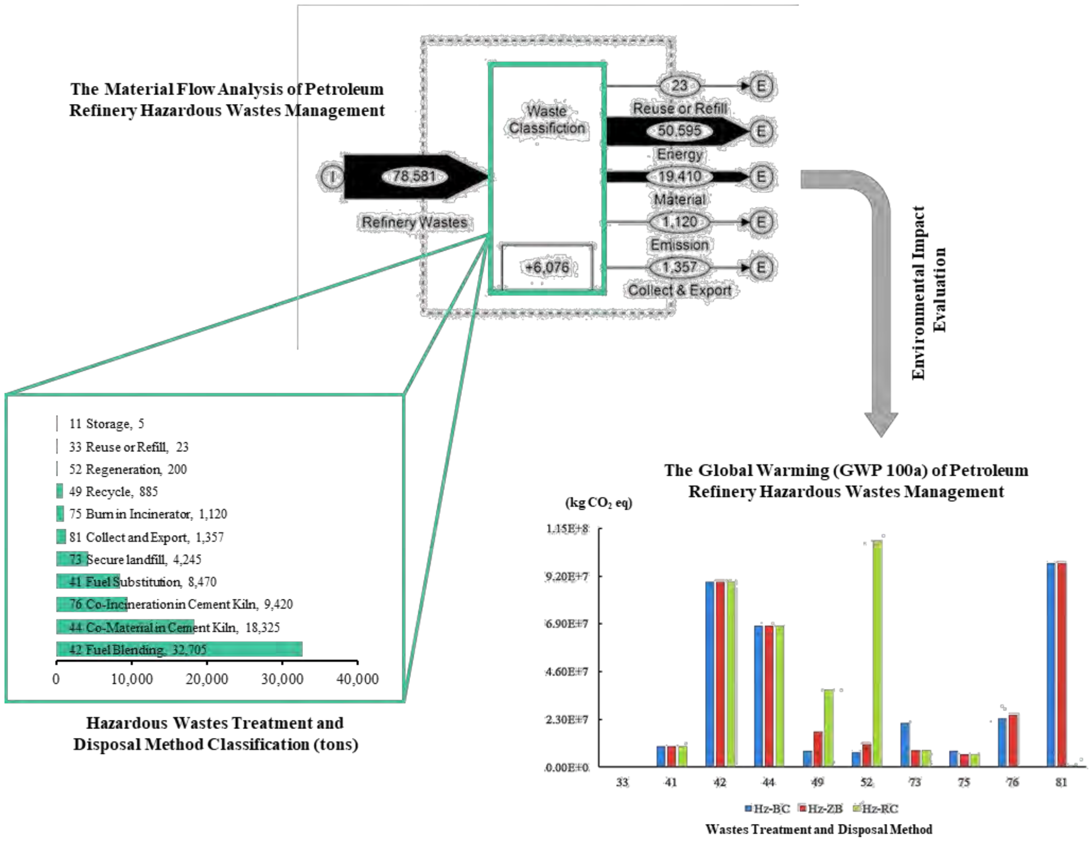
The waste treatment and disposal of oil refining industry sector are one of the significant aspects of environmental concerns. Because they are not only generated in substantial amounts, but also contained with various hazardous substances such as waste oils, spent catalysts, and mercury-contaminated materials. This study aimed to develop and evaluate the waste management strategies, from waste generator (WG) to waste processors (WP), using the material flow analysis (MFA, STAN v.2.6.601) and life cycle assessment (LCA, SimaPro v.8.3.0.0) as an assessment tool. The functional unit is the amount of waste generated from six refineries in the year 2015. The waste management schemes for hazardous (HZW) and non-hazardous (Non-HZW) were developed; the base case or existing operation (Option 1), zero waste to landfill and reduce burning in incinerators (Option 2) and enhancing recycling method (Option 3). The MFA results indicated that most of the HZW were disposed to produce energy, while the sorting method was the favorable option for Non-HZW. For the impact assessment, the base case and zero wastes to landfill and reduce burning in incinerators showed no significant difference for all of the impacts, but the enhancing recycling option indicated a decrease in the impacts for both HZW and Non-HZW. For global warming potential (GWP), the least impact value was the enhancing recycling, about 3.2958×10^8 kg CO_2 eq for HZW and 1.4095×10^7 kg CO_2 eq for Non-HZW. Therefore, the enhancing recycling is an appropriate method for waste utilization in order to reduce the environmental impacts. The MFA can be used as an assessment tool regarding the material balances and stock of the waste flow, while LCA can be used to evaluate the environmental impacts of the oil refinery waste management.

บทคัดย่อ

นันทวัชร อุไรรัตน์ : การประเมินวัฏจักรชีวิตของกระบวนการสุดท้ายของของเสียจากกระบวนการผลิตปิโตรเลียม (Life Cycle Assessment of End of Life Strategies for Wastes from Petroleum Production) อ.ที่ปรึกษา : ดร. อัมพิรา เจริญแสง และ ผศ. ดร. มานิตย์ นิธิธกุล 117 หน้า

การบำบัดและการกำจัดของเสียจากอุตสาหกรรมการกลั่นน้ำมัน เป็นหนึ่งในปัญหาสำคัญที่ส่งผลกระทบต่อสิ่งแวดล้อม ไม่เพียงแค่ของเสียมีปริมาณมากเท่านั้นแต่ยังประกอบไปด้วยวัสดุอันตรายที่แตกต่างกัน เช่น ของเสียที่มีน้ำมัน ตัวเร่งปฏิกิริยาที่ใช้แล้ว และ วัสดุที่ปนเปื้อนปรอท เป็นต้น ซึ่งการศึกษานี้มีวัตถุประสงค์เพื่อพัฒนาและประเมินแผนการการจัดการของเสียตั้งแต่ก่อกำเนิดจนถึงบำบัดและกำจัดของเสีย โดยใช้การวิเคราะห์การไหลของวัสดุ (Material Flow Analysis: MFA, STAN v.2.6.601) และการประเมินวัฏจักรชีวิต (Life Cycle Assessment: LCA, SimaPro v.8.3.0.0) เป็นเครื่องมือในการประเมินผลกระทบสิ่งแวดล้อม หน่วยการทำงานของการศึกษานี้คือปริมาณของของเสียจาก 6 โรงกลั่น ปี 2558 ซึ่งแผนการการจัดการสำหรับของเสียที่เป็นอันตรายและไม่เป็นอันตราย คือ การจัดการของเสียโดยวิธีปกติ (วิธีที่ 1) การลดการฝังกลบและการเผาในเตาเผาให้เป็นศูนย์ (วิธีที่ 2) และการเพิ่มการหมุนเวียนกลับมาใช้ใหม่ (วิธีที่ 3) ผลการวิเคราะห์การไหลของวัสดุพบว่า ของเสียที่เป็นอันตรายส่วนใหญ่ถูกบำบัดเพื่อผลิตเป็นพลังงาน ในขณะที่วิธีการคัดแยกประเภทของของเสียเป็นวิธีที่ของเสียที่ไม่เป็นอันตรายส่วนใหญ่ถูกส่งไปบำบัด สำหรับกผลกระทบต่อสิ่งแวดล้อมนั้น การจัดการของเสียโดยวิธีปกติและการลดการฝังกลบและลดการเผาในเตาเผาให้เป็นศูนย์มีค่าผลกระทบที่ไม่ต่างกันอย่างมีนัยสำคัญ แต่ในกรณีการเพิ่มการหมุนเวียนกลับมาใช้ใหม่จะมีค่าผลกระทบทางสิ่งแวดล้อมที่ลดลงอย่างมีนัยสำคัญสำหรับทั้งประเภทของเสียที่เป็นอันตรายและของเสียที่ไม่เป็นไม่อันตราย ซึ่งจากค่าศักยภาพในการทำให้เกิดภาวะโลกร้อน การเพิ่มการหมุนเวียนกลับมาใช้ใหม่จะมีค่าผลกระทบที่น้อยที่สุด คือ 3.30×10^{8} กิโลกรัมคาร์บอนไดออกไซด์เทียบเท่า สำหรับของเสียที่เป็นอันตราย และ 1.41×10^{7} กิโลกรัมคาร์บอนไดออกไซด์เทียบเท่า สำหรับของเสียที่ไม่เป็นอันตราย ดังนั้นแล้ว การเพิ่มการหมุนเวียนกลับมาใช้ใหม่คือวิธีที่เหมาะสมที่สุดที่ควรนำมาประยุกต์ใช้ในการจัดการของเสียเพื่อลดผลกระทบทางสิ่งแวดล้อม อีกทั้ง การวิเคราะห์การไหลของวัสดุสามารถใช้เป็นเครื่องมือในการประเมินสมดุลการไหลของของเสียและยอดคงค้างของของเสียในระบบและการประเมินวัฏจักรชีวิตสามารถใช้ประเมินผลกระทบที่มีต่อสิ่งแวดล้อมที่เกิดจากการจัดการของเสียของโรงกลั่นน้ำมัน

GRAPHICAL ABSTRACT



ACKNOWLEDGEMENTS

Foremost, I would like to express my sincere appreciation to my thesis advisor Dr. Ampira Charoensaeng and Asst. Prof. Manit Nithitanakul for their continuous support and invaluable help in my thesis work. Their guidance and suggestion helped me all the time for conducting and writing this thesis.

Besides, I am grateful for The Petroleum and Petrochemical College and Center of Excellence on Hazardous Substance Management for support, suggestion, and information that are used in this thesis work.

Finally, I gratefully acknowledge my parents and my friends for all their support and suggestion throughout the period of this thesis work.

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CHAPTER I
INTRODUCTION

1.1 Introduction

An oil refining, a part of petroleum industry sector, is a large-scale industry and brings significant economic benefits to the country. The refinery is dependent on high levels of investment and technology and produces various of products such as gasoline, kerosene, diesel, fuel oils, and asphalt are essential products and goods for human livings and as well as products for intermediate and downstream for petrochemical industries. In recent year, the demands of refinery products, their production capacity rapidly increase due to an adequate with consumption leading to the more investing and expansion of plants and facilities as well as improving the production process. As a consequence, increasing in the production leads to the more pollution and amount of waste that needs to be managed properly. The wastes generated from the oil refineries are mainly classified into wastewater, solid wastes, and hazardous wastes (Jafarinejad, 2016). Each type of waste needs specific treatment and disposal method because if the treatment or disposal method is not specific for the characteristic of wastes, additional time and cost to operate are required. Although the treatment or disposal method is appropriate, it needs to be concerned somewhat about their environmental impacts after disposal. In addition, some countries have not only issued the legislation that restricts the wastes of which their disposal options must be legal but also must be environmentally friendly sound solutions (Dando and Martin, 2013)

Nowadays, waste management and disposal are one of the main aspects in the refinery production that is seriously taken into an account because of not only their toxic and harmful properties but also the cost for the disposal. Therefore, it is necessary to understand the characteristic of waste in order to find an appropriate solution to prevent their emissions. The waste classification is also important to manage the wastes with the suitable method. Recently, material flow analysis (MFA) can be used as a tool to exhibit and classify the waste flow with specific time and space (Cencic and Rechberger, 2008). MFA clearly shows that the waste flow can help to determine the waste management system that is more beneficial for policymaking. The results of MFA can be assessed concurrently with the life cycle assessment (LCA) to estimate the environmental impacts of waste management. End of life cycle analysis (EoL), a part of LCA, is the method used to evaluate the impacts of wastes in terms of the environment or human health impacts. The EoL can be used to assess the impacts of waste disposal that occurs from the waste generation, waste processing throughout final disposal. Similar with LCA method, EoL can evaluate the impacts of waste disposal in several issues such as climate change or global warming potential, fossil depletion, human toxicity, particulate matter formation, terrestrial acidification (Buonocore *et al*., 2016). The data obtained from the EoL can be used to adjust or improve the production process in order to meet the environmental criteria and reduce the manufacturing costs. It can be seen that the MFA and LCA not only use to evaluate the environmental impacts but also can involve the benefit in terms of economic perspective which results in sustainable waste management.

This study aims to evaluate the waste flow and environmental impacts of waste management options for the petroleum refinery industry in Thailand using MFA and LCA as an assessment tool. The amount of wastes generated from petroleum refining sector is gathered and identified according to their type, hazardous level, and treatment option before disposing of. The waste classification is listed following their waste code which is regulated by the Department of Industrial Wastes, Ministry of Industry and Department of Mineral Fuels, Ministry of Energy, Thailand (2005). The environmentally friendly waste management scenarios for petroleum refining sector waste are developed based mainly on their environmental impacts and disposal cost. After gathering the inventory data including the waste treatment classification, and disposal method, this study compares the appropriate routes of waste management that have high potential in terms of environmentally friendly sound and disposal cost. Finally, the results from this study reveal an appropriate treatment scheme regarding waste management option for the refining industries with aims to manage and utilize the resource and environment available for sustainable solution.

1.2 Objectives

To the main objective is to conduct the material flow analysis (MFA) and evaluate the environmental impacts of waste treatment and disposal strategies from the petroleum refining industry, the sub-objectives consist of

- To classify the petroleum refinery wastes and conduct the waste flow in each route of the existing petroleum refinery waste management through MFA concept.
- To develop the waste treatment inventory and evaluate their environmental performance of the petroleum refinery waste end-of-life.
- To compare the existing waste treatment options with the alternative treatment methods in order to develop sustainable scenarios for waste treatment of petroleum refinery sector.

C HAPTER II
LITERATURE REVIEW

Because the growth in the demand of products from oil refining raises the production volume, the refining sector will generate more amount of wastes owing to their consumption rate continuously increase. The wastes from the oil refineries have various characteristics in specific mainly contaminated with oil. They need to classify and separate by category based on their hazardous properties in order to treat and dispose of with the suitable method. Material flow analysis (MFA) is used as a tool to clearly illustrate the waste route of each treatment and disposal method. The environmental and human health impacts from oil refinery wastes can be evaluated using life cycle assessment (LCA) procedure. The results from LCA can be applied to improve the production process or waste treating and disposal method in order to reduce the environmental and human health impacts.

2.1 The Petroleum Refining Industry Wastes

The wastes from oil refinery have different characteristics and properties according to their process or the deterioration of chemicals and materials. Most of the waste characteristics mainly contaminated with oil or hazardous chemicals that cause the various types and properties of waste. It is necessary to classify and separate the oil refinery wastes in order to manage with the proper method. The oil refinery wastes can be typically classified into wastewater, solid wastes, and hazardous wastes (Jafarinejad, 2016).

2.1.1 Wastewater

Water supplied in the production is used to operate the processes and maintenance the utilities in the plant. During the production, the water does not contact with the final product and about 80-90% of water supplied to the processes and maintenance will come out as wastewater. The wastewater discharges from many unit processes of the plant and other different usage purposes. Water supplied, is used for the routine operation of the processes and maintenance in the petroleum production and refinery, will contact with crude oils, chemical substances or other hydrocarbons. The wastewater that occurs from the plant will be treated and eliminated before discharging to the environment. The wastewater and their waste sources are listed in Table 2.1.

Table 2.1 The wastewater from petroleum refineries (Jafarinejad, 2016)

Water Pollutants	Waste Sources
Oil	Distillation units, hydrotreating, visbreaking, catalytic cracking, hydrocracking, lube oil, spent caustic, ballast water, utilities (rain)
H_2S (RSH)	Distillation units, hydrotreating, visbreaking, catalytic cracking, hydrocracking, lube oil, spent caustic
NH_3 (NH_4+)	Distillation units, hydrotreating, visbreaking, catalytic cracking, hydrocracking, lube oil, sanitary blocks
Phenols	Distillation units, visbreaking, catalytic cracking, spent caustic, ballast water
Organic chemicals (BOD, COD, TOC)	Distillation units, hydrotreating, visbreaking, catalytic cracking, hydrocracking, lube oil, spent caustic, ballast water, utilities (rain), sanitary blocks
CN^- (CNS^-)	Visbreaking, catalytic cracking, spent caustic, ballast water
TSS	Distillation units, hydrotreating, visbreaking, catalytic cracking, spent caustic, ballast water, sanitary blocks
Amines compounds	CO_2 removal in LNG plants

Where BOD = Biochemical oxygen demand
COD = Chemical oxygen demand
TOC = Total organic carbon
TSS = Total suspended solids

2.1.2 Solid Wastes

Solid wastes in the oil refinery can be divided into three categories by considering the characteristic of waste materials.

- Sludge: both oily and non-oily
- Other refinery wastes: miscellaneous liquid, semi-liquid, solid wastes
- Non-refining waste: demolition, domestic, and construction

The solid wastes and sludge from the production and refineries around 80% of the total are considered as a hazardous waste because of its containing heavy metals and toxic organics. The characteristic of solid waste classification and their sources are listed in Table 2.2.

The petrochemical plant solid waste streams can be classified based on the type of waste which can be separated into two main groups.

- Continuously generated wastes: from process units and wastewater treatment facilities.

- Intermittently generated wastes: from cleaning the process areas and off-site facilities (such as spent catalyst and product treatment wastes.

Table 2.2 The characteristic of solid wastes from petroleum refineries (Jafarinejad, 2016)

Waste Types	Categories	Sources
Oiled materials	Oily sludges	Tank bottoms, biological treatment sludges, residues from oil/water separator, such as the American Petroleum Institute (API) separator, parallel plate interceptor, and corrugated plate interceptor (CPI), sludge from flocculation flotation unit (FFU), dissolved air flotation (DAF), or induced air flotation (IAF) units, desalter sludges, contaminated oiled materials soil

Table 2.2 The characteristic of solid wastes from petroleum refineries (Jafarinejad, 2016) (continued)

Waste Types	Categories	Sources
Oiled materials	Solid materials	Contaminated soils, oil spill debris, filter clay acid, packing, activated carbon, calcium chloride sludge from neutralized HCl gas in isomerization process, tar rags, filter materials, coke dust (carbon particles and hydrocarbons), lagging
Non-oily materials	Spent catalyst (excluding precious metals)	Catalytic cracking unit, catalytic hydrocracking, catalytic reforming, hydro processing/hydrotreating, polymerization, residue conversion
	Other materials	Boiler feed water sludge, desiccants and absorbents, neutral sludge from alkylation plants, resins, flue-gas desulphurization (FGD) wastes
Drums and containers		Glass, metal, plastic, paint
Radioactive waste (if used)		Catalysts, laboratory waste
Scales		Leaded/unleaded scales, rust, e.g., from crude-oil desalting
Construction/ demolition debris		Scrap metal, concrete, asphalt, soil, asbestos, mineral fibers, plastic/wood
Spent chemicals		Laboratory, caustic, acid, additives, sodium carbonate, solvents, MEA/DEA (mono/diethanol amine), TML/TEL (tetra methyl/ethyl lead)
Pyrophoric wastes		Scale from tanks/process units

Table 2.2 The characteristic of solid wastes from petroleum refineries (Jafarinejad, 2016) (continued)

Waste Types	Categories	Sources
Mixed wastes		Domestic refuse, vegetation
Waste oils		Lube oils, cut oils, transformer oils, recovered oils, engine oils
Metals		Crude-oil/desalter sludge, spent catalyst fines in catalytic hydrocracking, hydrotreating/hydro processing, catalytic reforming, API separator sludge, biological sludge in wastewater treatment

Al- Qahtani (2011) conducted the pot experiment to study the effect of oil refinery sludge (ORS) and soil chemical composition by considering Uthmaniyah Oil Refinery (OUR) and Ab-Qaique Oil Refinery (AOR) which were different sludge treatment. The experimental soil used was a sandy soil which contains 95% sand, 3% silt, and 2% clay. The experimental soil was dried by air, passed through the 2 mm sieve, and filled in the plastic pots. Before planting, the water irrigation system was applied to keep moisture in the soil and five seeds were sown in each pot. It was harvested after 20 weeks and can be kept to two plants at 4-6 leaves stage with 4-5 cm of plant height. For the plant growth, it was measured by inspecting the plant height and dry matter which was determined by measuring its initial weight and dry weight at 60 $^{\circ}$C, then calculated dried matter yield of each plant. For the results of this study, they found that the ORS had the high concentration of plant nutrients and organic matters while the important nutrient for plants was low concentration such as P, K, Cu, Fe, Mn, and Zn.

The application of ORS did not show to improve the plant height due to low nutrient content, and the mean dried matter depended on the ORS was more than the control application during cultivation. The effect of plant mineral composition from the different ORS indicated that the N, K, Na, and Ca contents increased, but P and

Mg contents decreased. This because P ion is fixed by Ca ion from ORS due to the fact that CaO is used as a catalyst in the cleaning process. Furthermore, the soil chemical properties including salinity and sodicity slightly increased from the addition of ORS, but in case of pH, they remained constant indicating that they did not affect by ORS. The concentration of HCO_3 decreased because of the chemical reaction of bicarbonate in ORS with high CO_2 contents released during the plant growth. Therefore, the ORS can be used as a source of organic matters to improve the productivity of sandy soil and used in conjunction with inorganic fertilizer.

2.1.3 Hazardous Wastes

The hazardous wastes can cause tremendous effects on the environment, animals, and humans such as contaminated groundwater, soil degradation, and public health problems. The characteristics used to consider as the hazardous waste are ignitability, corrosivity, reactivity, and toxicity. If the wastes have at least one of the characteristics, they will be considered as the hazardous waste.

- Ignitability

Ignitable wastes can cause fires or spontaneously combustion and it also has a flash point less than 60 ºC (140 ºF). The examples of this wastes are used solvents and waste oils.

- Corrosivity

Corrosive wastes are bases or acids which pH is more than or equal to 12.5 or pH less than or equal to 2 and corrode the metal equipment or containers such as storage tanks, barrels, and drums.

- Reactivity

Reactive wastes can cause explosions when the violent reaction, generate toxic gas or vapor or explosive mixtures when compressed, contact or mix with water.

- Toxicity

Toxic wastes are harmful or fatal when absorb or ingest for animals and humans. For the environment, when disposing the toxic waste into the land, this can lead to high risk of the waste contaminated to groundwater or soil. Some maximum contaminated concentrations for the toxicity characteristic are listed in Table 2.3.

Table 2.3 The maximum concentration of contaminants (Jafarinejad, 2016)

Contaminants	Regulatory Level (mg/L)	Contaminants	Regulatory Level (mg/L)
Arsenic	0.5	Barium	100.0
Benzene	0.5	Cadmium	1.0
Chlorobenzene	100.0	Chloroform	6.0
Chromium	5.0	1,4-Dichlorobenzene	7.5
1,2-Dichloroethane	0.5	1,1-Dichloroethylene	0.7
2,4-Dinitrotoluene	0.13	Endrin	0.02
Hexachlorobenzene	0.13	Hexachlorobutadiene	0.5
Hexachloroethane	3.0	Lead	5.0
Mercury	0.2	Nitrobenzene	2.0
Pyridine	5.0	Selenium	1.0
Silver	5.0	Tetrachloroethylene	0.7
Trichloroethylene	0.5	Vinyl chloride	0.2

2.2 Waste Classification

Waste classification can be used to manage and handle the waste by proper methods as well as being as a criterion for selecting treatment and disposal methods. Department of Industrial Works (DIW), Ministry of Industry, Thailand (2005) regulate the waste code in 6 digits which is explained below,

XX YY ZZ

XX = Type of plant or manufacture or type of sewage or unused material

YY = Specific process of each plant or manufacture that will generate sewages or unused materials

ZZ = Specific characteristic of sewage or unused materials

The waste classification codes are subscripted as HA if they are considered as a hazardous waste and absolute entry and HM if they are considered as a hazardous waste and mirror entry. The petroleum refinery wastes can be divided into group 05 as shown in Table 2.4 followed by DIW.

Table 2.4 The example of waste code group number 05 petroleum and petrochemical waste code (DIW, 2005)

05	**Wastes from petroleum refining, natural gas purification and pyrolytic treatment of coal**	
05 01	**Wastes from petroleum refining**	
05 01 02	HA	Desalter sludges
05 01 03	HA	Tank bottom sludges
05 01 04	HA	Acid alkyl sludges
05 01 05	HA	Oil spills
05 01 06	HA	Oily sludges from maintenance operations of the plant or equipment
05 01 07	HA	Acid tars
05 01 08	HA	Other tars
05 01 09	HM	Sludges from on-site effluent treatment containing dangerous substances
05 01 10		Sludges from on-site effluent treatment other than those mentioned in 05 01 09
05 01 11	HA	Wastes from cleaning of fuels with bases
05 01 12	HM	Oil containing acids
05 01 13		Boiler feedwater sludges
05 01 14		Wastes from cooling columns
05 01 15	HA	Spent filter clays
05 01 16		Sulfur-containing wastes from petroleum desulfurization
05 01 17		Bitumen
05 01 99		Wastes not otherwise specified

Table 2.4 The example of waste code group number 05 petroleum and petrochemical industry waste code (DIW, 2005) (continued)

05	**Wastes from petroleum refining, natural gas purification and pyrolytic treatment of coal**	
05 06	**Wastes from the pyrolytic treatment of coal**	
05 06 01	HA	Acid tars
05 06 03	HA	Other tars
05 06 04		Wastes from cooling columns
05 06 99		Wastes not otherwise specified
05 07	**Wastes from natural gas purification and transportation**	
05 07 01	HM	Wastes containing mercury
05 07 02		Wastes containing sulfur
05 07 99		Wastes not otherwise specified

2.3 The Waste Treatment and Disposal Methods

The proper treatment and disposal methods can help to manage the various types of waste from the petroleum industries effectively. The waste treatment and disposal codes are classified the main categories as shown in Table 2.5, according to (DIW, 2005).

Table 2.5 Treatment and disposal codes (DIW, 2005)

Code	Method	Code	Method
011	Sorting for sale	064	Physical chemistry treatment
021	Keeping	065	Wastewater treatment by physical chemistry method
031	Sending back to disposal	066	Total wastewater treatment
032	Substitute material	067	Chemical stabilization

Table 2.5 Treatment and disposal codes (DIW, 2005) (continued)

Code	Method	Code	Method
033	Sending back to reuse or reload	068	Chemical stabilization/trap by cement or pozzolanic material
039	Reuse	069	Other treatments to reduce hazardous value
041	Renewable fuel	071	Landfill (only non-hazardous waste)
042	Mixed fuel	072	Landfill
043	Burning to energy	073	Landfill by stabilizing or solid form
044	Substitute material in cement kiln	074	Incineration in kiln
049	Reuse with other methods	075	Specify incineration only hazardous waste
051	Solvent recovery process	076	Incineration in cement kiln
052	Metal recovery process	077	Injection to underground
053	Acid/alkaline recovery process	079	Other disposal methods than those mentioned
054	Catalyst recovery process	081	Send to other countries
059	Other wastes recovery	082	Reclamation only non-hazardous
061	Biological treatment	083	Fermented of Fertilizer or improving soil only non-hazardous
062	Chemical treatment	084	Making the animal feed and only non-hazardous waste
063	Physical treatment		

Hasani and Nabhani (2016) studied the waste management system in petroleum refinery by considering their impacts to the environments, air, land, and water. The wastewater, which is come from cooling water, sanitary sewage water, process water, and storm water, was treated by facilities onsite before discharge to the environments. In some cases, the wastewater management by the underground injection might seep and contaminate to surface water which will affect the human health and environment. In addition, the other wastes from refineries such as hazardous and non-hazardous wastes were treated and disposed of, such as metals from the catalyst and crude oils. The spent catalysts were recovered by regeneration process or send to recycling plants. Residual refinery wastes were treated by incineration, landfilling, onsite chemical fixation, neutralization, and other methods.

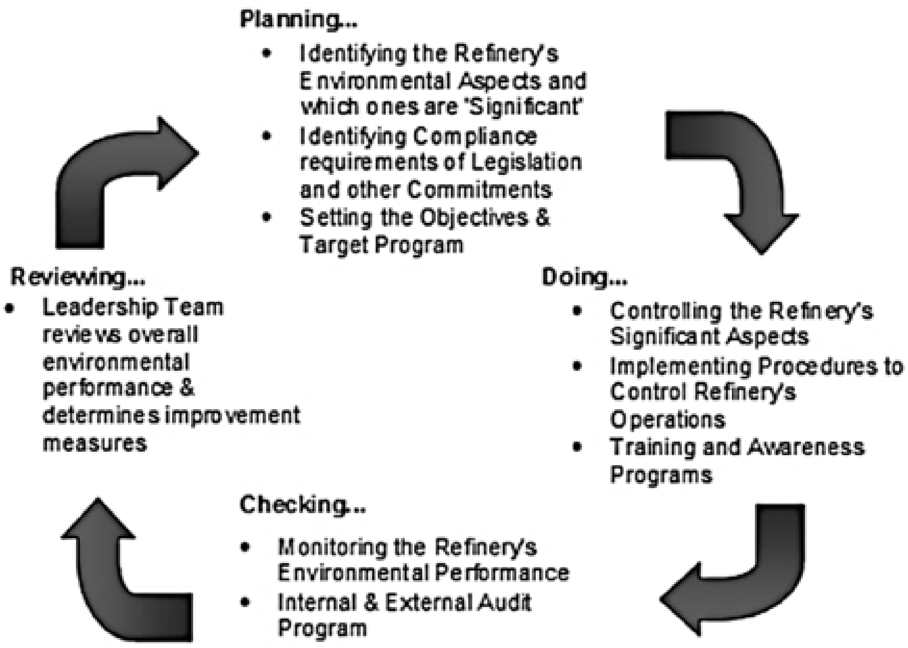

Figure 2.1 The refinery improvement process.

From this study, they suggested that the environmental management system (EMS) can help the continuous improvement, inspection, reviewing, and planning the process as shown in Figure 2.1. Therefore, EMS was used to manage the framework of environmental management topics in order to reduce the human health problem and the environmental impacts from the refineries operation.

2.3.1 The Waste Hierarchy Management

The waste management hierarchy can be used to specify the most proper waste management method. Figure 2.2 shows the waste management hierarchy which is used as a criterion to consider the refinery wastes disposal from the most favorable to the least favorable options as explained below;

Prevention - Using less material or substance in production process but it does not affect to the whole process. Especially for hazardous wastes, it must be used less as much as possible.

Reuse - Wastes are cleaned, checked, repaired, refurbished, or other methods in order to obtain the materials or items that are still use. The material or substance obtained can be applied to other processes or original process.

Recycle - Turning the wastes to the new material or substances by pass through the appropriate process and it also includes composting.

Recovery - Energy and materials are recovered from wastes by the suitable process with the characteristic of waste such as anaerobic digestion, incineration, pyrolysis, or metal reclamation.

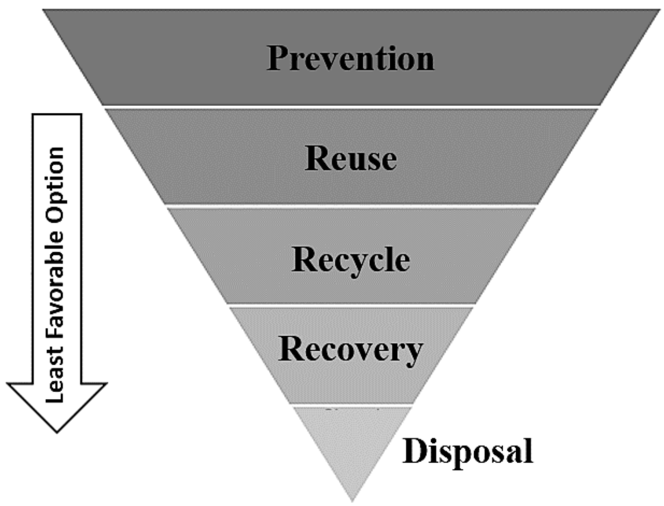

Figure 2.2 The waste hierarchy management.

Disposal - Incineration or landfill is a method which use to disposal the waste without the energy recover (Papargyropoulou *et al*., 2014).

Usapein and Chavalparit (2013) applied the 3R concept, reduce, reuse, and recycle, for managing industrial wastes from high-density polyethylene (HDPE) plant in Thailand. The waste generation was considered from four sources which were production, packaging, wastewater treatment, and maintenance. The life cycle assessment was used to evaluate the environmental impacts by considering the effects of greenhouse gas (GHG) emissions from each management method. The results of this study showed that the two main ways to manage the wastes from HDPE plant were selling to a recycling factory and sending to reuse and recycle facilities. Some of the recyclable wastes, 10.47% (57.29 tons), were eliminated by disposing of in landfill as illustrated in Figure 2.3.

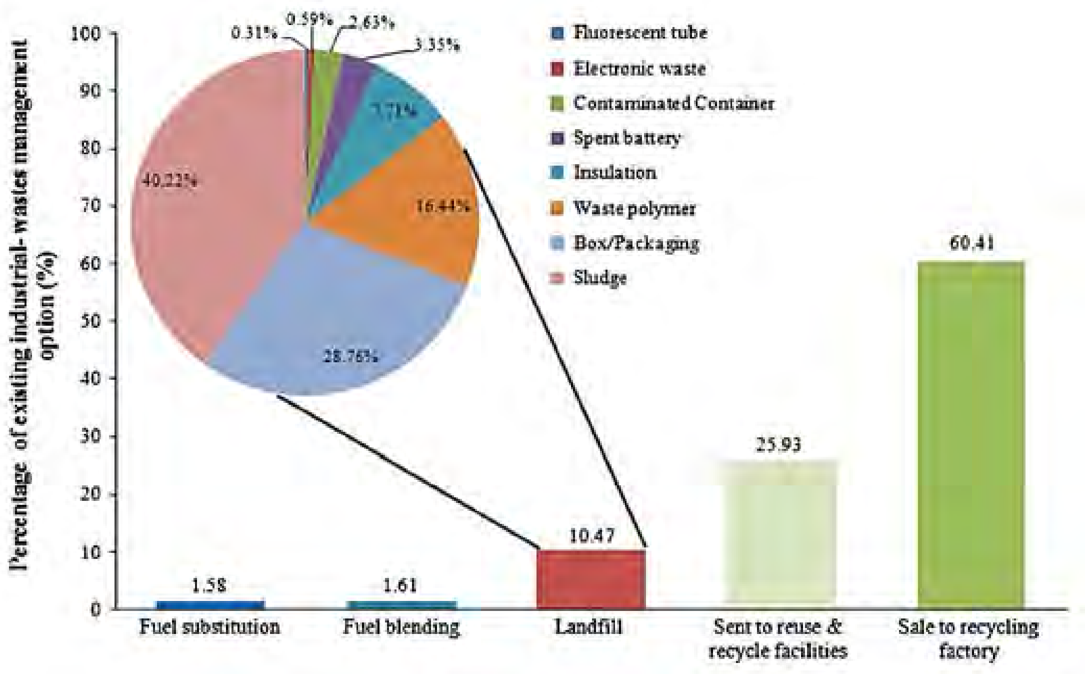

Figure 2.3 Waste management in HDPE case study plant.

The wastes that sent to the landfill for final disposal mainly composed of contaminated containers, spent batteries, insulation materials, off-specification polymers and plastics, box and packaging wastes, and sludge from wastewater treatment. The 3Rs concept was applied over one year to reduce the amount of waste to the landfills. Although the waste generated was decreased approximately by 33.88%, some wastes which are insulation materials, sludge, and contaminated containers were sent to dispose in the landfills.

In case of GHGs emission, they defined the functional unit as the required energy of producing 1 ton of clinker. The GHG emissions from /the packaging had the lowest CO_2 emissions when compared with bituminous coal and waste polymer because the main composition was Kraft paper that easily converted into energy using the lowest amount of energy consumption. They concluded that the priority step should be applied to manage the waste that is the waste reduction at its source and following by reuse and recycle, even though some of the recycling methods can emit some additional pollutants to the environment.

2.3.2 The Waste Disposal Routes

The wastes from the petroleum and petrochemical industry must be disposed of or eliminated by suitable methods in order to reduce the environmental impacts. If the treatment solutions are not suitable for the waste, it will spend more cost and time to handling and disposal to eliminate.

Dando and Martin (2013) studied the waste disposal method for the petroleum industry in order to proper management the waste.

- Landfill

The landfill is controlled to operate the processes under the legislation of each country because the risk to groundwater. This method does not immediately eliminate the waste but only stored in the land, and it does not need to spend the cost of treating or process the wastes.

- Underground Storage

For hazardous waste (HZW) treatments, the HZW can be stored securely in the underground such as abandoned mines, caverns or wells. The waste that will be storage does not contaminate or react with the storage areas. Therefore, before operating the process and choose the storage type, it needs to identify the waste characteristics and properties because the site selection will depend on the waste properties and the nature of the storage area.

- Incineration

The combustion of waste is the method that will convert the wastes or hazardous wastes into smaller, less toxic, and less dangerous material. This method has to use the appropriate conditions to control the process of combustion in order to reduce the air pollution from the combustion process. The incineration method widely uses to eliminate the wastes.

- Pyrolysis

The thermal conversion of wastes or sludge will produce gases as the second waste which a high calorific value. It can be used in a furnace or an incinerator refinery has a simple incineration.

- Biodegradation Method

The microbiological method can convert the refinery wastes into harmless compounds. The necessary conditions to reduce the degradation time are nutrients, suitable micro- organisms, amount of oxygen, temperature, and the concentration of contaminants. This technique can be used to treat the hazardous chemical wastes (re-biological treatment)

- Landfarming

Wastes are biodegraded on a soil surface by utilizing the micro-organisms in the soil under the appropriate conditions. This technique is used in the petroleum industry for many years because it is a simple and cost-effective method. In some areas, land-farming required a permission from the authorities.

- Composting

Composting method can be applied for oil contaminated soils. The contaminated soil will be replaced by the aeration and leave the bacteria to degrade the contaminant. The disadvantage is that this method uses more space. The treating time will be different between one to two years because of the property of the soil and organic wastes. Some processes can reduce the treating time by controlling the appropriate conditions that are suitable with the oil contaminated soil.

- Biopilling

Oily sludge and soil are mixed and treated with a predetermined amount of nutrients and control the appropriate conditions such as air, moisture levels, and temperature. After the biodegradation process, the product is used to cover on completed waste tips or garden area. This method is the adaptation of land-farming and composting.

- Disposal of Spent Catalyst

The catalysts from the refinery normally are metal supported by the inert carrier but some metals are valuable will be recycled and regenerated by the other manufacturers. Some industries can use spent catalyst in the production process by mixing or combing with some materials to produce a new product. The catalysts having are high calorific value can be used as a fuel and if the catalyst cannot be reused or recycled, it must be disposed of by the appropriate method such as the utilizing of spent catalyst uses as a material in asphalt mixture or dumping in the landfill (Alshamsi et al., 2012)

Cherubini and coworkers (2008) studied the waste management scenarios using LCA. They investigated four options for waste management, which are landfill with biogas utilization, landfill without biogas utilization, sorting plant with split inorganic waste, and direct incineration as following;

Scenario 0: The landfill

Wastes disposed by landfill were decomposed in anaerobic conditions and generated biogas. The biogas 50% was collected and burnt to converting CH_4 in order to reduce the impacts of CO_2. The remaining of biogas 50% was released to the atmosphere.

Scenario 1: Landfill with biogas recovery

The biogas was collected (50%), treated, and burnt to generate electricity. The remaining of biogas was burnt in flares (25%) and release to atmosphere (25%).

Scenario 2: Municipal Solid Waste (MSW) sorting plant

This scenario, the wastes had to separate into the organic part, inorganic part, and heavy waste and ashes. For the organic part, they were transported to another plant in order to produce biogas by anaerobic digestion. The inorganic part was sent to a Refuse Derived Fuel (RDF) production plant that is burnt the waste in an incineration to produce electricity. The last part was the heavy waste and ashes from RDF were delivered to landfills but ferrous metals were recovered.

Scenario 3: Incineration

Wastes were sent to the incineration plant to generate the electricity by combustion process and the ashes from combustion process were transported to the landfill.

The results found that the global impacts to the environment can be reported by gross and net impacts. The gross impacts were the effects of emission during life cycle without investigating the environmental benefits from energy outputs. However, the net impacts were the total emission of each scenario minus avoided emissions from energy output for each scenario as shown in Figure 2.4.

Scenario	GWP, kt CO_2	AP, t SO_2	EP, t NO_3	Dioxins, g TCDD
Scenario 0				
Gross	1914	546	126	0.24
Net				
Scenario 1				
Gross	966	338	126	0.35
Net	868	186	126	0.29
Scenario 2				
Gross	704	852	n.a.[a]	0.25
Net	−340	−441	n.a.[a]	−0.28
Scenario 3				
Gross	948	1902	n.a.[a]	1.38
Net	224	780	n.a.[a]	0.92

[a] For these scenarios landfilled wastes are without a significant organic content.

Figure 2.4 The impact categories of each scenario (GWP = Global Warming Potential, AP = Acidification Potential, and EP = Eutrophication Potential).

From Figure 2.4, the scenario 2 was the best method that might be used to manage the wastes because the energy outputs of this scenario can be replaced the original sources, it also provided environmental benefits, and reduced the ecological footprint. However, the main point that has to consider was environmental impacts even the incineration might be better than landfill method.

2.4 Material Flow Analysis (MFA)

Wastes generated from a production process in the refinery have high volume. Wastes come into the process and discharged from the plant are more complex because each process has a different characteristic and disposal methods. It necessary to know the waste mass flow balance of each waste category and disposal method in order to manage and illustrate the trend of waste from each production process. The waste flow of the wastes can be analyzed by material flow analysis (MFA), a system of material flow diagram with specific time and space (Cencic and Rechberger, 2008), to organize and illustrate the mass flow route from in and out of the defined boundary. The MFA process includes

- Define and set the goal and scope of system boundary.
- Capture the system or process structure and mass flows.
- Calculate and investigate the data obtained from production.
- Summarize and analyze the system process and perform a system balance (Wang and Ma, 2018).

The MFA diagram normally consists of the flowing of goods, substances, and materials. Goods are defined as an economic issue that involves with positive and negative value, i.e., fuel oils and drinking water. The substances involve a chemical issue by uniform units, i.e., Sulfur (S), Carbon Dioxide (CO_2). Finally, the materials are between goods and substances, i.e., Silicon (Si) and glass. Generally, MFA can define a diagram using a block box as a process and arrow stand for the flow path of each mass flow that connect with other processes (Cencic and Rechberger, 2008).

Saidi and Kamal (2017) evaluated the solid waste management by material flow analysis (MFA) for waste utilization in Shah Alam, Malaysia. The data obtained came from the recording of municipal solid waste for the selected year 2006, 2012, 2013, 2014, and 2015. The MFA diagram was generated in order to evaluate the municipal solid waste management in each year using software STAN. In 2006, MFA diagram as shown in Figure 2.5 illustrated the solid waste generation was about

191,955 tons/year. The utilization system only 5.5% for recycling activity, 1.0% for composting activity, and the rest was sent to the landfill. Subsequently, 5.0% for leachate treatment, 2.0% for biogas generated, and the remaining was dump in the landfill. In year 2006, there was no transfer station which can help to manage solid waste and reduce the solid waste dumped in the landfill.

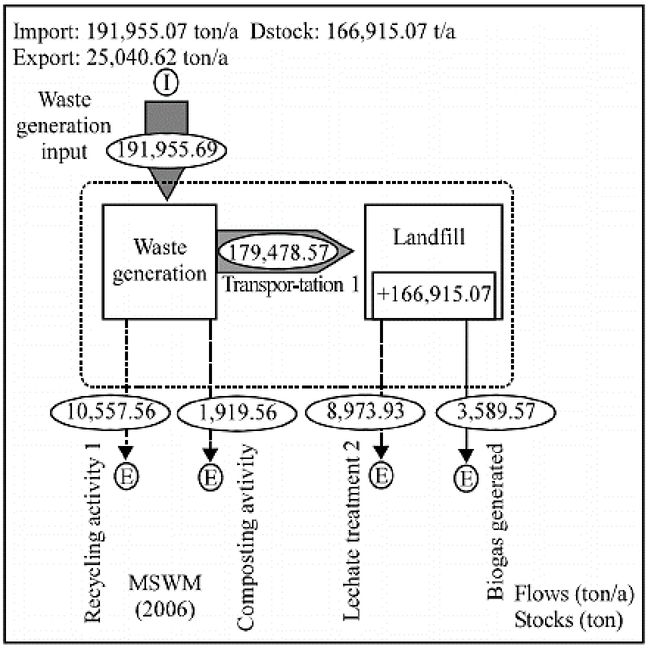

Figure 2.5 MFA municipal solid waste management (MSWM) in year 2006.

The 3R concept, which is a reduce, reuse, and recycle, was applied to manage the municipal solid waste before it was sent to dump in the landfill due to the data obtained in this study only came from the recycling activity and it was not the sustainable management. Figure 2.6 shows the municipal solid waste management with 3R concept activity with 10%, it means that the reducing activity would be increased and the solid waste at the landfill would be decreased.

The results of municipal solid waste management for selected year of 2006 and 2012-2015 showed that the solid waste dumped to the landfill was about 166,915 197,318, 194,938, 190,867, and 187,306 tons/year, respectively. After 3R concept was applied, the reducing activity was increased and it also affected to management cost by decreasing due to the lesser the solid waste in the landfill. In addition, the transfer station was constructed to increase the reduced activity. In addition, MFA used as a tool in order to generate the overview of process for evaluating the waste management system. Furthermore, the results from MFA can implement the planning of waste management with a proper system and toward the cost of waste management.

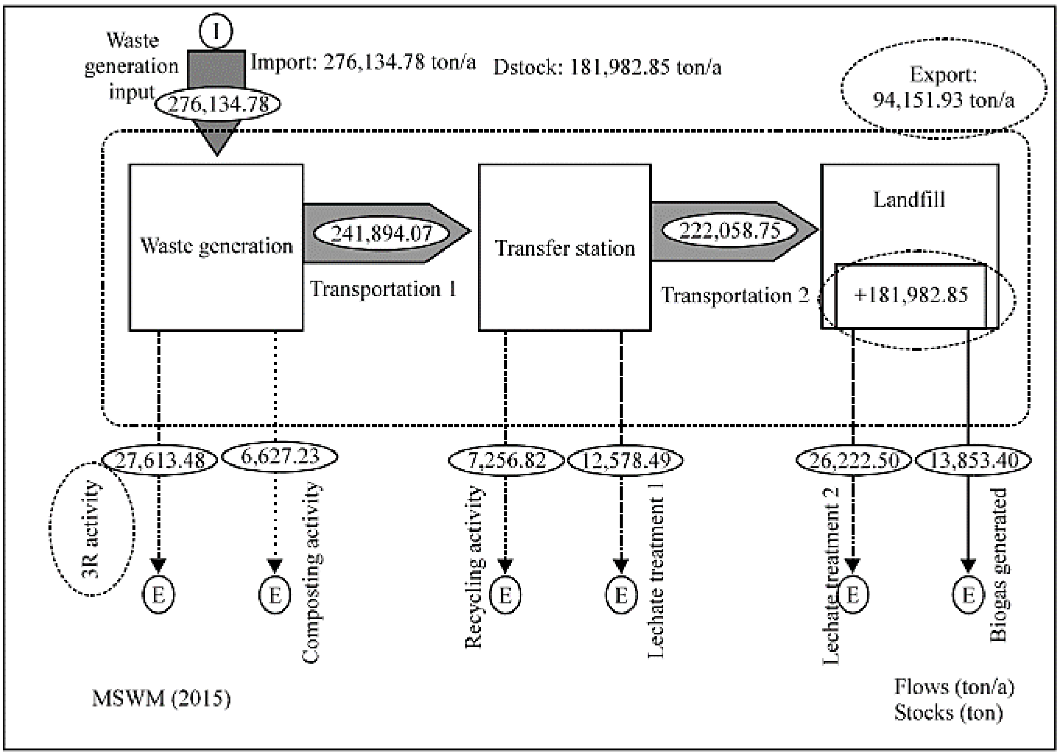

Figure 2.6 MFA of municipal solid waste management applied with 3R concept (reduce, reuse, and recycle) in year 2015.

2.5 The Life Cycle Assessment (LCA)

An environmental tool used to manage the wastes and evaluate the environmental impacts from a production or activity is the life cycle assessment (LCA). The information obtained from LCA can be used to improve the production process and choose the suitable method for treating and disposing the wastes. In addition, the international standard for environmental management and life cycle assessment is done under ISO 14040 principles and framework, ISO 14041goal and scope definition and inventory analysis (LCI), ISO 14042 life cycle impact assessment (LCIA), and ISO 14043 life cycle interpretation (Finkbeiner et al., 2006).

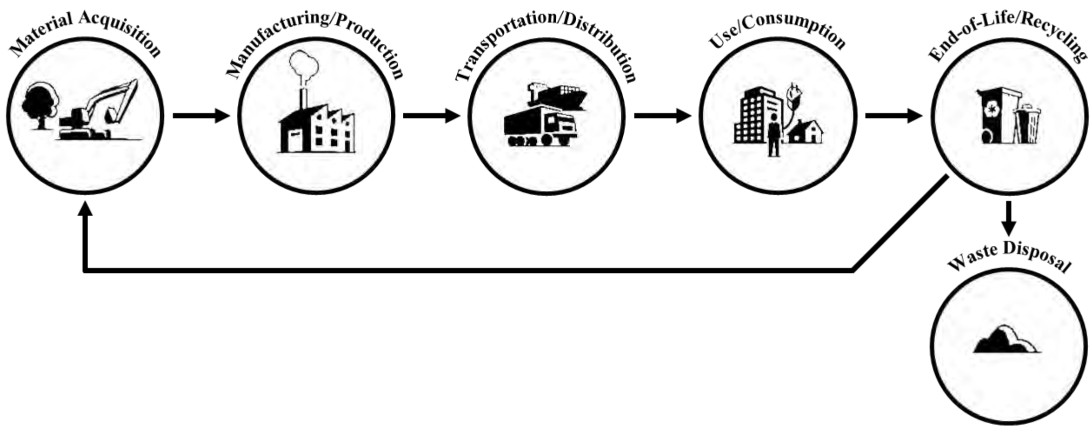

Figure 2.7 The life cycle of products from resources acquisition through the end-of-life of product.

The Life Cycle Assessment (LCA) is the process of analyzing and evaluating the impact of products on the environments. Throughout the life cycle of the product since the acquisition of raw materials, production process, transportation and distribution, and waste disposal. It is considered from birth to death (Cradle to Grave or Cradle to Gate) of the product by investigating the amount of energy, the raw material used, the wastes that are discharged to the environment and the community health. In order to find the ways to improve the production process or products and minimize the environmental impact using primary and secondary data gathered.

2.5.1 <u>The Life Cycle Assessment Procedures</u>

The data collection, evaluation, and analysis of the environmental impacts using the life cycle assessment can be made more systematic by following the life cycle assessment procedures that compose of four steps as shown in Figure 2.8. The life cycle assessment procedures help to improve the results more correct and effective. The results can be used to apply to the derided objectives such as product improvement, public policy making, and marketing development.

- Goal and Scope Definition

To define the system boundary and functional unit for study. This procedure is very important because if the system boundary and functional unit are defined not good enough, the results of the assessment are incorrect and ineffective.

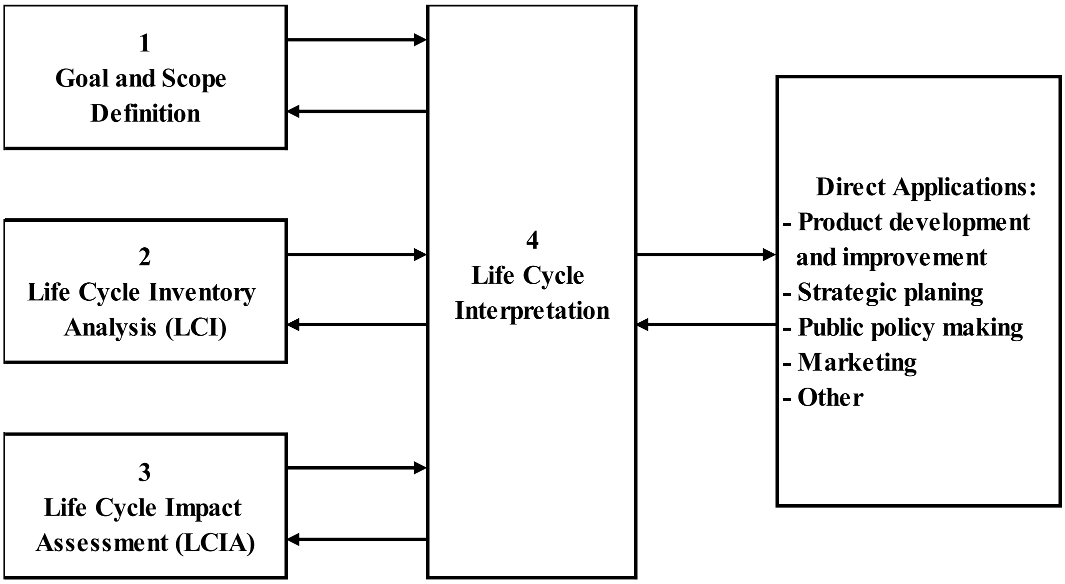

Figure 2.8 The life cycle assessment procedures.

- Life Cycle Inventory Analysis (LCI)

To collect and calculate the information from the processes defined. This procedure calculates the mass balance of the processes defined and considers the energy and pollution involved.

- Life Cycle Impact Assessment (LCIA)

To evaluate the environmental impacts using the data from these mass in and mass out and pollution of the process. The impact assessment can be divided into categories that are classification, characterization, and weighting.

- Life Cycle Interpretation

To analyze and summarize the data obtained from the life cycle assessment. The results must consist of goal and scope of the study that are defined.

2.5.2 The Approaches of Life Cycle Assessment

The life cycle assessment can be used to study the effects of the process on environmental or human health issues by considering some parts or all of the processes. The variants of life cycle assessment that use to control the scope of process study is separated into four types (Figure 2.9).

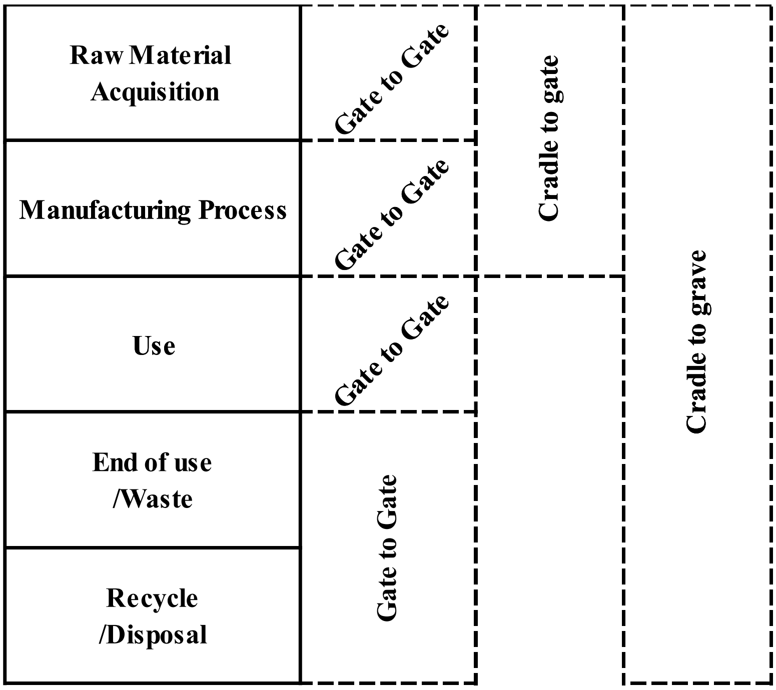

Figure 2.9 The approaches of life cycle assessment.

- Gate to Gate

This type uses when the life cycle assessment considers only some part of the whole process.

- Cradle to Gate

This type uses when considering all of the processes but it does not include the use or disposal of the product.

- Cradle to Grave

This type uses when evaluating the impacts of the raw material acquisition, manufacturing process, use and throughout the recycle or disposal of the product after the end of use.

- Cradle to Cradle

This type is a special approach of Cradle to Grave, the disposal process is the recycling of waste and makes the original or same product.

Qi and coworkers (2015) studied the environmental impacts of recycling mercury (Hg) containing waste from the industries located in Guizhou, China by considering 1×10^4 tons of Hg-containing waste as a functional unit which is about 110.28 tons of Hg and the industry was located in Guizhou, China. They used a gate to gate method to study the life cycle analysis. The treatment scenarios are divided into two scenarios that are Hg-containing waste recycling with end-of-life disposal (Hg-D) and Hg-containing waste recycling without end-of-life disposal (Hg-ND). The Life Cycle Impact Assessment (LCIA) was used to evaluate the effects of Hg-containing waste on the environment. For the results of this study, they considered mainly the effects on the environment which are carcinogens and non-carcinogens as exhibited in Figure 2.10.

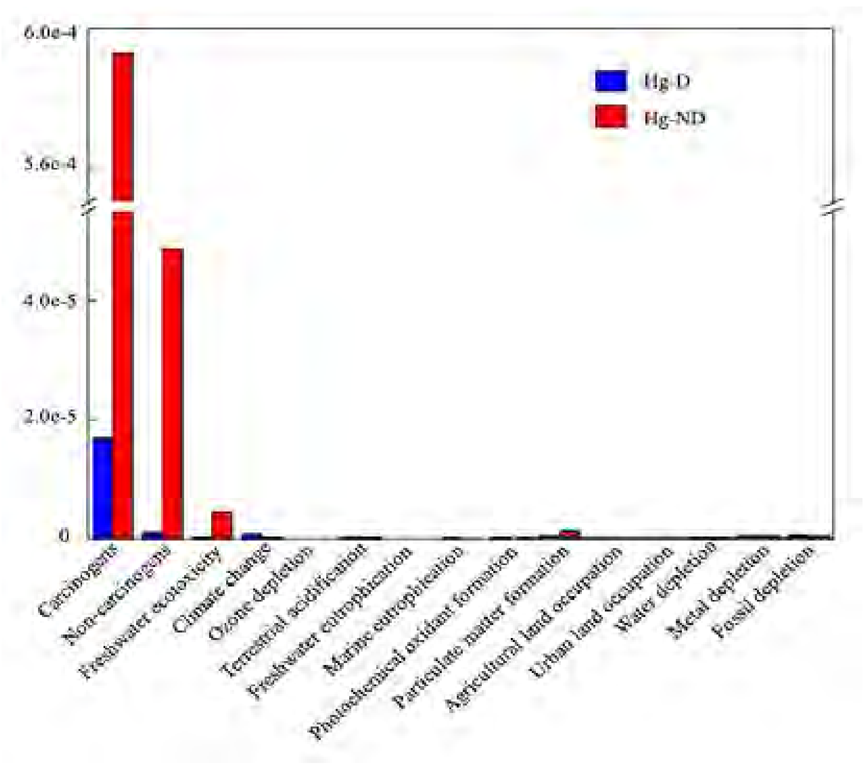

Figure 2.10 Life cycle impact assessment of Hg-D and Hg-ND results.

From Figure 2.10, Hg-D scenario was significantly lower than Hg-ND scenario for the main effect issues due to the fact that the pollution system did not control. In addition, Hg-D scenario directly emitted the pollution to air accounting for 81.29% in carcinogen and 97.77% in non-carcinogen. The Hg emissions to air can be reduced by controlling the Hg-recycling process.

Furthermore, the use of industrial hazardous waste (IHW) which was occurred from Hg-recycling process can affect the environment less than landfill disposal method when considered in carcinogens, ozone depletion, and urban land occupation issues. Therefore, recycling Hg-D and improving technology to control the waste can be reduced the environmental impacts from mercury.

CHAPTER III
EXPERIMENTAL

3.1 Scope of Research

The scope of this research is conducted to study the environmental performance of the petroleum refinery waste management which covers the following;

- The system boundary was scope at the end of life of waste management considering treatment and disposal system.
- The functional unit was defined as the management of the total amount of collected petroleum refinery waste in Thailand in the year 2015. The waste generated was collected from 6 refineries is 94,823 tons which included the wastes that were stored in refinery and sent to treatment or disposal plant.
- Based on waste data obtained from DIW (Thailand), the treatment and disposal method of the refinery sector is classified into 14 categories. The transportation sector electricity, and water supplied are not taken into the account for the calculation.
- The scenarios defined in this research are to study the environmental performances and compare with the "base case" or current waste management method. These scenarios are waste management strategy scheme including minimization of zero waste to landfill, burn in incinerator, and enhance recycling method.

3.2 Methodology

This study was done under the use of software in section 3.2.1 which can be used for evaluating the environmental impacts and the study procedures were explained in section 3.2.2

3.2.1 Software

- STAN v.2.6.601 used for calculating the material flow route
- SimaPro v.8.3.0 used for evaluating the environmental impacts
- Microsoft office 2016 (Excel)

3.2.2 Experimental Procedures

3.2.2.1 Define The System Boundary and Collect The Related Data of Petroleum Refinery Waste Flows

Set the scope of system boundary (Figure 3.2) that uses for studying the end-of-life of the petroleum refinery wastes and collect the related data such as the amount of generated wastes, treatment and disposal codes, and waste types (Hazardous/non-hazardous wastes) or other information that involves with the objrctives and system boundary.

3.2.2.2 Classify The Wastes, Build The Waste Inventory, and Set The Petroleum Refinery Waste Management Options

Classify and identify the data obtained from petroleum refinery wastes following the waste properties and waste codes from Department of Industrial Wastes, Ministry of Industry, Thailand (2005). The wastes that have similar property are separated in the same category and chaacterized the petroleum refinery wastes by treatment and disposal method in order to buid the waste inventory.

Set the waste management options for comparing the different waste management schemes in order to consider the amount of waste in each waste flow route after treating and disposing. The waste management options are also separated by hazardous and non-hazardous property of wastes.

3.2.2.3 Study The Material Flow Analysis Using STAN Software V.2.6.601 and Compare The MFA Results of Each Petroleum Refinery Waste Management Options

Conduct the material flow analysis (MFA) by input the data obtained considering the mass in and out of each waste flow route in the system boundary using STAN software v.2.6.601 to perform the material balance.

Compare the results of material flow after treating and disposing of each petroleum refinery waste management option.

3.2.2.4 Evaluate The Environmental and Human Health Impacts Using The Life Cycle Assessment (LCA) Procedures With Simapro Software V.8.3.0 of Each Waste Management Option

Use the MFA results to input the amount of waste flow route in each waste management options in SimaPro software v.8.3.0. The data that input in

SimaPro Software are considerd by the waste characteristic and also for the treatment and disposal methods that are need the specific process to evaluate the environmental impacts from each waste management option.

3.2.2.5 Compare and Analyze The Environmental and Human Health Impactts of Each Waste Management Option

Gather the results from SimaPro software of each waste management option in order to compare the environmental impacts and analyze the results to find the appropriate waste management option that can be used for applied in the petroleum refineries.

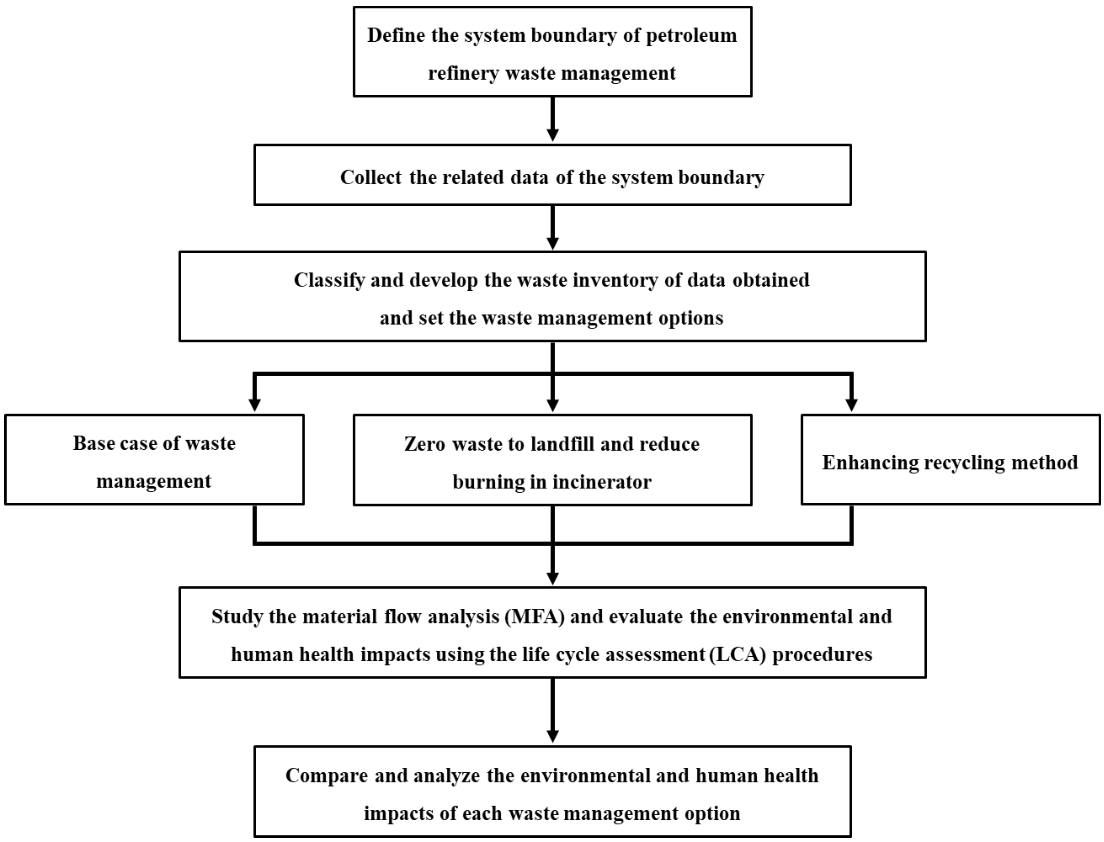

Figure 3.1 The experimental procedures diagram.

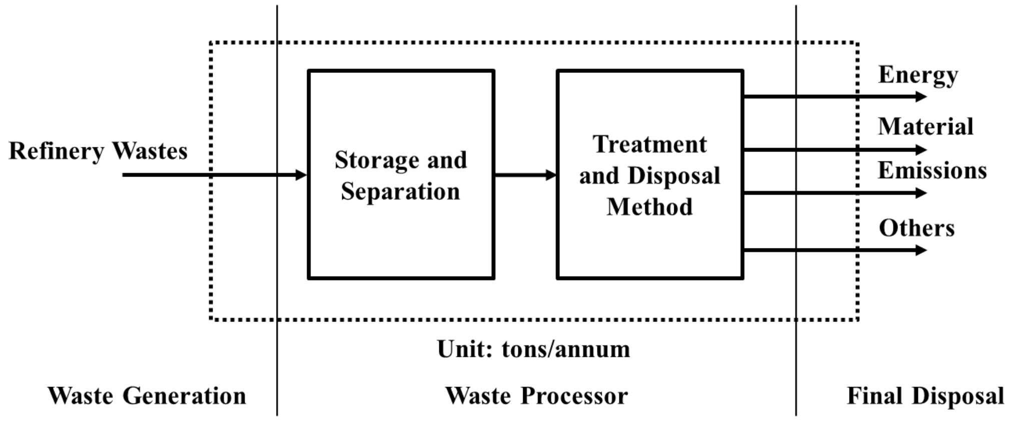

Figure 3.2 Petroleum refinery waste management system boundary.

Petroleum refinery waste management options are defined based on the objective that is to develop sustainable scenarios for waste treatment of petroleum refinery sector. They can be separated into 3 options in Table 3.1.

Table 3.1 The defined waste management options

Options	Key Aspects	Changes
Base case of waste management	The current waste treatment method (2015).	No
Zero wastes to landfill and incinerator	Reduce emissions from landfills and incineration to the environments.	The disposal method by landfill and incinerator are minimized by moving to other methods (except the refinery wastes contaminated with mercury, sulfur, and chloride).
Enhancing recycling method	Minimize the wastes that are still disposed by treating with the recycling method, reduce the emissions to the environments.	The treatment method by recycling and regeneration are the main method to treat the wastes.

CHAPTER IV
RESULTS AND DISCUSSION

The MFA and LCA are a useful tool for environmental including waste management. In this work, the end-of-life of waste management of oil refining industry was conducted. The waste flow boundary was scoped from waste generator to its final disposal at the waste processor. The total amount of collected petroleum refinery wastes was set as the functional unit of this study. The waste data was obtained from the waste disposal report at the year 2015 (DIW, 2015). The waste flow was developed through the material balance concept using STAN (v.2.6.601), MFA analysis software. After that, the waste inventory was conducted and evaluated the environmental impacts through LCA using Simapro (v.8.0.0). The CML 2000 method was used and the environmental impacts included 10 categories indicated by mid-point level. Three waste treatment scenarios were developed regarding waste management hierarchy by considering their waste property and characteristic. The results of MFA and LCA of each waste management scenario were compared and discussed in order to find the appropriate environmentally friendly sound solution for refinery waste management.

4.1 Waste Classification

From the waste report obtained from the DIW (2015), wastes generated from a petroleum refinery were varied by types, and physical and chemical characteristics such as used lube oils, aqueous liquid wastes, spent and discarded chemicals, oil contaminated materials, and spent catalysts. To manage these wastes, it is necessary to classify the wastes into specific categories. In general rules of thumb, hazardous wastes must be separated from non-hazardous wastes in order to select a proper treatment or disposal method. Due to their hazardous properties, if hazardous waste does not separate, it can cause a high risk to contaminate with other wastes. These mixed wastes then are claimed to treat or dispose of as hazardous wastes. Therefore, this is the reason that why the waste classification is very important.

According to Department of Industrial Works (DIW), Ministry of Industry, Thailand (2005), the industrial wastes are classified by the process of waste generation and the disposal method. In this study, the petroleum refinery waste data was obtained from 6 oil refineries in Thailand (2015) as illustrated in Appendix A1. The wastes were classified into 20 categories by considering their hazardous and non-hazardous property, physical and chemical characteristics, the waste disposal code, amount of waste generated as listed below,

1) Oily Sludge
2) Used Lube Oil
3) Oil Contaminated Materials
4) Spent Catalyst
5) Spent and Discarded Chemicals
6) Sulfur Waste
7) Copper Slag
8) Contaminated Container
9) Discarded Electronic Equipment
10) Battery
11) Aqueous Liquid Waste
12) Metal Waste
13) Contaminated Soil and Sand
14) Construction and Demolition Waste
15) Bio Sludge
16) Paper Waste
17) Wood Waste
18) Waste from Production Process
19) Waste from Water Preparation
20) Rubber and Plastic Wastes

According to the waste disposal report (Table 4.1), the waste treatment and disposal methods are classified by the waste code (DIW, 2015). In addition, some wastes were stored in their facilities and sent to treatment or disposal plants later.

The wastes from oil refining process in the year 2015 were 94,823 tons and were categorized into 20 categories. They were treated or disposed at the waste processors (WP), by 92,936 tons and the rest of them were stock at the waste generators (WG). The common wastes attributed were oily sludge, spent catalyst, aqueous liquid waste, and construction and demolition wastes. It is interesting to note that the wastes stored at the WG accounted for 1,887 tons, of which mainly were spent catalysts.

Table 4.1 The amount of waste from petroleum refineries separate by category

No.	Waste Type	Amount (tons)	
		Storage	**Disposal**
1	Oily Sludge	-	16,100
2	Used Lube Oil	10	280
3	Oil Contaminated Materials	86	6,280
4	Spent Catalyst	1,691	9,022
5	Spent and Discarded Chemicals	2	4,485
6	Sulfur Waste	10	490
7	Copper Slag	10	5,800
8	Contaminated Container	11.7	963
9	Discarded Electronic Equipment	8.3	225
10	Battery	4	49
11	Aqueous Liquid Waste	-	26,720
12	Metal Waste	-	7,302
13	Contaminated Soil and Sand	-	2,350
14	Construction and Demolition Waste	3	10,250
15	Bio Sludge	-	1,000
16	Paper Waste	-	70
17	Wood Waste	0.5	650
18	Waste from Production Process	50.5	525
19	Waste from Water Preparation	-	285
20	Rubber and Plastic Wastes	-	90
Total (tons)		1,887	92,936
		94,823	

In waste processing system, the wastes from the oil refinery are sent to treatment and disposal facilities. The wastes contained same or similar characteristics can be treated by several methods. The choice of treatments does not only depend upon the emissions after disposal, but also the cost of the transportation to the final disposal. However, the waste disposal codes of the waste from an oil refining industry that reports to DIW are divided into 14 codes as shown below,

11 Sorting
21 Storage
33 Reuse or refill
41 Fuel substitution
42 Fuel blending
44 Co-material in cement kiln
49 Recycle
52 Reclamation or regeneration of metal and metal compound
71 Sanitary landfill
73 Secure landfill of stabilized and/or solidified wastes
75 Burn in hazardous waste incinerator
76 Co-incineration in cement kiln
81 Collect and export
82 Land reclamation

Tables 4.2 presents the amounts (tons) of the waste from the refineries separated by type and treatment or disposal method. The waste stocked in the waste generator did not include in this table.

From Table 4.2, it can be seen that the waste profile mainly composed of aqueous liquid wastes (No. 11) 26,720 tons (28.75%), oily sludge (No. 1) 16,100 tons (17.32%), and construction and demolition waste (No. 14) 10,250 tons (11.03%). In addition, the least amount was battery (No. 10), which is about 49 tons (0.05%).

In cases of sorting by treatment and disposal method, the wastes were mostly discharged to the fuel blending method (Code 42) 33,095 tons, co-material in cement kiln method (Code 44) 18,375 tons, and co-incineration in cement kiln method (Code 76) 9,435 tons.

Table 4.2 Waste classification separated by treatment and disposal method as classified based on the DIW disposal code

No.	Waste Type	Amount (tons)	%	Treatment and Disposal Code													
				11	21	33	41	42	44	49	52	71	73	75	76	81	82
1	Oily Sludge	16,100	17.32				6,250	7,350						200	2,300		
2	Used Lube Oil	280	0.30					180		100							
3	Oil Contaminated and Contaminated Materials	6,280	6.76				220	2,560	3,030				20	350		100	
4	Spent Catalyst	9,022	9.71					200	6,495		100		900	70		1,257	
5	Spent and Discarded Chemicals	4,485	4.83					4,455					30				
6	Sulfur Waste	490	0.53					100				250	20	120			
7	Copper Slag	5,800	6.24						5,800								
8	Contaminated Container	963	1.04			23		10		80			850				
9	Discarded Electronic Equipment	225	0.24							40			185				
10	Battery	49	0.05		5					30			14				
11	Aqueous Liquid Waste	26,720	28.75				2,000	17,100						500	7,120		
12	Metal Waste	7,302	7.86	6,540						662			100				
13	Contaminated Soil and Sand	2,350	2.53					750	1,000				600				
14	Construction and Demolition Waste	10,250	11.03					100	2,050		100	5,850	550				1,600
15	Bio Sludge	1,000	1.08										1,000				
16	Paper Waste	70	0.08	70													
17	Wood Waste	650	0.70	510				100				40					
18	Waste from Production Process	525	0.56				250	90		5		180					
19	Waste from Water Preparation	285	0.31				70	100				100			15		
20	Rubber and Plastic Wastes	90	0.10	40								50					
Total		92,936	100	7160	5	23	8,790	33,095	18,375	917	200	6,470	4,269	1,240	9,435	1,357	1,600

4.2 Waste Management Strategy

To manage the petroleum refinery wastes properly, the waste sorting according to their types, characteristics, and amounts is an important step. Besides their hazardous level, absolute entry (HA) and mirror entry (HM), the waste of which has high amount should be prioritized. For the sorting step, the refinery wastes were separated into two categories; hazardous wastes (HZW) and non-hazardous wastes (Non-HZW) as shown in Tables 4.3 and 4.4.

From Table 4.3, the hazardous wastes were classified and separated into 14 categories of waste types and 11 waste disposal methods (waste disposal code) and the total amount of the HZW waste was about 76,755 tons. The HZW wastes from the aqueous liquid waste (No. 11) had the highest amount, accounting for 34.81% of the total HZW or 26,720 tons. While, the most treatment and disposal method used was the fuel blending (Code 42), which is about 32,705 tons. The least amount of HZW was battery (No. 10), about 45 tons (0.06%) and the least used treatment and disposal method was the storage method (Code 21), about 5 tons.

Table 4.4 exhibits the waste profile for the non-hazardous wastes, which can be separated into 10 categories of waste types and 10 disposal methods. The total amount of Non-HZW was 16,181 tons. The construction and demolition waste (No. 14) had the highest amount, which accounts for 46.35% or 7,500 tons, while the highest portion of treatment and disposal method was the sorting method (Code 11), which was about 7,160 tons. It is interesting to note that, the Non-HZW mostly composed of recyclable or reusable materials, and its portion is much lower compared with the HZW. Besides, the least amount of non-hazardous wastes also come from battery (No. 10) 4 tons (0.02%) and the least used treatment and disposal method was co-incineration in cement kiln method (Code 76) 15 tons.

Table 4.3 Waste management strategy (base case) for hazardous wastes classified by the DIW disposal code

Waste Type	Amount (tons)	%	Treatment and Disposal Code										
			21	33	41	42	44	49	52	73	75	76	81
11 Aqueous Liquid Waste	26,720	34.81			2,000	17,100					500	7,120	
1 Oily Sludge	16,100	20.98			6,250	7,350					200	2,300	
4 Spent Catalyst	9,022	11.75				200	6,495		100	900	70		1,257
3 Oil Contaminated and Contaminated Materials	6,280	8.18			220	2,560	3,030			20	350		100
7 Copper Slag	5,800	7.56					5,800						
5 Spent and Discarded Chemicals	4,485	5.84				4,455				30			
14 Construction and Demolition Waste	2,750	3.58				100	2,000		100	550			
13 Contaminated Soil and Sand	2,350	3.06				750	1,000			600			
15 Bio Sludge	1,000	1.30								1,000			
8 Contaminated Container	963	1.25		23		10		80		850			
12 Metal Waste	750	0.98						650		100			
2 Used Lube Oil	280	0.36				180		100					
9 Discarded Electronic Equipment	210	0.27						25		185			
10 Battery	45	0.06	5					30		10			
Total (tons)	76,755	100	5	23	8,470	32,705	18,325	885	200	4,245	1,120	9,420	1,357

Table 4.4 Waste management strategy (base case) for non-hazardous wastes classified by the DIW disposal code

Waste Type	Amount (tons)	%	Treatment and Disposal Code									
			11	41	42	44	49	71	73	75	76	82
14 Construction and Demolition Waste	7,500	46.35				50		5,850				1,600
12 Metal Waste	6,552	40.49	6,540				12					
17 Wood Waste	650	4.02	510		100			40				
18 Waste from Production Process	525	3.24		250	90		5	180				
6 Sulfur Waste	490	3.03			100			250	20	120		
19 Waste from Water Preparation	285	1.76		70	100			100			15	
20 Rubber and Plastic Wastes	90	0.56	40					50				
16 Paper Waste	70	0.43	70									
9 Discarded Electronic Equipment	15	0.09					15					
10 Battery	4	0.02							4			
Total (tons)	16,181	100	7,160	320	390	50	32	6,470	24	120	15	1,600

4.3 Material Flow Analysis (MFA) of Base Case Scenario

The wastes flow of the refinery waste disposal was conducted by mass or substance flow using MFA software (STAN v.2.6.601). The MFA can be expressed regarding the material balance of each waste type and its treatment and disposal method. From the data obtained in Section 4.1 and 4.2, the material flow of the refinery waste disposal was separated into hazardous wastes and non-hazardous wastes as shown in Figures 4.1 and 4.2. After the wastes were treated or disposed of, the waste treatment process can generate wastes as an additional waste or known as the 2nd waste that needs to be treated properly before final disposal. However, three alternative option of waste treatment routes could be selected, which are defined as 1) the wastes that can produce to energy, 2) wastes that can be recycled and used as a recycled material, and 3) the wastes that are processed and finally emit the emissions. The end-products were accounted in order to estimate the environmental impacts from each route and compare the results between the base case and the other scenarios in the next step.

This study, the waste flow is expressed in terms of material balance starting from waste generation to its disposal options and finally towards through its end of life or final disposal. The boundary also includes the 2nd waste generated from the waste treatment processes which includes energy, material, and emissions. From Figures 4.1, the amount of hazardous wastes in the year 2015 was about 78,581 tons. After they were separated into following waste categories, they were distributed to energy by 50,595 tons, material by 19,410 tons, and emissions category by 1,120 tons, respectively. The rests of them remained as a stock stored in the waste generator, which was about 1,826 tons.

For the non-hazardous wastes (Figure 4.2), the wastes accounted in boundary was about 16,242 tons. After the waste separation, the wastes were treated by recovery into energy about 725 tons, emissions about 120 tons, and material about 82 tons, respectively. The wastes stored at the waste generator facility and in the separation and sorting processors were about 61 tons. In addition, the non-hazardous wastes were mainly sent to sorting process, which accounted for 7,160 tons.

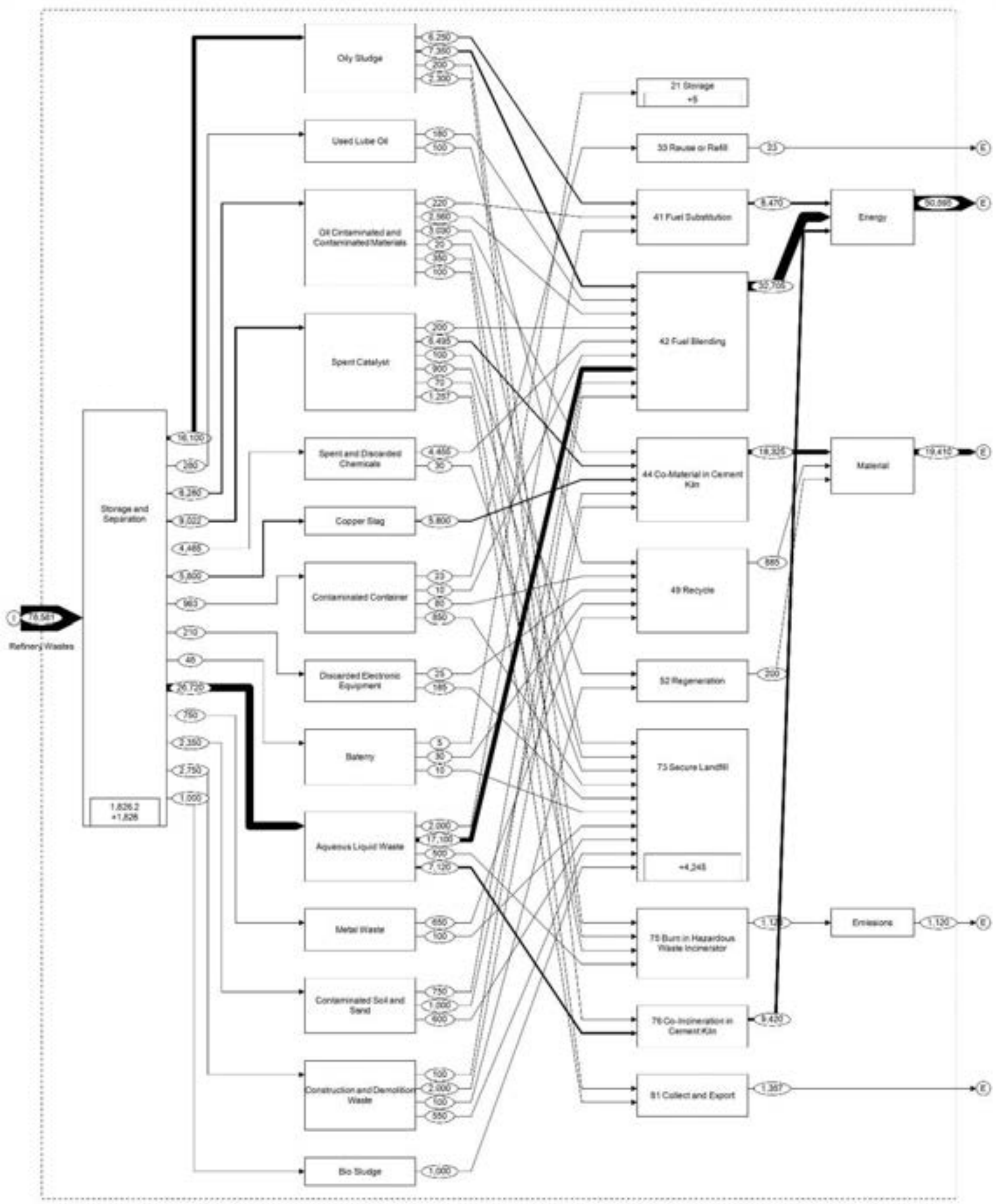

Figure 4.1 The material flow analysis of the hazardous waste of the petroleum refinery waste in Thailand (2015) (base case scenario) (ton/year).

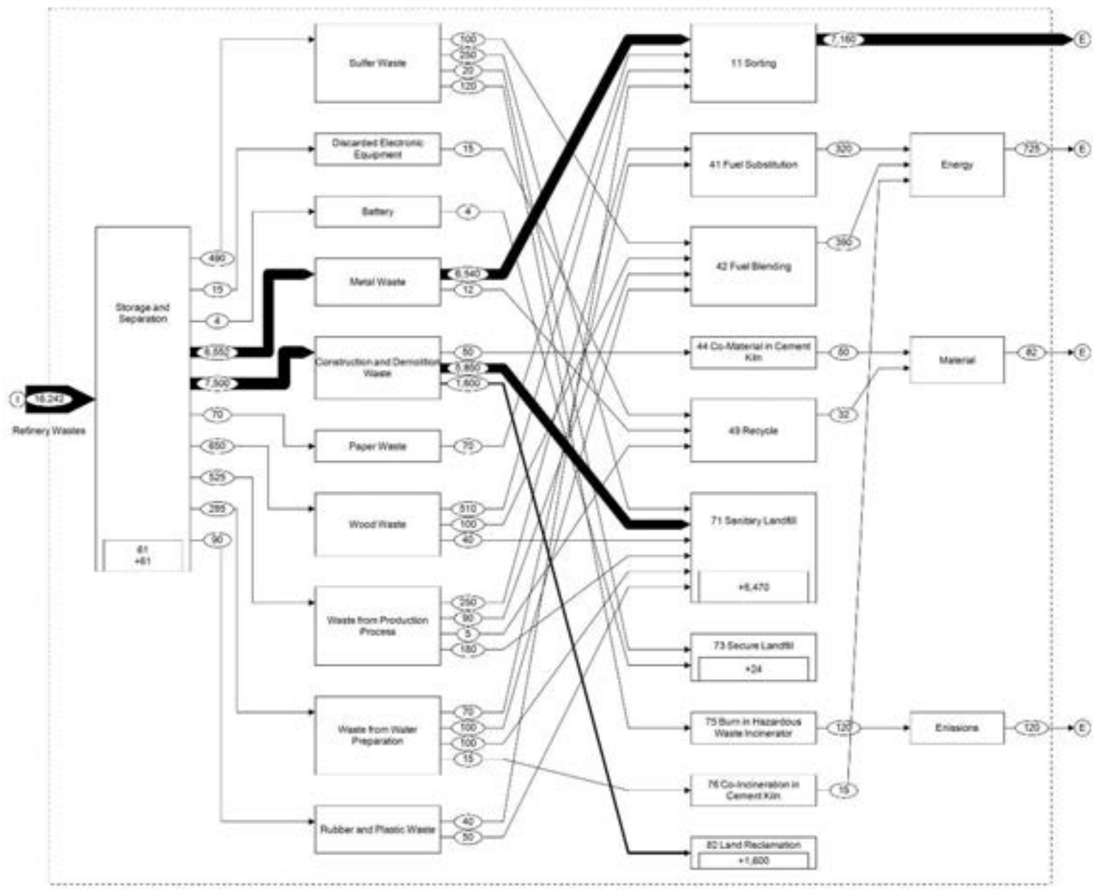

Figure 4.2 The material flow analysis of the non-hazardous waste of the petroleum refinery waste in Thailand (2015) (base case scenario) (ton/year).

4.4 Material Flow Analysis of Zero Wastes to Landfill and Incinerator

According to waste management hierarchy (see Figure 2.2), the waste treatment and disposal methods of the oil refinery wastes which are sanitary landfill (Code 71), secure landfill of stabilized and/or solidified wastes (Code 73) and burn in hazardous waste incinerator (Code 75) were optimized by an appropriate disposal route based on the waste management hierarchy concept.

In order to minimize the environmental impacts, the wastes that are disposed of by landfilling or burning in an incinerator must be reduced because these methods contribute highly adverse impacts such as groundwater pollution from landfill leachate and greenhouse gas emissions from landfill gases. However, the hazardous wastes (e.g.

oily sludge, spent catalyst, and spent chemicals), contained specific property that cannot be transformed to energy or recycling to be a recycled material, were counted as treated by the regulated methods. The scenario of waste minimization concepts by reduction the wastes sent to landfill and incinerator, was defined as “zero wastes to landfill and incineration”. Tables 4.5 and 4.6 show the wastes profile of the “zero wastes to landfill and incineration” scenario.

Table 4.5 shows the waste minimize scheme of the “zero wastes to landfill and incineration” scenario for the hazardous wastes. In this scenario, the wastes disposed by secure landfills (Code 73) and hazardous waste incinerators (Code 75) were treated alternately by other possible methods. The circle symbol depicts the purposed options for the waste treatment and disposal method as modifying from the base case to the “zero wastes to landfill and incineration” scheme. The treatment and disposal method was followed by the arrow in order to reduce the wastes disposed of by these two methods as the criteria below,

- Considering the existing treatment and disposal method (base case) using the waste management hierarchy scheme as in Figure 2.2, the treatment options are prioritized by the current disposal method.

- If the waste cannot be applied to the purposed methods, the existing or regulated method is selected.

It is noted for the waste disposal by secure landfills that, twenty tons of oil-contaminated materials cannot be moved to other alternative methods because they are defined as wastes that contain/consist of/contaminated with mercury. As reported by manufacturers that the mercury-contaminated wastes are secure-treated with the specific process, mercury recovery (Lee *et al.*, 2017) or exported to an oversee waste processors. Also, 600 tons of contaminated soil and sand contaminated with sulfur (as reported by the waste generators) are required a specific treatment due to their hazardous properties. The waste contaminated with sulfur can be treated by, for example, substitution as a raw material for producing cement concrete (Wongsirathat and Chavalparit, 2014). It is noted that the presence of sulfur or chlorine in the waste could corrode the equipment used in the process, thus not allowing to treat in cement kilns. Similar reason for 350 tons of oil-contaminated and contaminated materials, they must be disposed of by burning in hazardous waste incinerators (Code 75) because they contaminated with chlorides.

Due to the development of waste utilization technology, some wastes from the refining industry (Table 4.5) can be treated by an alternative treatment method to minimize the impacts through its whole end-of-life. Akcil and coworkers (2015) reviewed the metal recovery from spent catalyst. They found that there are many recycling methods such as chlorination, acid leaching, alkali leaching, bioleaching, or roasting with soda salts that can be used for recovering Mo, Ni, Co and V from the spent catalysts.

Zabaniotou and Theofilou (2006) used a sewage sludge as a conventional fuel substitution in a cement kiln. The new technology involved the mixing of sewage sludges with pet coke and incinerating the sludge mixture at high temperatures. The cement kilns burn fuels at 1400 ºC, at this temperature, the sludge does not emit dioxins which is a harmful substance to the human health.

Dutta and coworkers (2017) studied the recovery of nanomaterials by recycling spent battery. The cells used to recycle are such as Zn-MnO_2 alkaline battery, Li-ion, Zn-C, and Ni-MH battery. The cells were regenerated to produce the nanomaterials (Li, Zn, Mn, Pb, Co, Au, Ni, or rare earth) by a specific process. Most of these processes are such as hydrometallurgy, laser radiation, and grinding (with additives) with the production yield more than 90%.

According to the data shown in Table 4.6, it was noted that about 250, 20, and 120 tons of sulfur wastes deposed by sanitary landfills (Code 71), secure landfills or waste stabilization or solidification (Code 73), and hazardous waste incinerators (Code 75), respectively cannot be modified.

Table 4.5 Waste flow of the minimization of zero waste to landfill and incinerator scenario for hazardous waste

Waste Type	Treatment and Disposal Code									
	21	33	41	42	44	49	52	73	75	76	81
11			2,000	17,100						7,620	
1			6,250	7,550						2,300	
4				200	6,495		1,070				1,257
3			220	2,560	3,030			20	350		100
7					5,800						
5				4,485							
14				100	2,000	550	100				
13				750	1,000			600			
15										1,000	
8		23		10		930					
12						750					
2				180		100					
9						210					
10	5					40					
Total (tons)	5	23	8,470	32,935	18,325	2580	1,170	620	350	10,920	1,357

Table 4.6 Waste flow of the minimization of zero waste to landfill and incinerator scenario for non-hazardous waste

Waste Type	Treatment and Disposal Code									
	11	41	42	44	49	71	73	75	76	82
14	5,850			50						1,600
12	6,540				12					
17	550		100							
18		250	90		185					
6			100			250	20	120		
19		70	100						115	
20	90									
16	70									
9					15					
10					4					
Total (tons)	13,100	320	390	50	216	250	20	120	115	1,600

After realignment of the refinery wastes treatment option, the differences of waste management in each treatment and disposal scheme, the base case or existing petroleum refinery waste management and zero waste to landfill and incinerator are illustrated in Figure 4.3. IT can be seen that from the MFA analysis, the wastes disposed by the secure landfills (Code 73) was dramatically decreased from 4,245 tons to 620 tons (85.39%) and the wastes that are burnt in the hazardous waste incinerator (Code 75) was decreased from 1,120 tons to 350 tons (68.75%). As a consequence, the preferable option was the reclamation or regeneration of metal and metal compound method (Code 52), indicated by an increase of wastes treated by this option, from 200 tons to 1,170 tons or 485% and followed by the metal recycling option (Code 49) that the wastes input to this option were increased from about 885 tons to 2,580 tons or 192%.

The volume of wastes input to the base case and zero waste to landfill and incinerator for non-hazardous waste are shown in Figure 4.4.

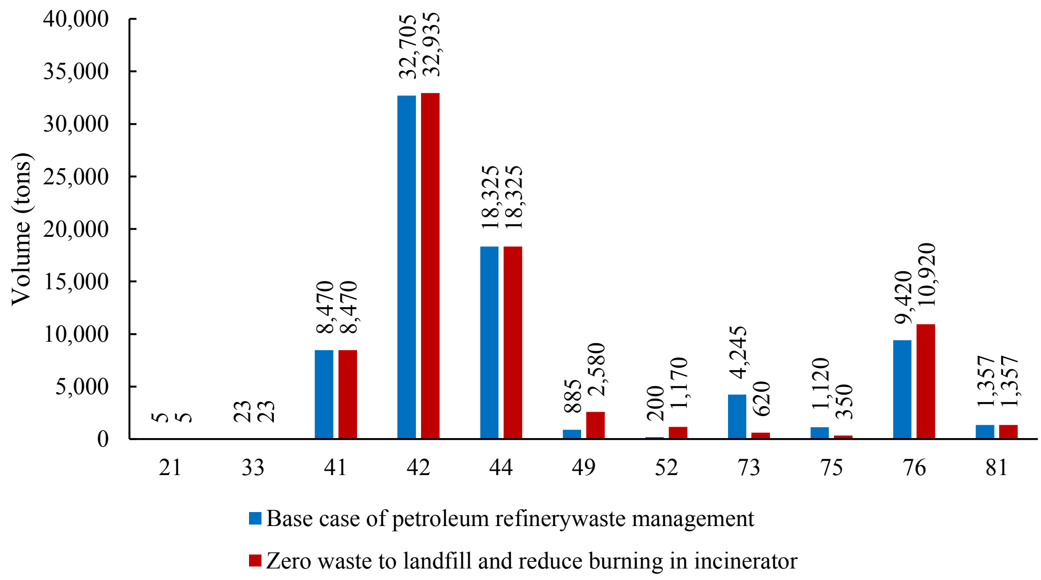

Figure 4.3 The volume of wastes input to the base case and zero waste to landfill and incinerator for non-hazardous waste.

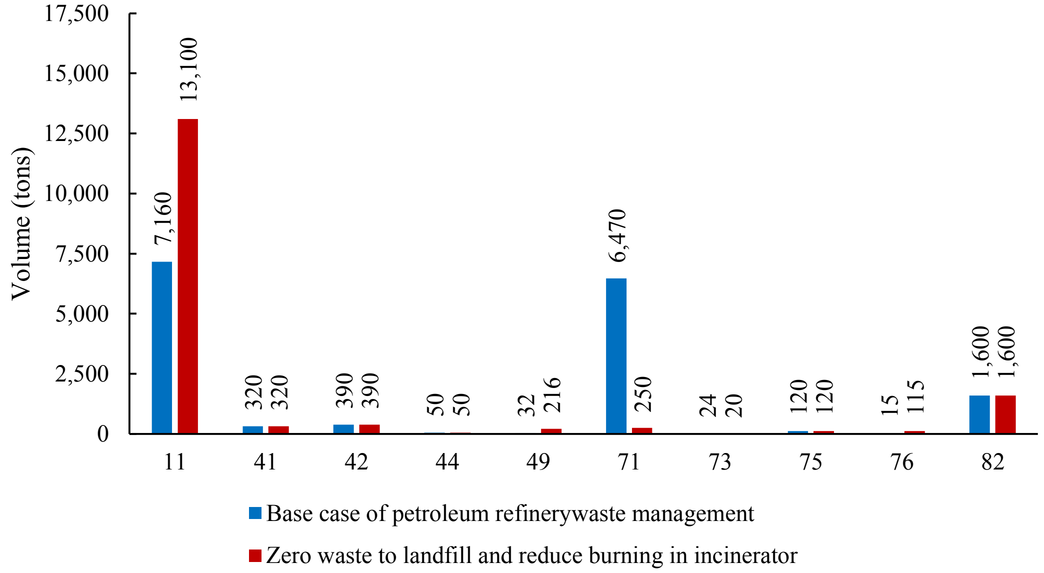

Figure 4.4 The volume of wastes input to the base case and zero waste to landfill and incinerator for non-hazardous waste.

From Figure 4.4, the amount of waste treated by the sanitary landfills (Code 71) was decreased from 6,470 tons to 250 tons (96.14%) and by the secure landfills (Code 73) was decreased from 24 tons to 20 tons (16.67%). The preferable option for treating the non-hazardous wastes was the co-incineration in cement kiln method (Code 76), which was indicated by the increase of the waste input from about 15 tons to be 115 tons (667%), followed by the recycling method (Code 49), the waste input was increased from 32 tons to be 216 tons (575%).

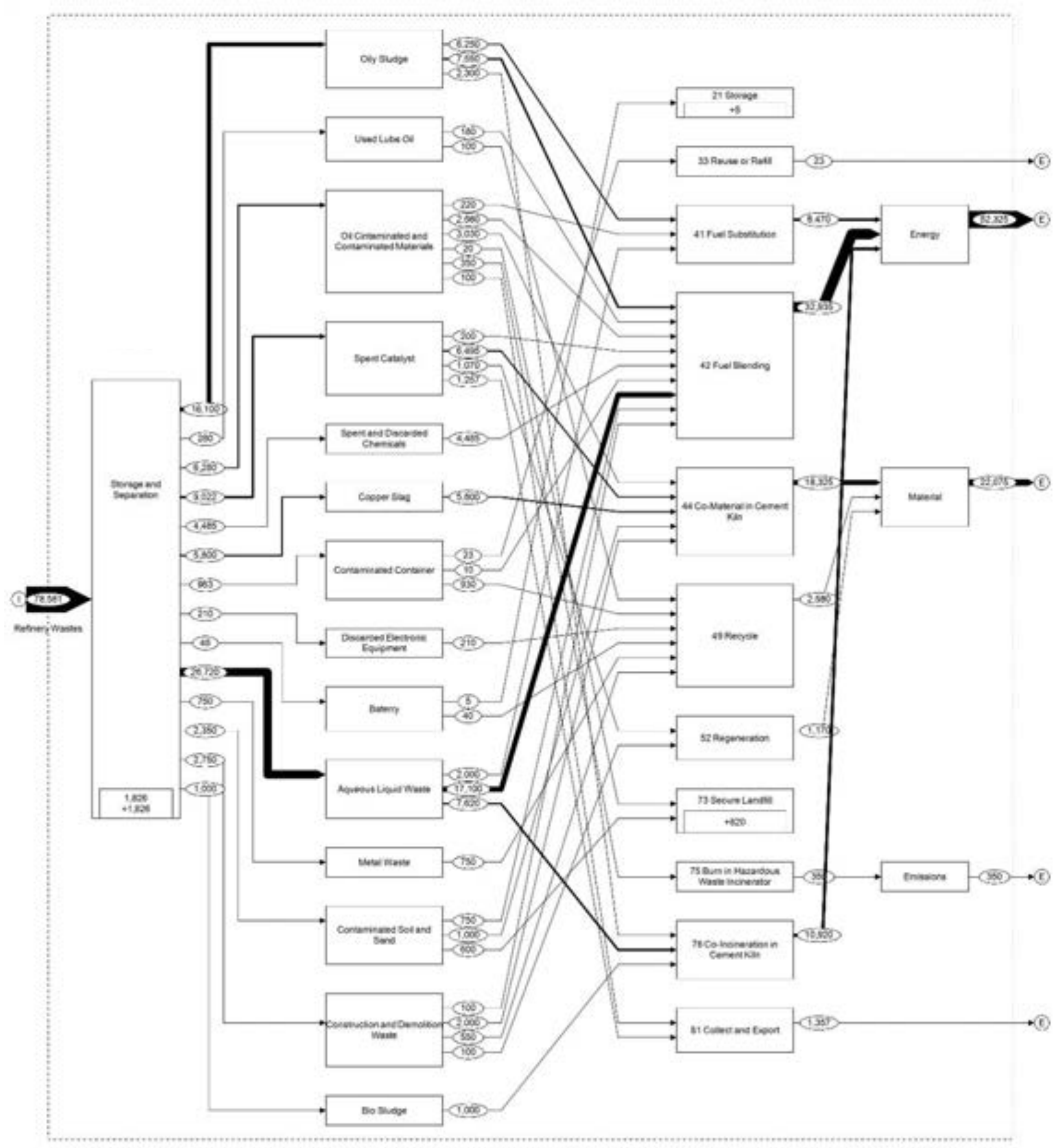

Figure 4.5 Material flow analysis of zero waste to landfill and incinerator for hazardous wastes (ton/year).

According to zero waste to landfill and incinerator scenario, the material flow analysis of the hazardous waste disposal is shown in Figure 4.5, the wastes at their end products were changed to energy category up to 52,325 tons and material category up to 22,075 tons. From this case, the wastes discharged to the emission category were decreased to be 350 tons.

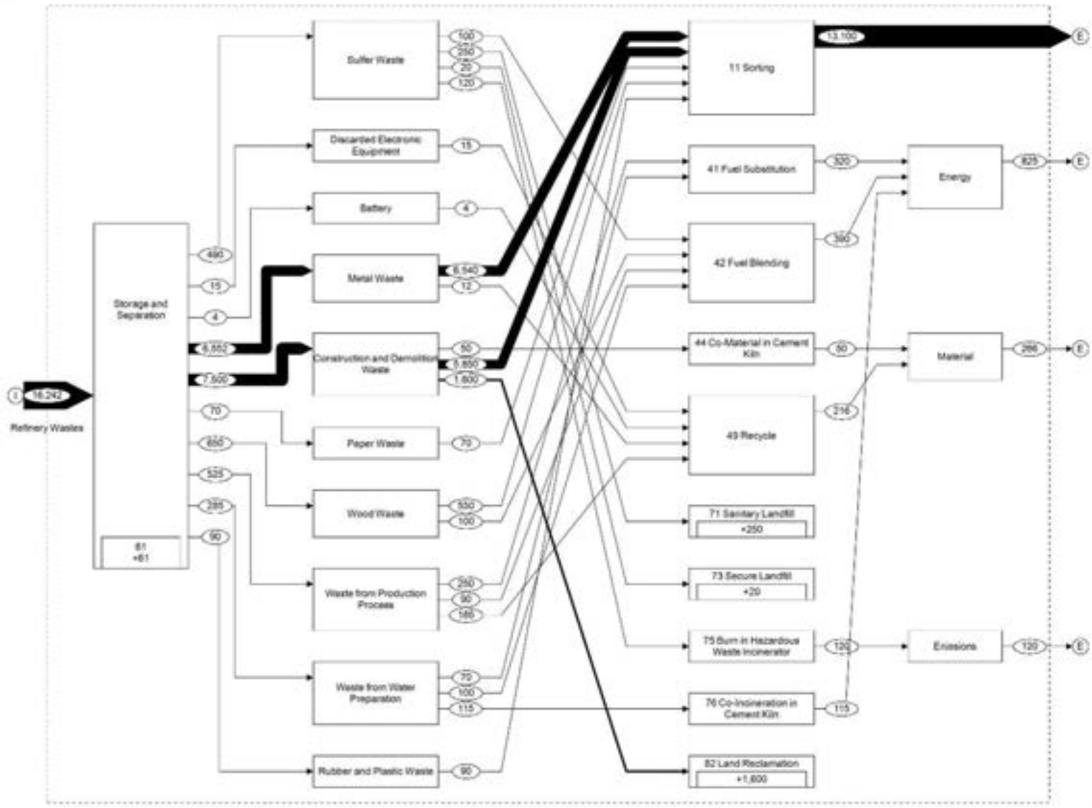

Figure 4.6 Material flow analysis of zero waste to landfill and incinerator for non-hazardous wastes (ton/year).

In Figure 4.6, the material flow analysis of non-hazardous wastes was relocated to energy category up to 825 tons and material category up to 266 tons. For emission category, the volume of the waste did not change (120 tons) but the wastes that were sent to a sorting process increase this waste route up to 13,100 tons.

4.5 Material Flow Analysis of Enhancing Recycling Method

The refinery waste disposal was managed by enhancing waste utilization through recycling methods (Code 49). This scenario includes the reclamation or regeneration of metal and metal compound (Code 52). Due to the existing methods including sanitary landfill method (Code 71), secure landfill of stabilized and/or solidified wastes method (Code 73), burn in hazardous waste incinerator method (Code 75), co-incineration in cement kiln method (Code 76), collect and export method (Code 81), and land reclamation method (Code 82) can cause tremendous impact to the environments. Therefore, the waste utilization or recycling method need to be carried out. In addition, the environmental impacts from the waste export method (Code 81) also counted the emissions from the transportation.

The waste classification in this scenario was improved using the data obtained from zero wastes to landfill and incinerator scenario by considering the existing recycling method and related treatment methods as shown in Tables 4.7 and 4.8. However, the wastes that were realignment almost comes from the co-incineration in cement kiln method (Code 76), collect and export method (Code 81), and land reclamation method (Code 82). This is due to some wastes required a specific treatment process which cannot be modified from the existing treatment method.

Because of the characteristic and property of each waste, the specific process used for recycling the petroleum refinery waste is required. Hu and coworkers (2013) studied the oily sludge treatment from upstream and downstream in petroleum industry. Oily sludge consisted of the petroleum hydrocarbon, 5-86.2% and the rests are water and solids. In this study, the oily sludge was recycled by recovery method using solvent extraction process.

Usapein and Chavalparit (2015) studied the utilization of bio-sludge from the petrochemical plant. The sludge mainly contained moisture content about 90%, volatile solid, 77.00%, and ash, 20.474%. The recycling method of bio-sludge was a co-material for producing fertilizer by mixing with sawdust and microbial inoculums.

Lawson and coworkers (2001) studied the recycling of construction and demolition wastes. The composition of the construction wastes mainly was cement concrete, metals, and excess mortars, while the demolition wastes concrete are, masonry, paper and plastics, and asphalt. The construction and demolition wastes were recycled by crushing to produce a graded product or recovering.

Wasielewski and Sobolewski (2011) studied the utilization of spent ion-exchange resin. These spent resins composed of a mixture of Purolite and Amberlyst resins based on a styrene or styrene-divinylbenzene matrix with a functional sulfo group (-SO_3^-). The recycling method in this study used an ion-exchange resin as an additive in the coal batch by coking process.

Lin and coworkers (2017) investigated the use of a spent catalyst and waste sludge as a co-material in cement clinker preparation. The spent catalyst was collected from the refinery and waste sludge was taken from cutting stone and steel company. The clinker preparation process was operated by feeding the material in the furnace with 1,400 ˚C and crushing in a ball mill.

The information obtained from the published works can help for considering the waste treatment options. Therefore, the wastes can be treated by the recycling method (Code 49) and reclamation or regeneration of metal and metal compound method (Code 52) for both of hazardous wastes and non-hazardous wastes.

According to the data in Table 4.7, the results showed that the enhancing of recycling method or Code 49 by treating the wastes from other disposal methods into this method. In the secure landfill of stabilized and/or solidified wastes method (Code 73), 20 (spent mercury absorbent) and 600 tons (soil contaminated sulfur) of wastes were still disposed of by the original method. Likewise, the burning in hazardous waste incinerator method (Code 75), 350 tons (spent chloride absorbent), and collect and export method (Code 81), 100 tons (spent mercury absorbent). The wastes disposed by the existing method could be affected to other wastes or processes if it will treat with the wastes in the considered treatment method.

In Table 4.8, all of the refinery wastes from the sanitary landfill method (Code 71), secure landfill of stabilized and/or solidified wastes method (Code 73), burning in hazardous waste incinerator method (Code 75), co-incineration in cement kiln method (Code 76), and land reclamation method (Code 82) can be recycled due to the recycling processes are suitable for the waste characteristic and property. Moreover, the non-hazardous wastes can be recycled and managed easier than the hazardous wastes.

Table 4.7 Waste classification of enhancing recycling method scenario for hazardous waste

Waste Type	Treatment and Disposal Code										
	21	33	41	42	44	49	52	73	75	76	81
11			2,000	17,100		7,620					
1			6,250	7,550			2,300				
4				200	6,495		2,327				
3			220	2,560	3,030			20	350		100
7					5,800						
5				4,485							
14				100	2,000	550	100				
13				750	1,000			600			
15						1,000					
8		23		10		930					
12						750					
2				180		100					
9						210					
10	5					40					
Total (tons)	5	23	8,470	32,935	18,325	11,200	4,727	620	350	0	100

Table 4.8 Waste classification of enhancing recycling method scenario for non-hazardous waste

Waste Type	Treatment and Disposal Code									
	11	41	42	44	49	71	73	75	76	82
14	5,850			50	1,600					
12	6,540				12					
17	550		100							
18		250	90		185					
6			100		390					
19		70	100		115					
20	90									
16	70									
9					15					
10					4					
Total (tons)	13,100	320	390	50	2,321	0	**0**	0	0	0

After the waste treatment for hazardous wastes was optimized by enhancing recycling method, the difference of each waste group in this scenario was compared with the base case as shown in Figure 4.7. The other waste groups, the storage method (Code 21), reuse or refill method (Code 33), fuel substitution method (Code 41), and co-material in cement kiln method (Code 44), were optimized by following the zero waste to landfill and incinerator options. The results indicated that the wastes treated by the recycling method (Code 49) were increased from 885 tons to 11,200 tons or 1,165.5% and by regeneration method (Code 52) were increased from 200 tons to 4,727 tons or 2,263.5%. The wastes treated by the secure landfill of stabilized and/or solidified wastes (Code 73) were decreased from 4,245 tons into 620 tons (-85.39%), the burning in hazardous waste incinerator method (Code 75) were decreased from 1,120 tons to 350 tons (-68.75%), and by the collecting and exporting method (Code 81) were decreased from 1,357 tons to 100 tons (-92.63%).

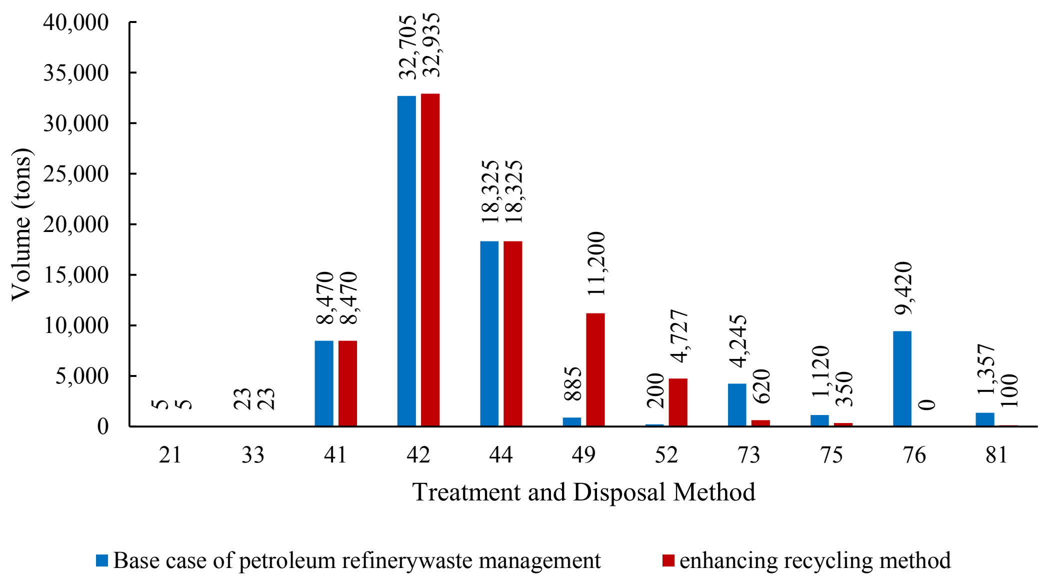

Figure 4.7 The comparing between the base case and enhancing recycling method for hazardous waste.

The amount of wastes that were managed by enhancing recycling method scenario was compared with the base case for non-hazardous wastes as shown in Table

4.7 The result indicated that the waste disposed of by the recycling method (Code 49) was increased from 32 tons to 2,321 tons (7,153.13%). The other waste, except the wastes from the sorting method (Code 11), fuel substitution method (Code 41), fuel blending method (Code 42), and co-material in cement kiln method (Code 44), can be replaced by the recycling method (Code 49).

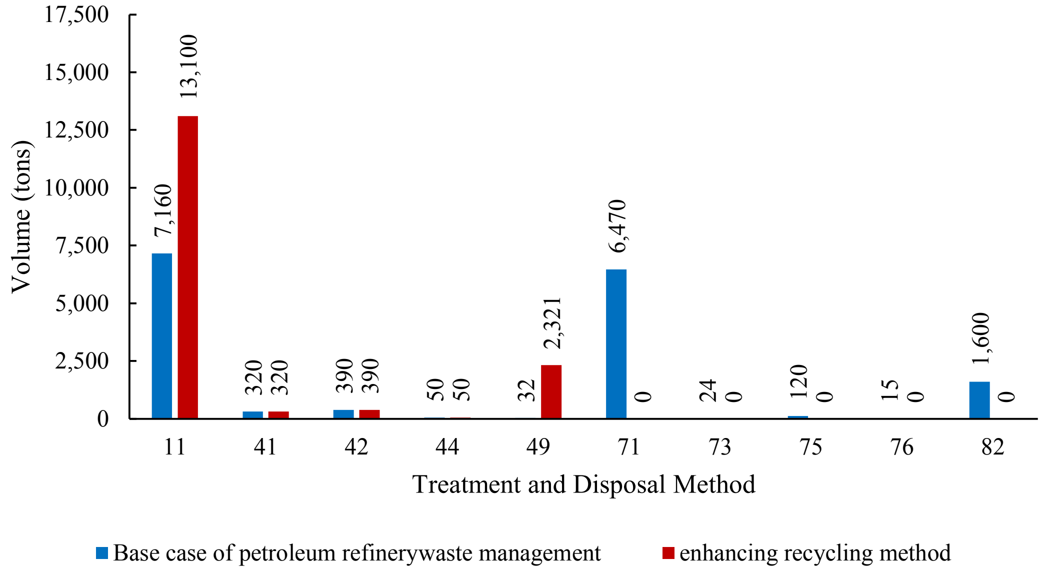

Figure 4.8 The comparing between the base case and enhancing recycling method for non-hazardous waste.

In Figure 4.9, the result of the material flow analysis indicated that the treatment of hazardous wastes by enhancing recycling method can utilize the wastes, which are abount 41,405 tons to be energy recovery. This is less than the zero waste to landfill and reduce burning in incinerator scenario due to the fact that some wastes treatment method to be discharged as the material recovery, which was abount 34,252 tons. However, the wastes that were changed to emissions were about 350 tons.

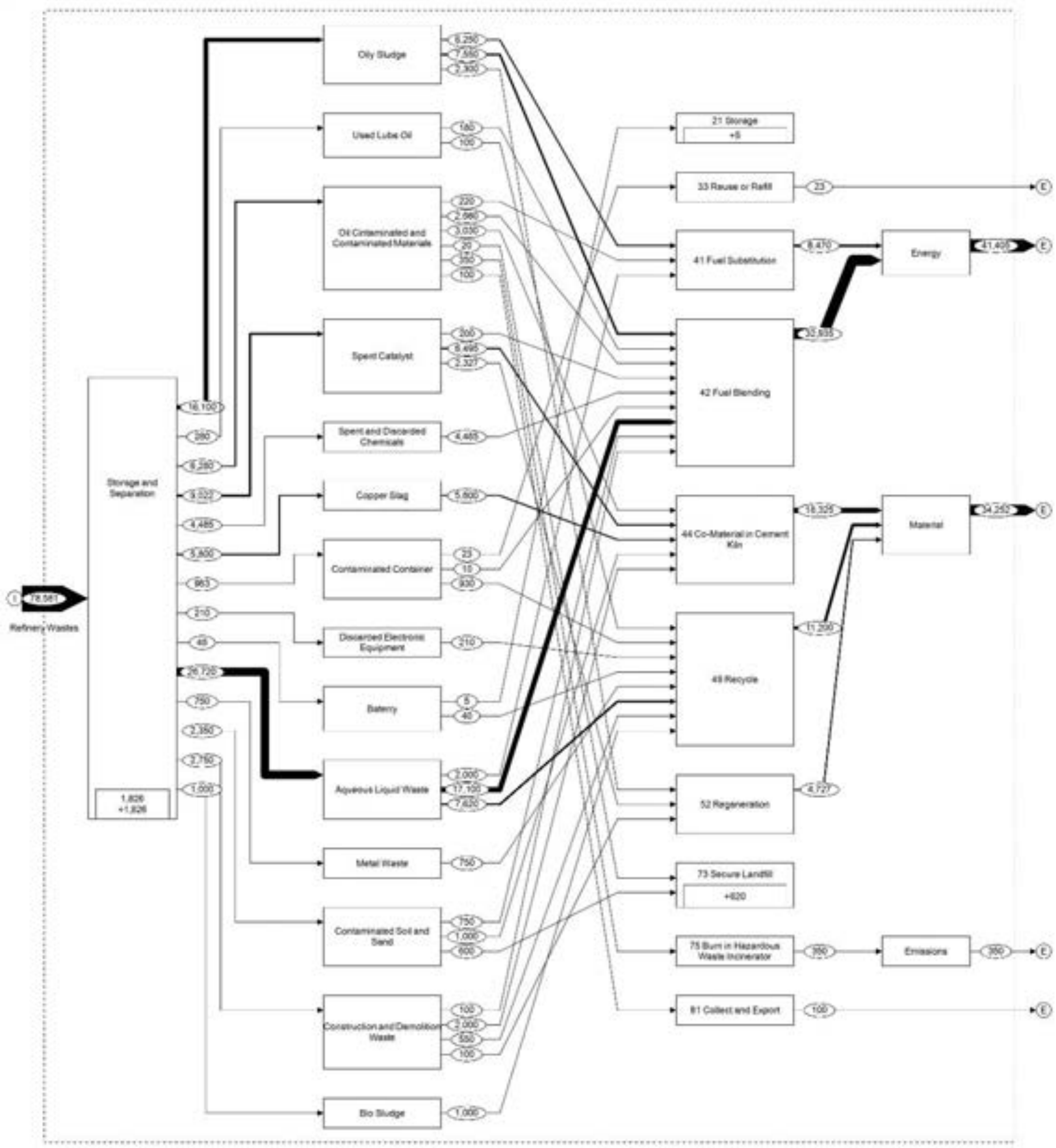

Figure 4.9 Material flow analysis of the enhancing of recycling method for hazardous wastes (ton/year).

From Figure 4.10, non-hazardous waste flow in this scenario were realignment by removing the emissions which could be caused by the waste treatment in this category with the recycling method. The waste transformed to the energy production was decreased to 710 tons after improved by this scenario comparing with the zero waste to landfill and reduce burning in incinerators scenario. The material recycled product was increased to 2,371 tons from the wastes sent to the recycling method.

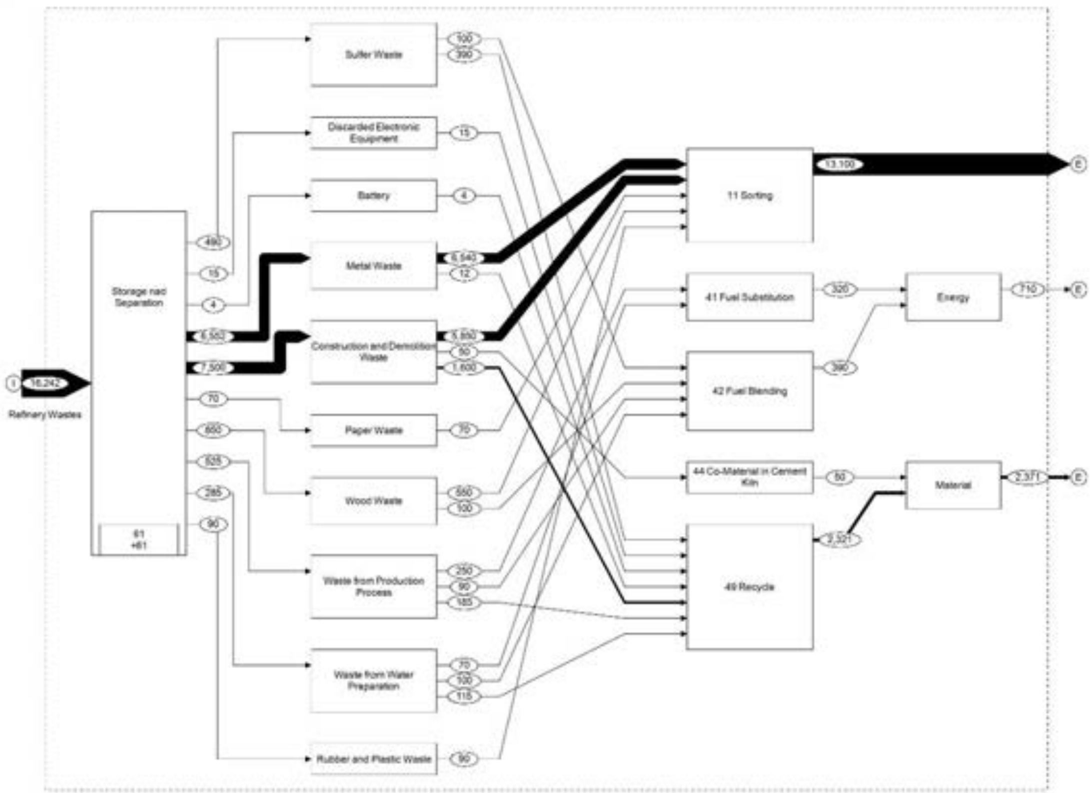

Figure 4.10 Material flow analysis of the enhancing of recycling method for non-hazardous wastes (ton/year).

4.6 Environmental impacts of End-of-Life of Petroleum Refinery Wastes

Due to the growth of the oil refining industry, their production generated more wastes each year. The waste processing begins with that they are sent from the waste generator to treat or dispose at the waste processor. The choice of the treatment or disposal methods depends on their properties and economic feasibility. Notwithstanding, each treatment method has different adverse impacts on the environment. It needs to know impacts of each treatment in order to find the better methods which has less impacts contributed to the environment. In this study, the oil refinery waste management scheme was separated into 3 scenarios that were the base case of waste management, zero wastes to landfill and reduce burning in incinerator, and enhancing recycling method. In each scenario, it consists of various treatment methods which is explained in the section 4.1. The defined scenario was counted and evaluated their environmental impacts through SimaPro software by the European, CML-IA method due to the principle of best available practice. This method is also recommended for simplified study and indicated by mid-point level. The environmental impact categories in this method compose of 10 categories as below,

- Depletion of abiotic resources (kg Sb eq) and fossil (MJ)
- Climate change (kg CO_2 eq)
- Stratospheric Ozone Depletion (kg CFC 11 eq)
- Human Toxicity (kg 1,4-DB eq)
- Fresh-Water Aquatic Eco-Toxicity (kg 1,4-DB eq)
- Marine Ecotoxicity (kg 1,4-DB eq)
- Terrestrial Ecotoxicity (kg 1,4-DB eq)
- Photo-Oxidant Formation (kg C_2H_4 eq)
- Acidification (kg SO_2 eq)
- Eutrophication (kg PO_4^{3-} eq)

The meanings of each impact category are explained in Appendix D and used for assessing the environmental impacts of the petroleum refinery wastes treatment scenario. In addition, the base case of the waste management is defined as BC scenario, zero wastes to landfill and reduce burning in incinerators as ZB scenario, enhancing recycling method as RC scenario, hazardous wastes as Hz, and non-hazardous as Non-Hz. These abbreviations are used for explaining the results of waste on the environments by impact category.

4.6.1 Environmental Impacts of Petroleum Refinery Hazardous Wastes

The waste flow analysis obtained from the material flow analysis was used for applying to calculate the environmental impacts of the petroleum refinery wastes using SimaPro software. The results of the environmental impact analysis of each scenario in are displayed in Figure 4.11. The lowest environmental impact in each impact category was achieved by the enhancing recycling method scenario. Because the direct emissions to the environments from the base case and zero wastes to landfill and burning in incinerator scenario are reduced by increasing the wastes in recycling method. In addition, due to the fact that the recycling method has lower impact values compared with the landfill and incineration method (Villanueva and Wenzel, 2007). It is in agreement with the waste management hierarchy that the least favorable option should not be the disposal method.

Although the recycling method (Scenario 5) had few impacts than those of the two scenarios, the high amounts of wastes which were treated by recycling method can increase the impact values, which are similar to those of the base case and zero wastes to landfill and reduce burning in incinerator scenario.

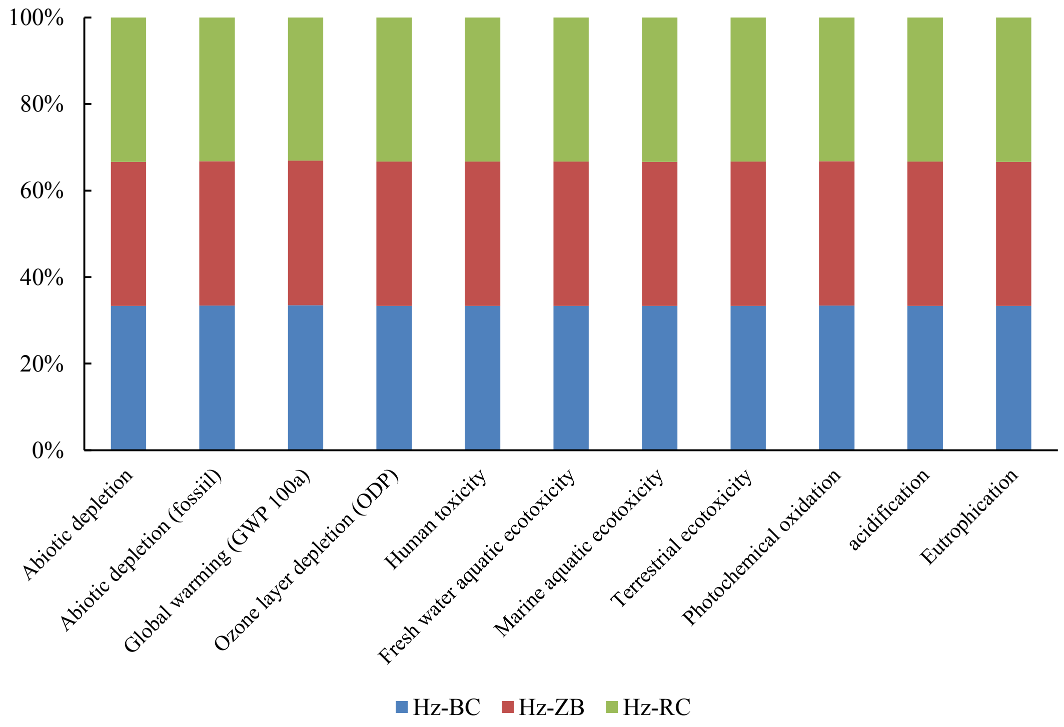

Figure 4.11 The relative contribution of environmental impacts of hazardous wastes for 3 scenarios.

4.6.2 Environmental Impacts of Petroleum Refinery Non-Hazardous Wastes

For non-hazardous wastes in Figure 4.12, the overall environmental impacts were not different compared with the hazardous wastes. The impacts were mainly caused by the base case and zero wastes to landfill and reduce burning in incinerator scenario. The reason for this owing to the wastes disposed of by other treatment and disposal methods (e.g., secure landfill, co-incineration in cement kiln, and land reclamation), still generate the emissions that contribute to environmental impacts as much as enhancing recycling method did.

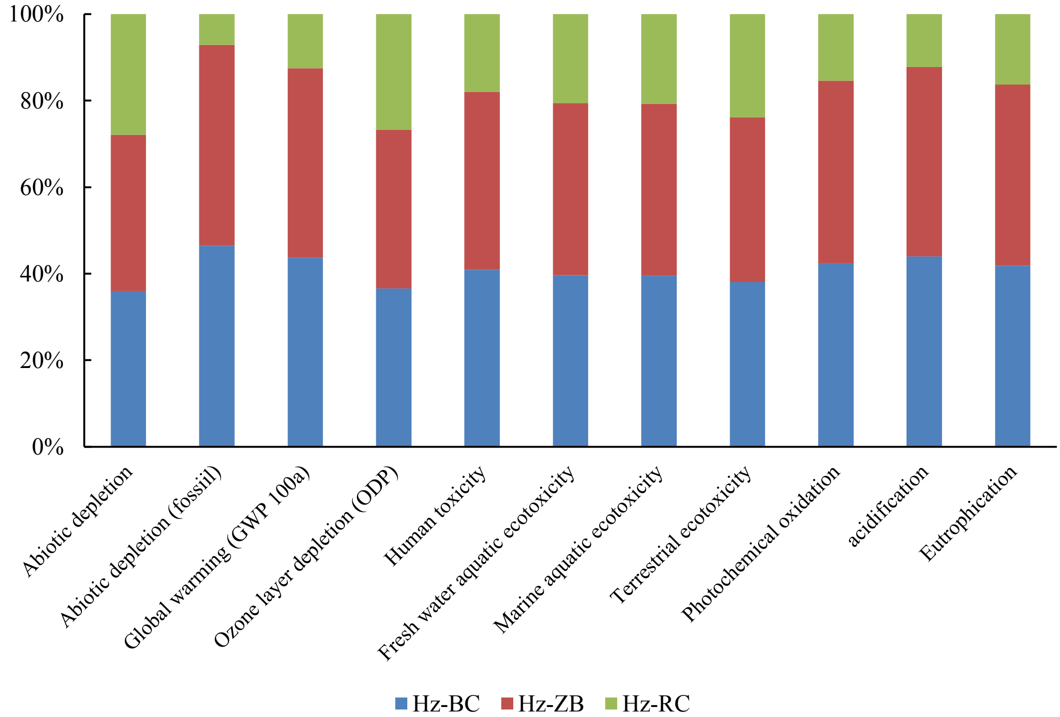

Figure 4.12 The relative contribution of environmental impacts of non-hazardous wastes for 3 scenarios.

Furthermore, the details of each scenario that emit the impact on the environments were explained in Section 4.6 by selecting the potential impacts that commonly found in the waste management.

4.7 The Main Impact Categories of Petroleum Refinery Waste Management Strategies

The potential impact categories on waste management were selected based on that they are directly involved in the human and environmental concerns. It needs to understand the sources of the emissions in order to find the proper way to manage the wastes from the petroleum refinery. The four impact categories were selected, composing of the global warming (GWP 100a), human toxicity, terrestrial toxicity, and acidification of hazardous and non-hazardous wastes. In addition, the different impact category values among these scenarios are illustrated in Appendix E. The meanings of each scenario are explained in Table 4.9.

Table 4.9 The meaning of defined scenario number

Scenario No.	Meaning
1	Base case of waste management for hazardous wastes
2	Base case of waste management for non-hazardous wastes
3	Zero wastes to landfill and incinerator for hazardous wastes
4	Zero wastes to landfill and incinerator for non-hazardous wastes
5	Enhancing recycling method for hazardous wastes
6	Enhancing recycling method for non-hazardous wastes

4.7.1 The Main Impact Categories of Hazardous Wastes

4.7.1.1 Global Warming (GWP 100a)

The impact of GWP in treating hazardous wastes by scenario 1, 3, and 5 were 3.3369×10^{8}, 3.34×10^{8}, and 3.30×10^{8} kg CO_2 eq, respectively. The impacts of GWP from the other treatment and disposal methods are shown in Figure 4.13. It can be seen that the most GWP impact in Scenario 3 are caused by recycling method (Code 49) and reclamation or regeneration of metal and metal compound method (Code 52). For the recycling method (Code 49), the emission values were increased from 7.76×10^{6} to 1.71×10^{7} kg CO_2 eq due to the increase of recycling steel or metal part. The reclamation or regeneration of metal and metal compound method (Code 52) had higher GWP increasing from 7.33×10^{6} to 1.12×10^{7} kg CO_2 eq because of the higher amount of wastes being treated more than that of scenario 1.

It is interesting to note that the treatment by reclamation or regeneration of metal and metal compound method (Code 52) in Scenario 3 which has high value of global warming potential due to the emissions generated by the recycling of molybdenum (Nuss and Eckelman, 2014) was moved from the collecting and exporting method (Code 81). For this reason, the GWP for the disposal by collecting and exporting method (Code 81) of Scenario 3 demonstrated low impact value. Moreover, Scenario 3 had the lowest GWP impact because of the decrease of wastes treated by the co-incineration in cement kiln method (Code 76) and collecting and exporting method (Code 81), Moreover, the high GWP for three scenarios emitted by the fuel blending method (Code 42) which mainly come from oily tank cleaning wastewater or sodium phosphate. In case of the treatment by co-material in cement kiln method (Code 44), the GWP impact generated by the treatments of copper slag and spent catalyst.

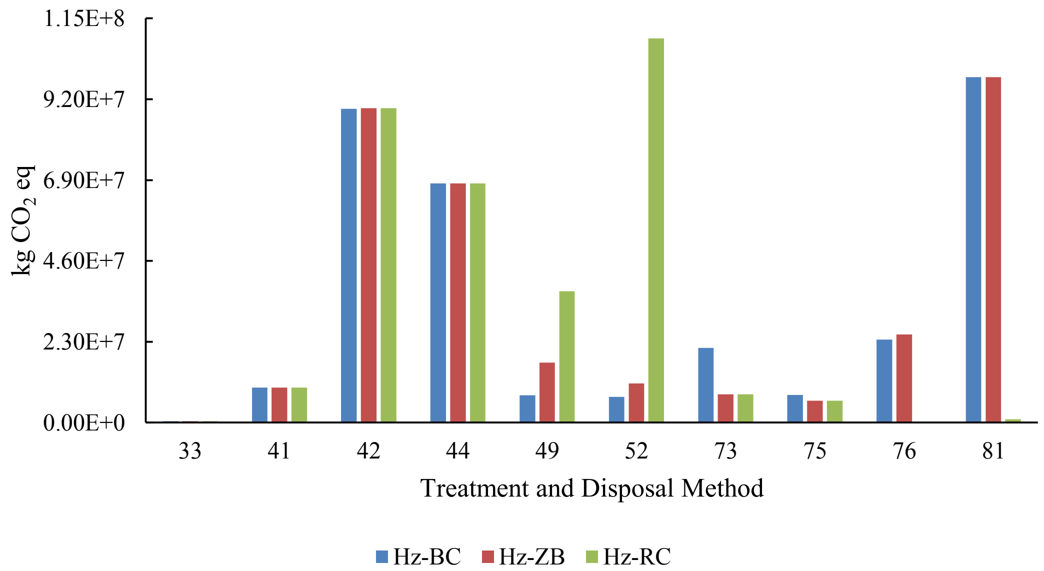

Figure 4.13 Global warming (GWP 100a) (kg CO_2 eq) of each treatment and disposal method for hazardous wastes.

4.7.1.2 Human Toxicity

The impact of human toxicity (HT) categories of hazardous wastes was about 8.83×10^9, 8.83×10^9, and 8.82×10^9 kg 1,4-DB eq which generated by scenario 1, 3, and 5, respectively. There are not significantly different in HT values among 3 scenarios and the impacts from other treatment and disposal methods are displayed in Figure 4.14. In the case of scenario 5, the treatment by the reclamation or regeneration of metal and metal compound method (Code 52) contributed to the high value of human toxicity, which was caused by the treatment of molybdenum.

On the other hand, the lowest human toxicity value was generated by scenario 3 due to the moving of wastes treated by the co-incineration in cement kiln method (Code 76) into other treatment and disposal methods. The decrease of HT in this scenario was caused by collect and export method (Code 81) is from 6.88×10^9, scenario 1, to 2.78×10^5 kg 1,4-DB eq.

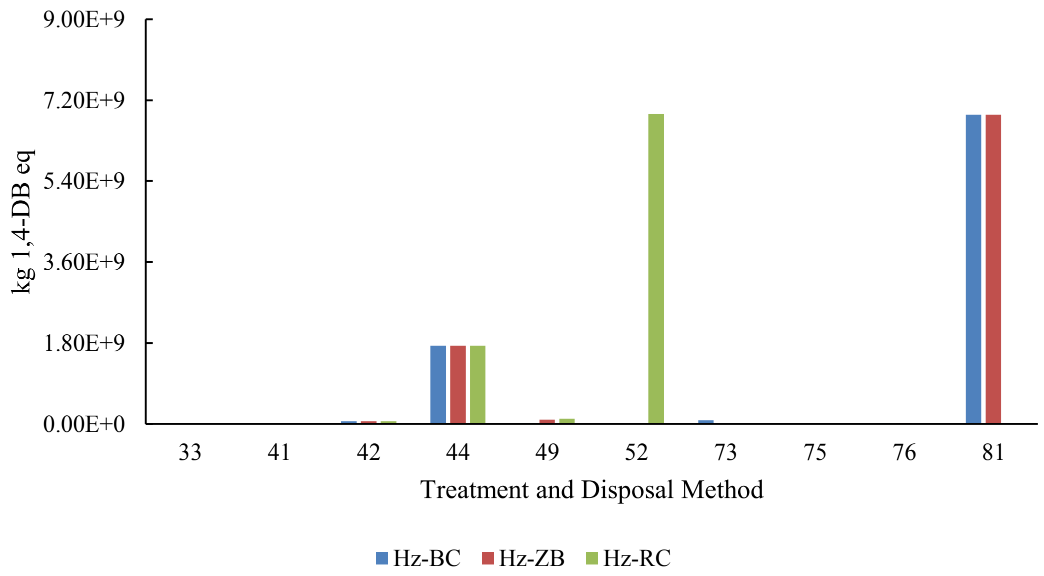

Figure 4.14 Human toxicity (kg 1,4-DB eq) of each treatment and disposal method for hazardous wastes.

4.7.1.3 Terrestrial Toxicity

The impact of Terrestrial toxicity (TT) category for hazardous wastes were 5.27×10^6, 5.27×10^6, and 5.25×10^6 kg 1,4-DB eq generated by scenario 1, 3, and 5, respectively. The impact from other treatment and disposal methods are illustrated in Figure 4.15. In the case of treatment Code 49, the terrestrial toxicity impact was increased from 4.60×10^4 kg 1,4-DB eq in scenario 1 (base case) to 1.38×10^5 kg 1,4-DB eq in scenario 3 because of the increase of the wastes treated by recycling steel method. In addition, the reclamation or regeneration of metal and metal compound method (Code 52) had high terrestrial toxicity impact because of the disposal of molybdenum. After moving the wastes in secure landfill of stabilized and/or solidified wastes method (Code 73) to other treatment and disposal methods, the impact of TT was decreased from 1.29×10^5 kg 1,4-DB eq, which was mainly caused by the disposal of steel in scenario 1 (base case), to be 1.85×10^4 kg 1,4-DB eq in scenario 3. In addition, the impact of terrestrial toxicity by the fuel blending method (Code 42) caused by the treatment of copper slag and co-material in cement kiln method (Code 44) caused by the treatment of oily debris.

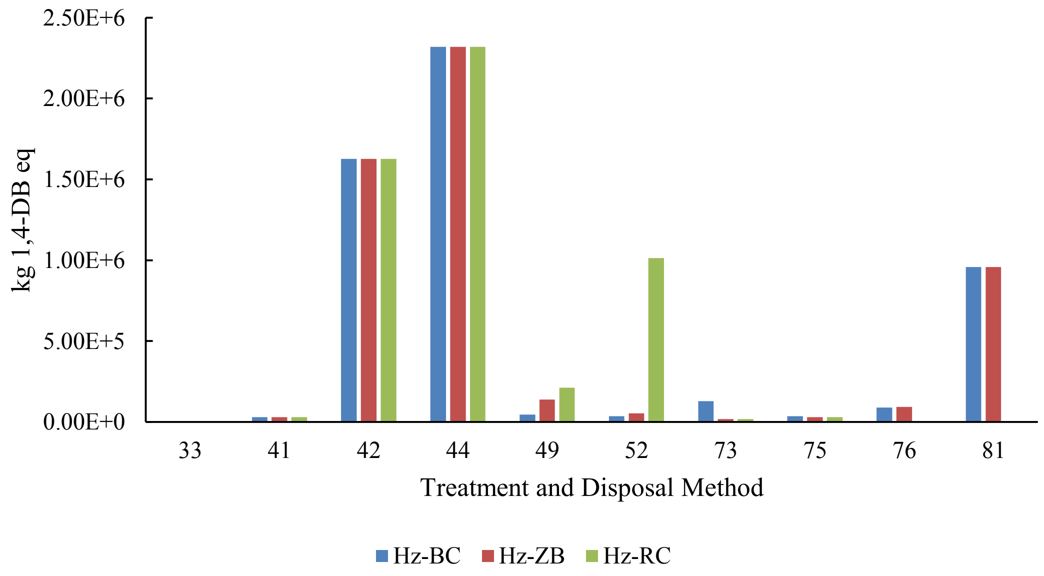

Figure 4.15 Terrestrial toxicity (kg 1,4-DB eq) of each treatment and disposal method for hazardous wastes.

4.7.1.4 Acidification

The impact of acidification for hazardous wastes were 6.45×10^{6}, 6.45×10^{6}, and 6.43×10^{6} kg SO_2 eq generated by scenario 1, 3, and 5, respectively. The impact from other treatment and disposal methods are shown in Figure 4.16. In scenario 3, the increasing of acidification impact is caused by recycling method (Code 49), from 3.60×10^{4} (scenario 1) to 9.34×10^{4} kg SO_2 eq because of the increase of electronic wastes. Moreover, the decreasing of the impact from acidification in the secure landfill of stabilized and/or solidified wastes method (Code 73), scenario 3 which was 5.67×10^{4} from 1.37×10^{5} kg SO_2 eq in scenario 1. This is due to the less waste disposed of by the landfill method.

Similar to the other impact categories, the emissions from acidification generated by reclamation or regeneration of metal and metal compound method (Code 52) in Scenario 5 was mainly caused by the treatment of molybdenum, that was moved from the collecting and exporting method (Code 81). Moreover, the treatment by co-material in cement kiln method (Code 44), showed the high acidification impact value which was mainly caused by the treatment of a copper slag.

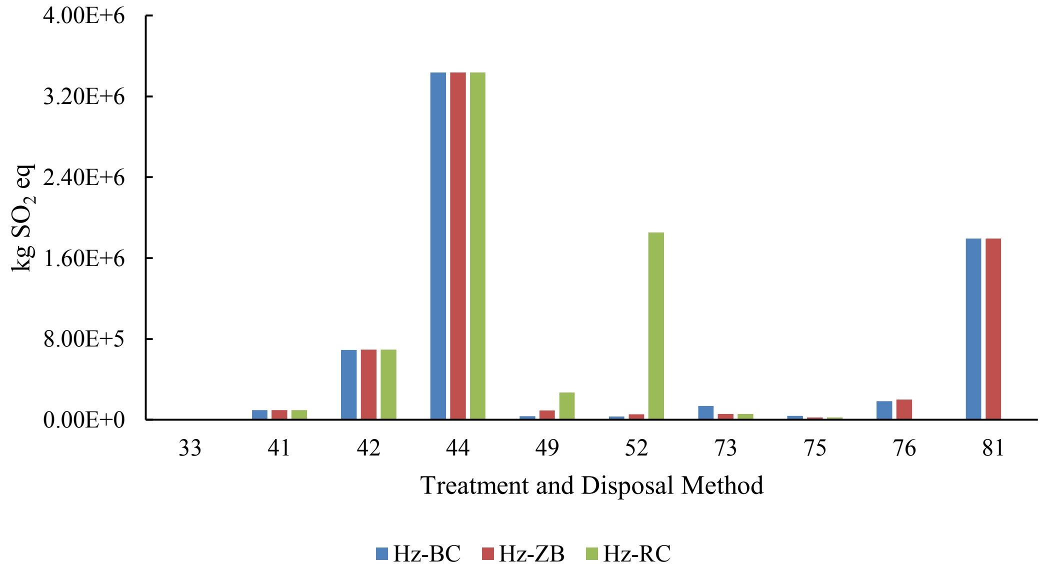

Figure 4.16 Acidification (kg SO_2 eq) of each treatment and disposal method for hazardous wastes.

4.7.2 The Main Impact Categories for Non-Hazardous Wastes

4.7.2.1 Global Warming (GWP 100a)

The impacts of GWP for non-hazardous wastes were 4.93×10^7, 4.94×10^7, and 1.41×10^7 kg CO_2 eq generated by scenario 2, 4, and 6, respectively. The impacts from other treatment and disposal methods are shown in Figure 4.17. The increasing of global warming impact come from treatment by sorting method (Code 11) and recycling method (Code49) in Scenario 4. For treatment Code 11, Scenario 4, the GWP value increased from 1.35×10^6 (Scenario 2) to 4.13×10^6 kg CO_2 eq due to more waste being treated by this method. The GWP of this treatment method (Code 11) was mainly generated by discarded insulation wastes which used polystyrene foam as a dataset for the aeeseement. In the case of treatment by the recycling method (Code 49), the GWP increases from 4.08×10^5 kg CO_2 eq in scenario 2 to 9.20×10^5 kg CO_2 eq in scenario 4 due to the treatment process or the sorting facilities in database. The impact of GWP also increased in scenario 6 for treatment by Code 49, about 1.43×10^6 kg CO_2 eq, that was caused by an increase of the treatment of metal wastes.

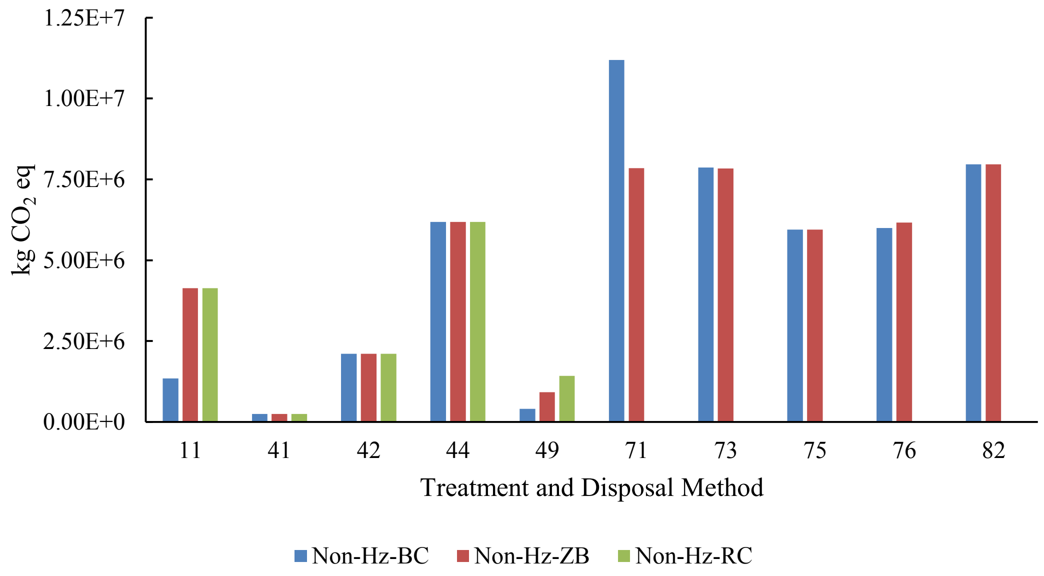

Figure 4.17 Global warming (GWP 100a) (kg CO_2 eq) of each treatment and disposal method for non-hazardous wastes.

The decrease of GWP for sanitary landfill method (Code 71) in Scenario 4 was observed, from 1.12×10^{7} (Scenario 2) to 7.84×10^{6} kg CO2 eq because the realignment of the high amount of wastes that treated by this method was move to treat by the other treatment methods.

4.7.2.2 Human Toxicity

Human toxicity impact value of non-hazardous wastes was found to be 4.05×10^{7}, 4.08×10^{7}, and 1.78×10^{7} kg 1,4-DB eq of generated by Scenario 2, 4, and 6, respectively. The impact from other treatment and disposal methods are shown in Figure 4.18. The higher human toxicity impact of Scenario 4, especially were generated from the sorting method (Code 11) and recycling method (Code 49). For the treatment Code 11 in Scenario 4, the human toxicity impact increased from 6.56×10^{6} (Scenario 2) to 7.12×10^{6} kg 1,4-DB eq due to the treatment of the metal wastes. For treatment Code 49 in Scenario 4 the human toxicity impact increased form 2.20×10^{6}, Scenario 2, to 2.76×10^{6} kg 1,4-DB eq because of the treatment of electronic wastes.

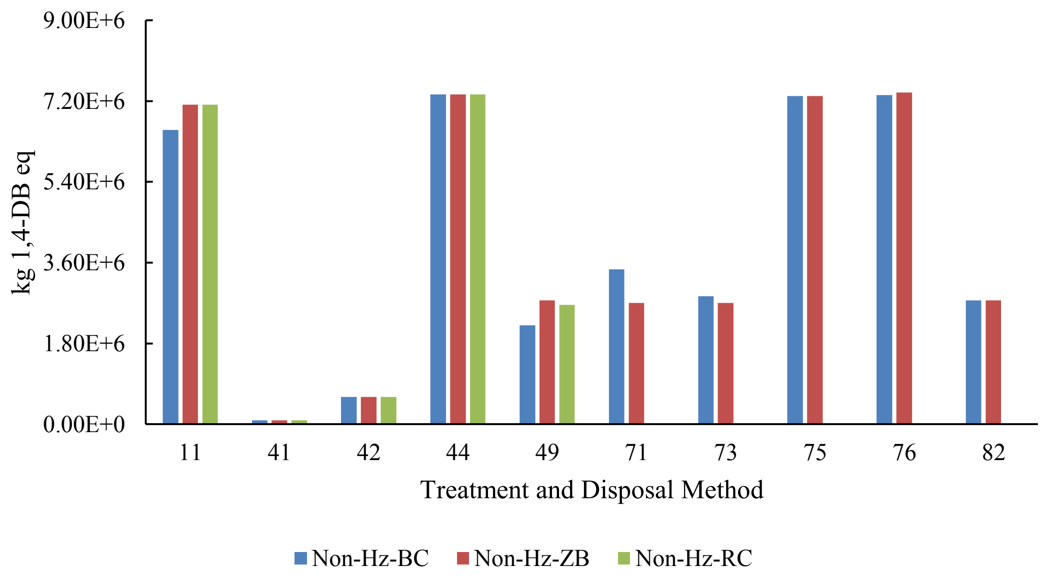

Figure 4.18 Human toxicity (kg 1,4-DB eq) of each treatment and disposal method for non-hazardous wastes.

In the case of the treatment by sanitary landfill method (Code 71) in Scenario 4, the human toxicity impact value was decreases from 3.45×10^{6} kg 1,4-DB eq in Scenario 2 to 2.71×10^{6} kg 1,4-DB eq because the impacts of the Scenario 2 came from human toxicity impact which is caused by the decrease of the amount of waste sent to the landfill in Scenario 4.

4.7.2.3 Terrestrial Toxicity

Terrestrial toxicity impact values for non-hazardous wastes were 3.00×10^{5}, 2.99×10^{5}, and 1.88×10^{5} kg 1,4-DB eq generated by Scenario 2, 4, and 6, respectively. The impacts from other treatment and disposal methods are illustrated in Figure 4.19. The Scenario 2 had the highest terrestrial toxicity which is generated by fuel blending method (Code 42) and mainly come from the disposal of oily debris wastes. In the case of sorting method (Code 11), the terrestrial toxicity impact value was increased from 1.08×10^{4} kg 1,4-DB eq in Scenario 2 to 1.36×10^{4} kg 1,4-DB eq in Scenario 4, even more it was still the similar value in Scenario 6. This because the metal wastes were sent to treat by the other method.

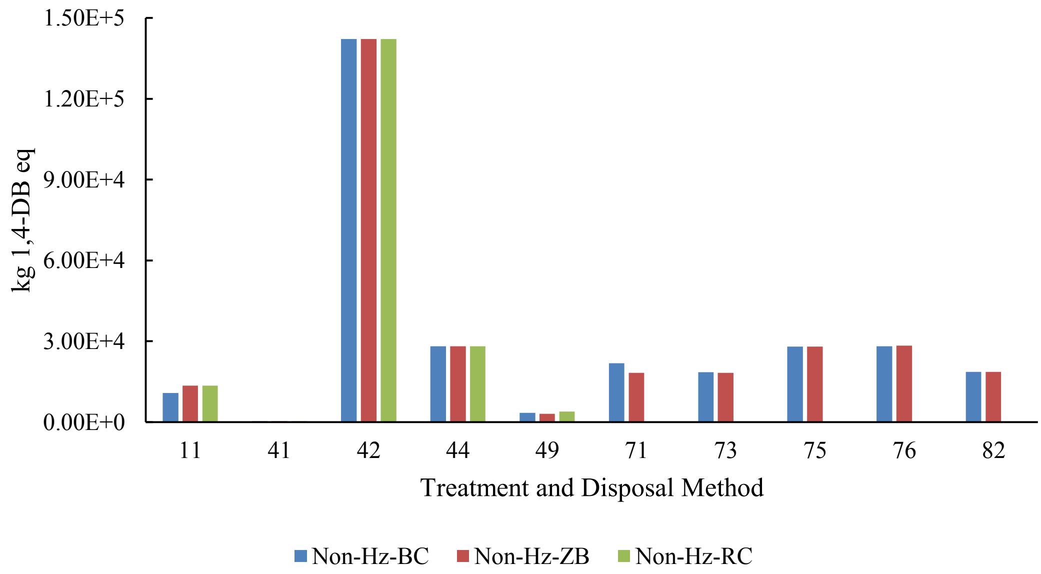

Figure 4.19 Terrestrial toxicity (kg 1,4-DB eq) of each treatment and disposal method for non-hazardous wastes.

The decrease of this impact in Scenario 4 of sanitary landfill method (Code 71) was changed from 2.18×10^{4} (Scenario 2) to 1.83×10^{4} kg 1,4-DB eq in which most of the impacts come from the landfill.

4.7.2.4 Acidification

Acidification impact values for non-hazardous wastes were 2.89×10^{5}, 2.87×10^{5}, and 8.03×10^{4} kg SO_2 eq generated by Scenario 2, 4, and 6, respectively. The impacts from other treatment and disposal methods are displayed in Figure 4.20. The highest impact of this category came from Scenario 2 of which the highest impact value was obtained by the sanitary landfill method (Code 71) and the treatment by landfill was the most contributed to this category. The impact of acidification was decreased from 7.17×10^{4} to 5.55×10^{4} kg SO_2 eq in Scenario 4 because the wastes sent to the landfill are moved to treat by other methods.

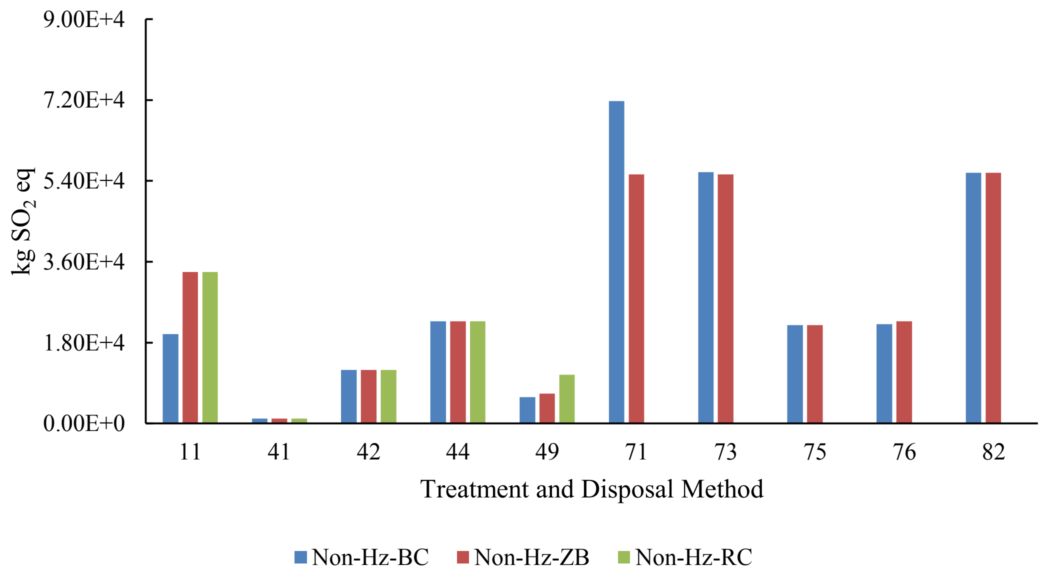

Figure 4.20 Acidification (kg SO_2 eq) of each treatment and disposal method for non-hazardous wastes.

In the case of the increase of acidification impact value in the sorting method (Code 11) and recycling method (code 49), the impact of acidification generated by the sorting method (Code 11) in Scenario 2 was increased from 1.99×10^{4}

kg SO_2 eq to 3.37×10^4 kg SO_2 eq in Scenario 4 due to the fact that the wastes from the sanitary landfill method (Code 71) were sent to treated by this method and the impacts mainly caused by the treatment of metal wastes. For the recycling method (Code 49), the increase of acidification impact values generated by scenario 2 were observed from 5,891.76 kg SO_2 eq to 6,611.53 kg SO_2 eq because of the increase of the amount of wastes treated by this method, which is the treating of the electronics waste. The same trend was observed for Scenario 6 that upto 1.09×10^4 kg SO_2 eq is released because of the increasing of the electronics wastes.

4.8 The Enhancing Recycling Method with 70% Recovery

The previous section (the enhancing recycling method scenario), the waste flow was calcuclated and the environmental impacts of each scenario were evaluated with 100% recovery of petroleum refinery wastes for treatment method by recycling (Code 49) and reclamation or regeneration of metal and metal compound (Code 52). So this study has the recycling rate was assumed to be 70% in order to compare with the results of 100% recovery. The wastes classification was classified based on Table 4.7 for hazardous wastes and Table 4.8 for non-hazardous wastes as illustrated in Table 4.10 and 4.11.

The total amount of wastes that were sent to treat by recycling method (Code 49) with 70% recovery as shown in Table 4.10 were decreased from 11,200 tons to 8,614 tons and reclamation or regeneration of metal and metal compound (Code 52) decreased from 4,727 tons to 3,660 tons. In case of disposal method by co-incineration in cement kiln (Code 76), the wastes were increased from 0 to 3,276 tons as well as the wastes in collect and export method (Code 81) were increased from 100 tons to 477 tons.

The decrease of the waste that was treated by recycling method (Code 49) with 70% recovery was decreased from 2,321 tons to 1,690 tons while the wastes were disposed of by sanitary landfill method (Code 71), secure landfill of stabilized and/or solidified wastes method (Code 73), burning in hazardous waste incinerator method (Code 75), co-incineration in cement kiln method (Code 76), and land reclamation method (Code 82) were increased to 75 tons, 6 tons, 36 tons, 34 tons, and 480 tons, respectively.

Table 4.10 Waste classification of enhancing recycling method with 70% recovery for hazardous waste

Waste Type	Treatment and Disposal Code										
	21	33	41	42	44	49	52	73	75	76	81
11			2,000	17,100		5,334					
1			6,250	7,550			1,610				
4				200	6,495		1,950				
3			220	2,560	3,030			20	350		100
7					5,800						
5				4,485							
14				100	2,000	550	100				
13				750	1,000			600			
15						700					
8		23		10		930					
12						750					
2				180		100					
9						210					
10	5					40					
Total (tons)	5	23	8,470	32,935	18,325	8,614	3,660	620	350	3,276	477

Table 4.11 Waste classification of enhancing recycling method with 70% recovery for non-hazardous waste

Waste Type	Treatment and Disposal Code									
	11	41	42	44	49	71	73	75	76	82
14	5,850			50	1,120					
12	6,540				12					
17	550		100							
18		250	90		185					
6			100		273					
19		70	100		81					
20	90									
16	70									
9					15					
10					4					
Total (tons)	13,100	320	390	50	1,690	75	6	36	34	480

4.8.1 <u>The MFA of Enhancing Recycling Method with 70% Recovery</u>

The waste management flow route in this section was calculated by the amount of wastes that were sent to treat with recycling method (Code 49) and reclamation or regeneration of metal and metal compound (Code 52) at recycling rate 70% recovery and the rests accounting for (30%) were sent to dispose of by the original disposal method. The waste flow route of hazardous wastes are shown in Figure 4.21 and non-hazardous wastes in Figure 4.22, respectively.

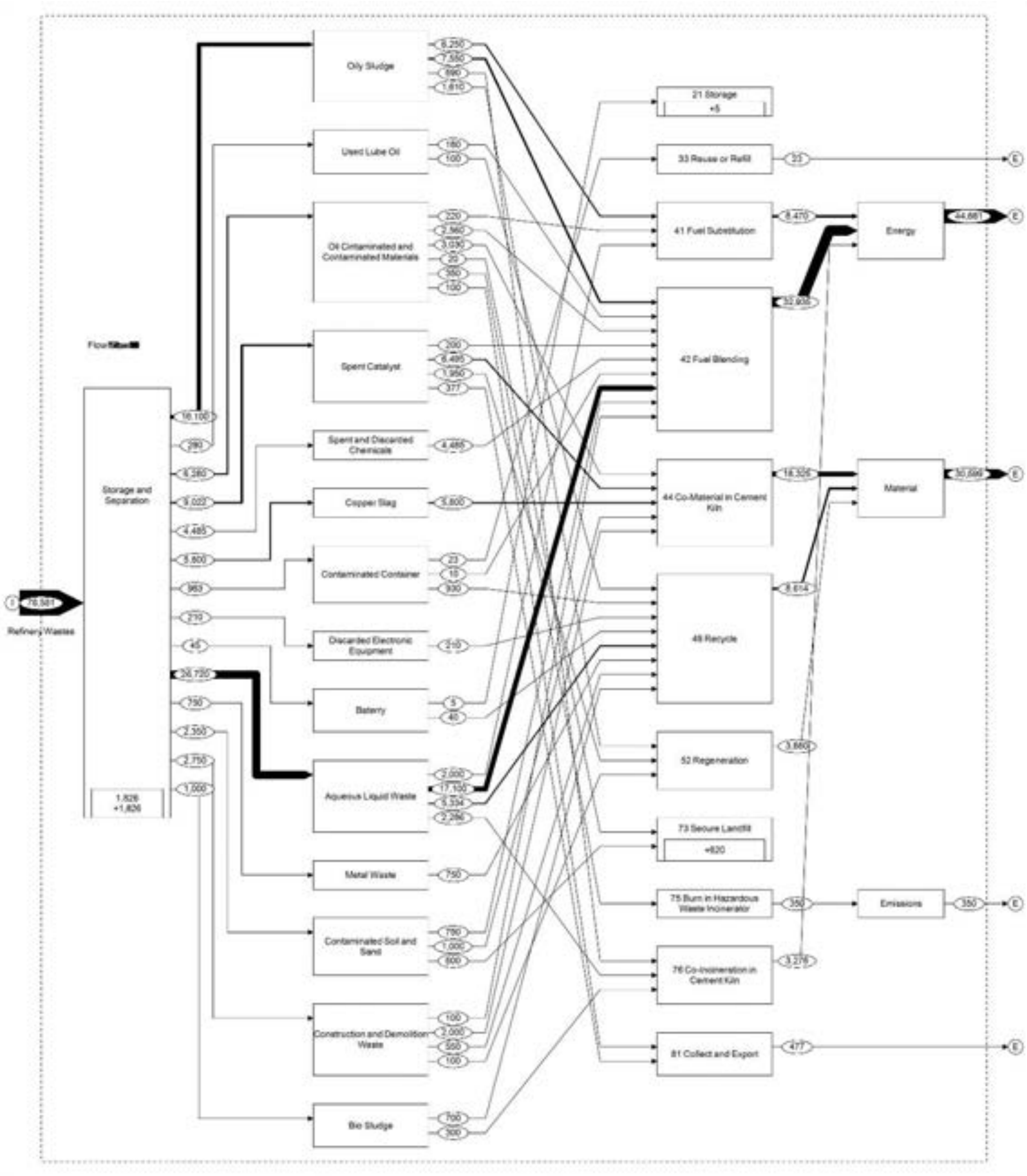

Figure 4.21 Material flow analysis of the enhancing of recycling method with 70% recovery for hazardous wastes (ton/year).

Form Figure 4.21, the hazardous wastes were mostly disposed of as the energy recovery, about 44,681 tons and followed by the material recovery, about 30,599 tons and discharged as emissions, about 350 tons. The rests were sent to treat by reuse or refill method, about 23 tons and collect and export, about 477 tons.

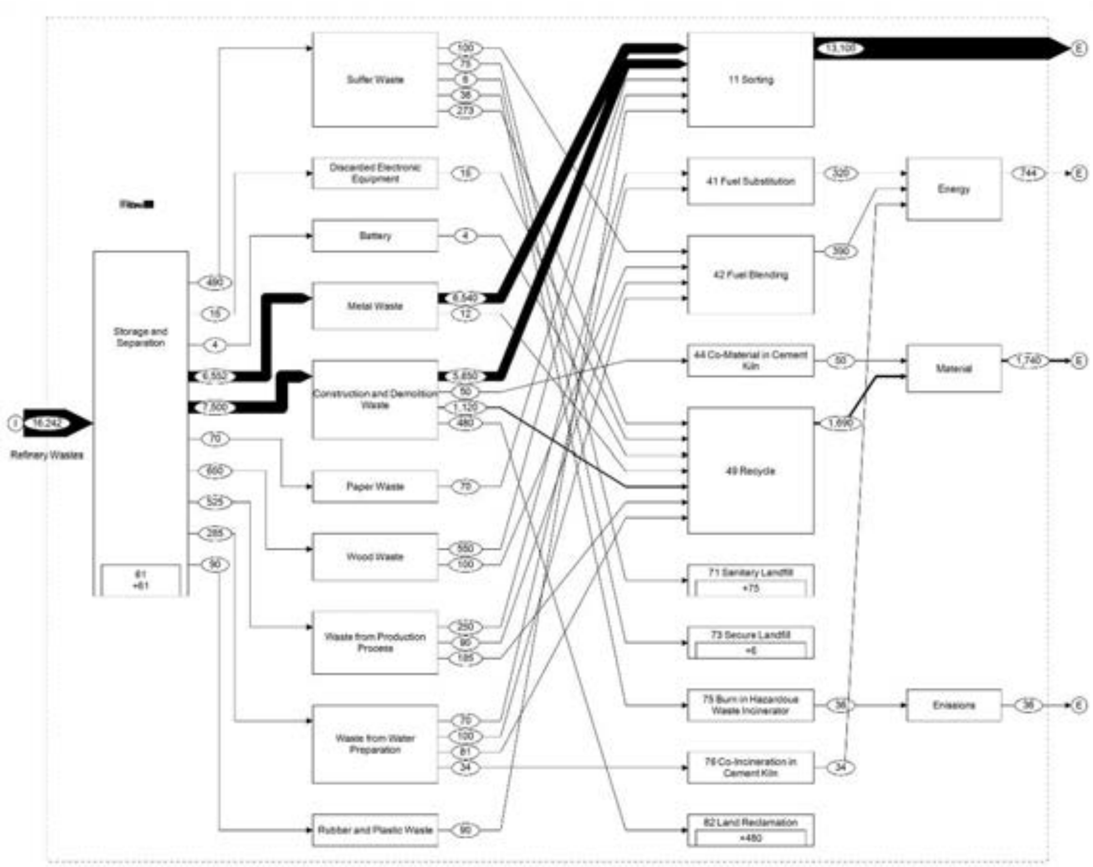

Figure 4.22 Material flow analysis of the enhancing of recycling method with 70% recovery for non-hazardous wastes (ton/year).

In Figure 4.21, the non-hazardous wastes were mainly sent to dispose of by the material recovery, about 1,740 tons, energy recovery, about 744 tons, and emissions 36 tons. Most of the non-hazardous wastes were treated by sorting method, which is about 13,100 tons.

4.8.2 The Environmental Impacts of the Enhancing Recycling Method with 70% Recovery for Hazardous Wastes (Hz-RC 70%) Compared with 100% Recovery (Hz-RC)

The scenario of hazardous wastes management that were recycled with 70% recycling rate were used to conducted the environmental impacts in order to compare the results with 100% recycling rate as shown in Figures 4.23 to 4.26 for global warming potential (GWP 100a), human toxicity, terrestrial toxicity, and acidification potential impacts, respectively.

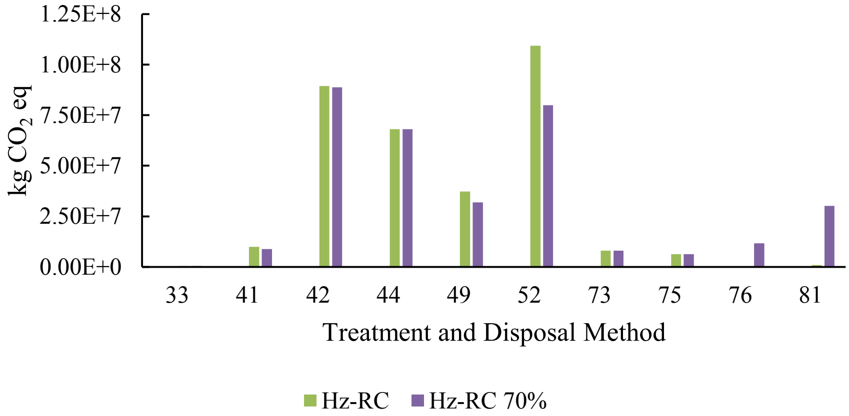

Figure 4.23 Global warming (GWP 100a) (kg CO_2 eq) of each treatment and disposal method by recycled with 70% recovery for hazardous wastes.

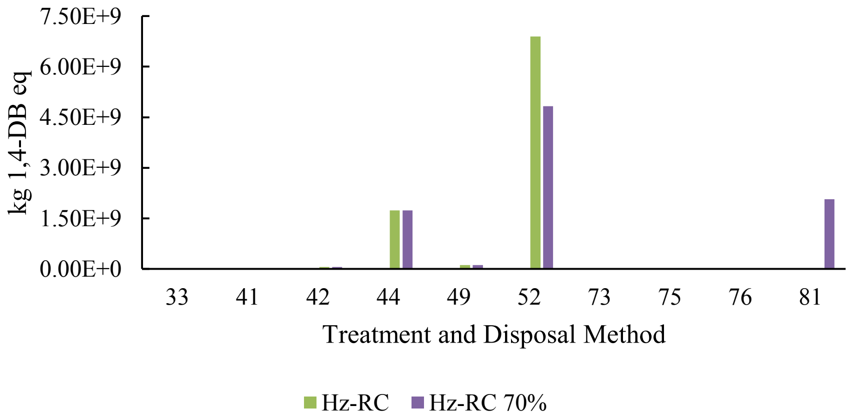

Figure 4.24 Human toxicity (kg 1,4-DB eq) of each treatment and disposal method by recycled with 70% recovery for hazardous wastes.

The environmental impacts of hazardous wastes in Figures 4.23 to 4.26 showed that most of the environmental impacts from recycling method (Code 49) and reclamation or regeneration of metal and metal compound method (Code 52) with 70% recycling rate were lower than recycling method with 100% while the most total emissions that were generated from 70% recycling rate were higher than 100% recycling rate (Appendix F). The high impact value of collecting and exporting method (Code 81) was generated from the recycling of spent catalyst waste. The high global warming of co-incineration in cement kiln method (Code 76) was generated from its incineration process and aquos liquid waste (Appendix G).

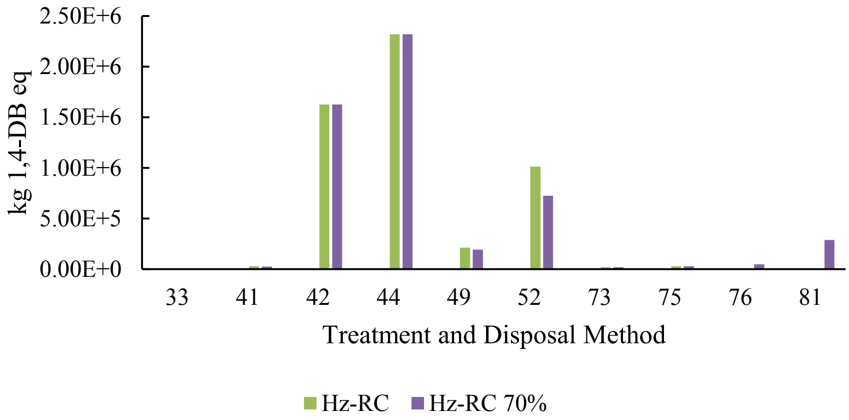

Figure 4.25 Terrestrial toxicity (kg 1,4-DB eq) of each treatment and disposal method by recycled with 70% recovery for hazardous wastes.

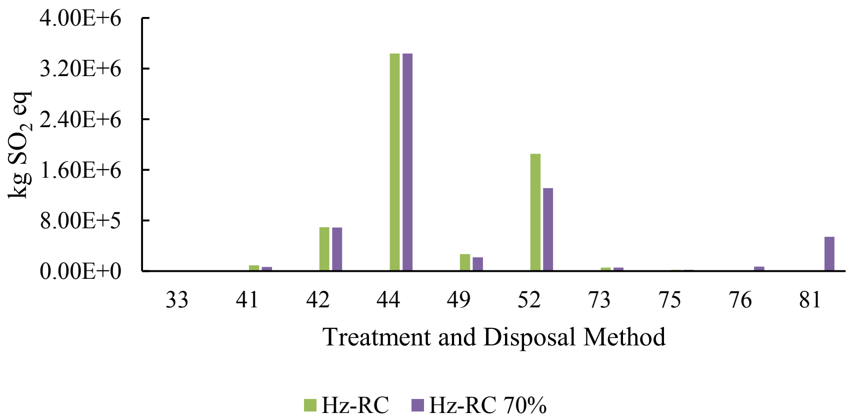

Figure 4.26 Acidification (kg SO_2 eq) of each treatment and disposal method by recycled with 70% recovery for hazardous wastes.

4.8.3 The Environmental Impacts of The Enhancing Recycling Method with 70% Recovery for Non-Hazardous Wastes (Non-Hz-RC 70%) Compared with 100% Recovery (Non-Hz-RC)

The environmental impacts of non-hazardous wastes scenario that were recycled at 70% recovery were evaluated the environmental impacts as displayed in Figures 4.27 to 4.30 for global warming potential (GWP 100a), human toxicity, terrestrial toxicity, and acidification potential impacts, respectively.

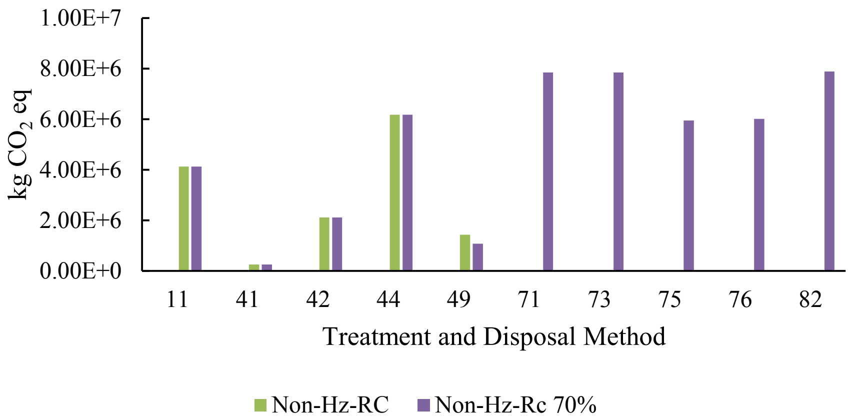

Figure 4.27 Global warming (GWP 100a) (kg CO_2 eq) of each treatment and disposal method by recycled with 70% recovery for non-hazardous wastes.

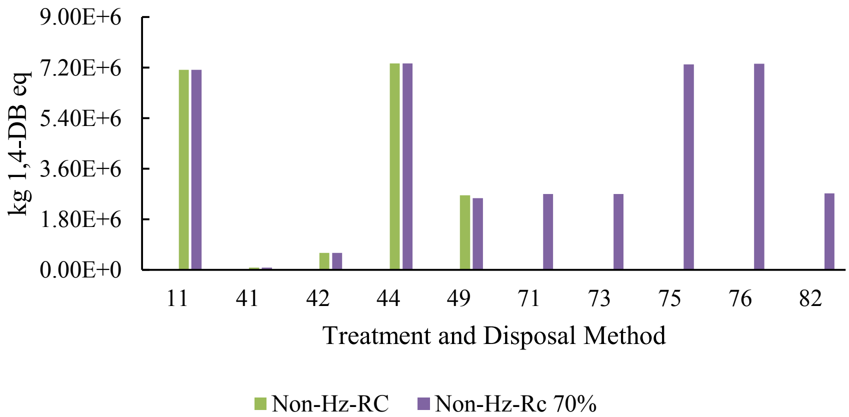

Figure 4.28 Human toxicity (kg 1,4-DB eq) of each treatment and disposal method by recycled with 70% recovery for non-hazardous wastes.

From Figures 4.27 to 4.30, the environmental impacts from recycling method (Code 49) with 70% recycling rate were lower than 100% while the wastes that were sent to disposed of by sanitary landfill method (Code 71), secure landfill of stabilized and/or solidified wastes method (Code 73), burning in hazardous waste incinerator method (Code 75), co-incineration in cement kiln method (Code 76), and land reclamation method (Code 82) were high impact value due to the 30% of the waste still was disposed of by original method. Moreover, the total impact value of non-hazardous wastes in each category for 70% recycling rate was higher than 100% (Appendix F).

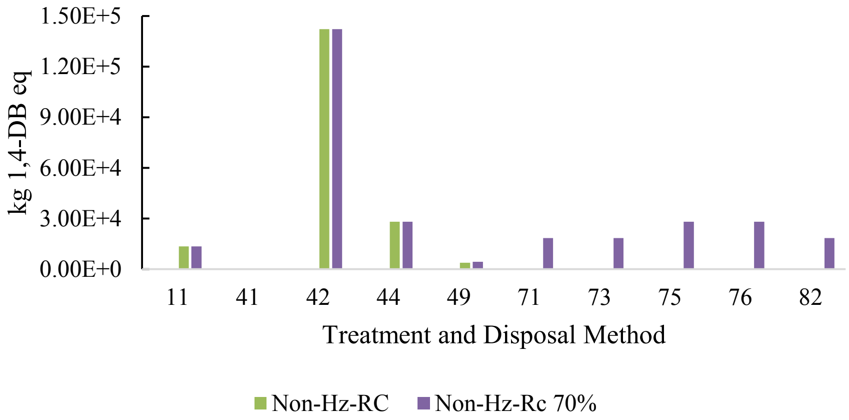

Figure 4.29 Terrestrial toxicity (kg 1,4-DB eq) of each treatment and disposal method by recycled with 70% recovery for non-hazardous wastes.

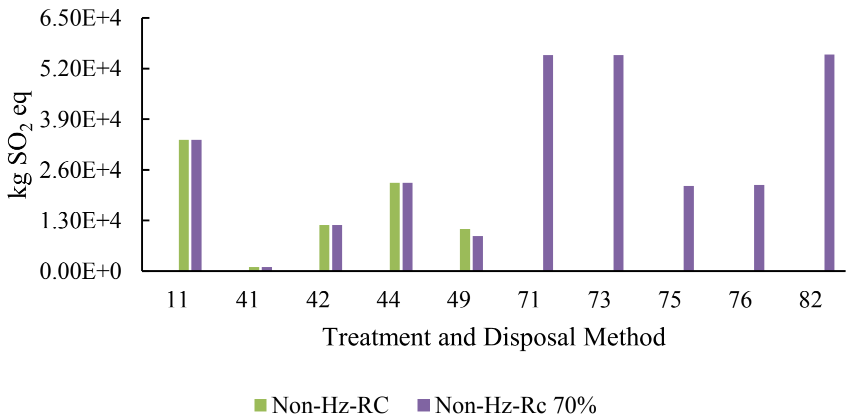

Figure 4.30 Acidification (kg SO_2 eq) of each treatment and disposal method by recycled with 70% recovery for non-hazardous wastes.

From the recycling method at 70% recycling rate of both hazardous wastes and non-hazardous wastes, it was found that the increase of amount of wastes in disposal process was generated more environmental impacts. The total impact value of hazardous wastes of 70% recycling rate was not much higher impact than 100% sucha as global warming potential value increased about 1.29%. In case of non-hazardous waste, the total impact value of 70% recycling rate was greatly higher impact than 100% sucha as global warming potential value increased about 249.52%.

4.8.4 The Comparing of Enhancing Recycling Method with 70% Recovery by Considering the Functional Unit with Ton of Wastes

The environmental impacts of refinery wastes from the previous section were evaluated with the total amount of hazardous wastes or non-hazardous waste as the functional unit. In order to compare the environmental impacts with the same amount, this section conducted using enhancing recycling method with 100% and 70% recycling rate to illustrate the impacts of each waste treatment and disposal method with one ton of waste. In addition, it was also calculated the environmental impacts from the treatment process for recycling method (Code 49), reclamation or regeneration of metal and metal compound method (Code 52) and collecting and exporting method (Code 81) or it was defined as the offset ooption.

4.8.4.1 The Comparing of Enhancing Recycling Method with 70% Recovery by Considering the Functional Unit with Ton of Wastes for Hazardous Wastes

The environmental impacts of hazardous wastes using functional unit with ton of wastes as in Figures 4.31 to 4.34 for global warming (GWP 100a), human toxicity, terrestrial toxicity, and acidification, respectively, were calculated with the 100% (Hz-RC) and 70% (Hz-RC 70) recycling rate. The environmental impacts from each process were assumed recycling rate at 70% recycling rate (Hz-Rc 70 offset).

From Figures 4.31 to 4.34, the environmental impacts with the functional unit of one ton of waste were not different for 100% and 70% recycling rate, exempt for the collect and export method (Code 81) which was indicated the impacts for 70% recycling rate due to the fact that the spent catalyst still are disposed of by these methods. After calculating the impacts from the process, it was found that the environmental impacts were greatly reduced for recycling method (Code 49) and reclamation or regeneration of metal and metal compound (Code 52) and disposal by collecting and exporting method (Code 81). Moreover, the high impact of treatment Code 52 for both of 100% and 70% recycling rate was generated from the treatment of spent catalyst that was sent to treat by this method.

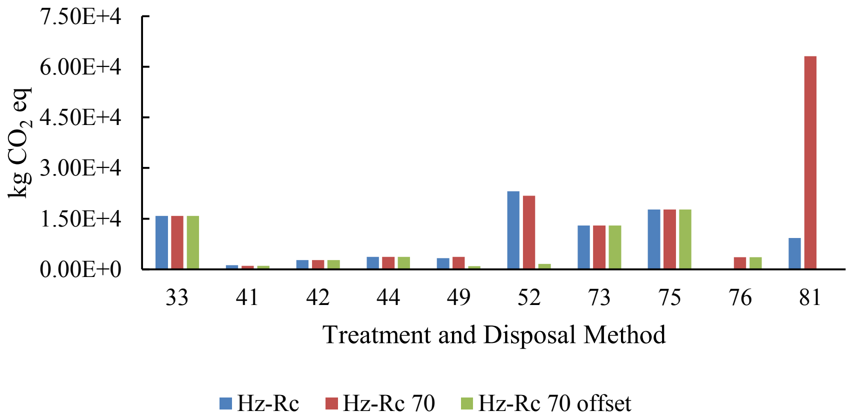

Figure 4.31 Global warming (GWP 100a) (kg CO_2 eq) of each treatment and disposal method by enhancing recycling method with 100% and 70% recovery for hazardous wastes using the functional unit with one ton of waste.

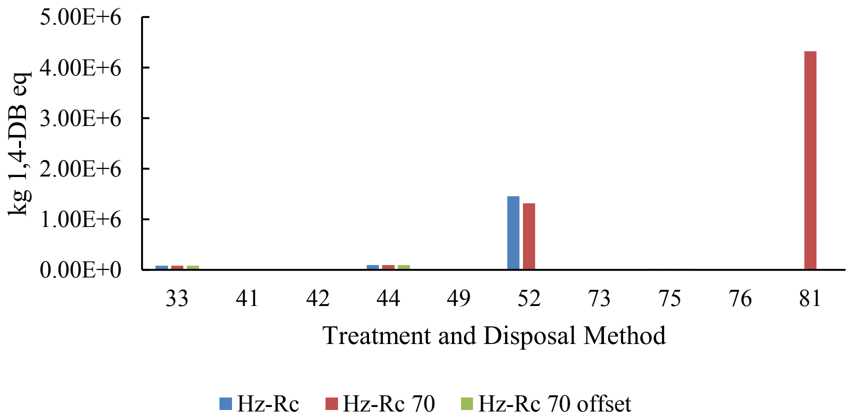

Figure 4.32 Human toxicity (kg 1,4-DB eq) of each treatment and disposal method by enhancing recycling method with 100% and 70% recovery for hazardous wastes using the functional unit with one ton of waste.

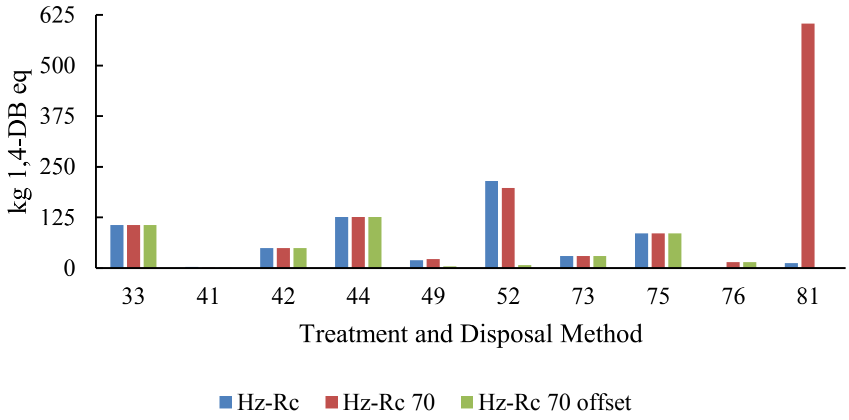

Figure 4.33 Terrestrial toxicity (kg 1,4-DB eq) of each treatment and disposal method by enhancing recycling method with 100% and 70% recovery for hazardous wastes using the functional unit with one ton of waste.

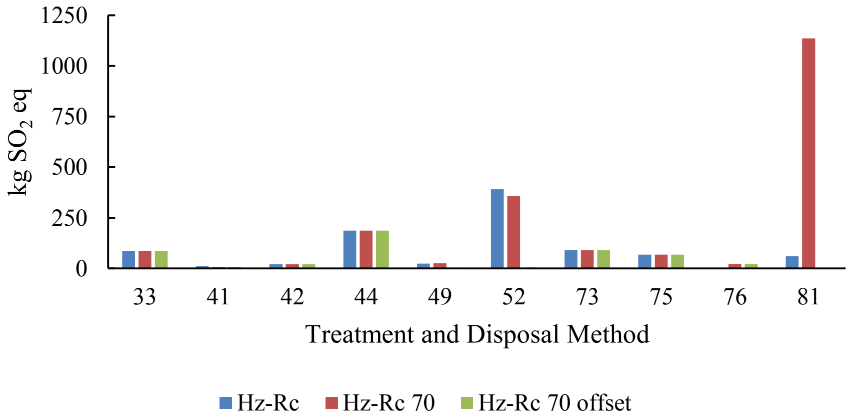

Figure 4.34 Acidification (kg SO_2 eq) of each treatment and disposal method by enhancing recycling method with 100% and 70% recovery for hazardous wastes using the functional unit with one ton of waste.

4.8.4.2 The Comparing of Enhancing Recycling Method with 70% Recovery by Considering the Functional Unit with Ton of Wastes for Non-Hazardous Wastes

The environmental impacts from recycling with 100% (Non-Hz-Rc) and 70% (Non-Hz-RC 70) recovery and process (Non-Hz-Rc 70 offset) were displayed in Figure 4.35, 4.36, 4.37, and 4.38 for global warming (GWP 100a), human toxicity, terrestrial toxicity, and acidification, respectively.

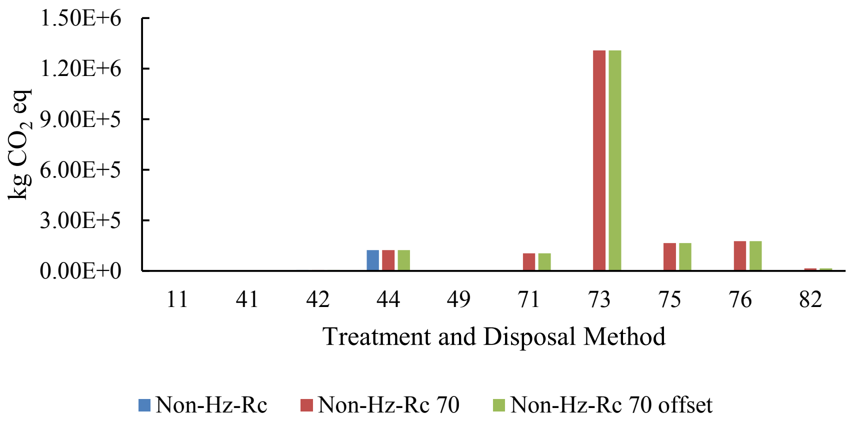

Figure 4.35 Global warming (GWP 100a) (kg CO_2 eq) of each treatment and disposal method by enhancing recycling method with 100% and 70% recovery for non-hazardous wastes using the functional unit with one ton of waste.

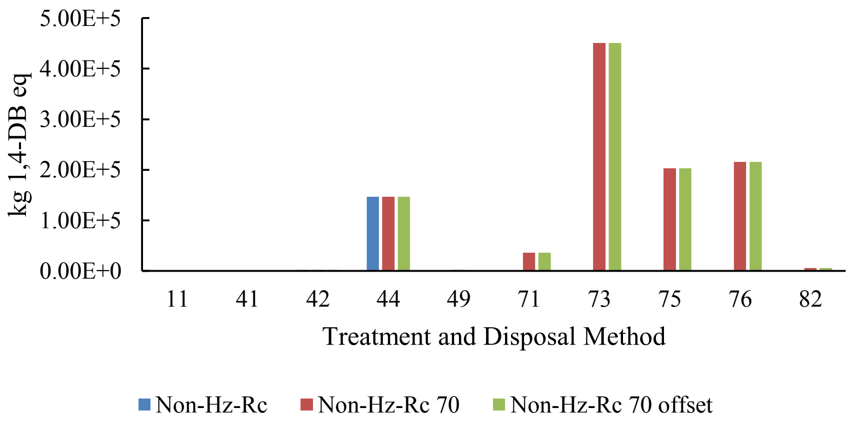

Figure 4.36 Human toxicity (kg 1,4-DB eq) of each treatment and disposal method by enhancing recycling method with 100% and 70% recovery for non-hazardous wastes using the functional unit with one ton of waste.

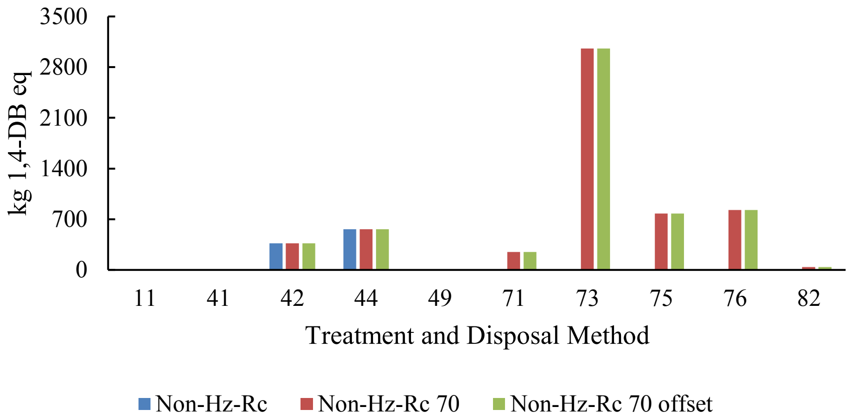

Figure 4.37 Terrestrial toxicity (kg 1,4-DB eq) of each treatment and disposal method by enhancing recycling method with 100% and 70% recovery for non-hazardous wastes using the functional unit with one ton of waste.

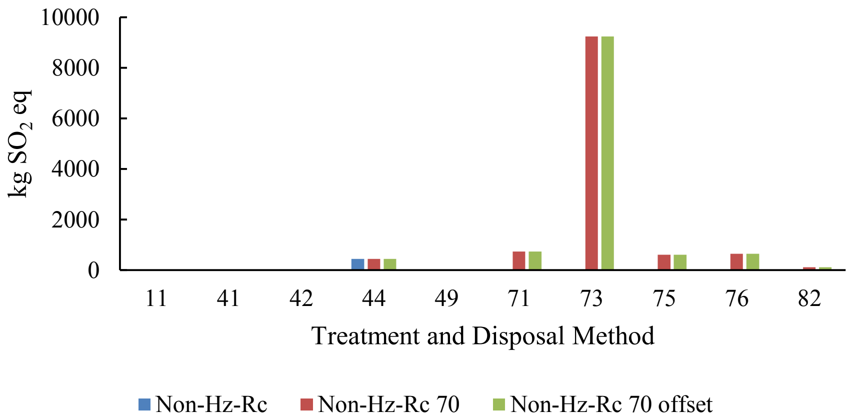

Figure 4.38 Acidification (kg SO_2 eq) of each treatment and disposal method by enhancing recycling method with 100% and 70% recovery for non-hazardous wastes using the functional unit with one ton of waste.

Figures 4.35 to 4.38 showed that the impacts from the recycling scenario with 70% recycling rate were high value even though the amount of wastes were low. Moreover, the highest impact of total categories was generated from the secure landfill of stabilized and/or solidified wastes method (Code 73). In case of the environmental impacts of the recycling method (Code 49), the impacts were reduced compared the recycling with 100% to 70% recycling rate.

Moreover, the waste management by enhancing recycling method scenario with 70% recycling rate for hazardous wastes seemed to be similar value of global warming potential with household hazardous waste management (Fikri E. *et al.*, 2015) when comparing with the functional unit ton of waste, except the global warming potential value of 100% recycling rate was lower.

The MFA and LCA analysis results for both hazardous wastes and non-hazardous wastes found that the waste characteristics and the treatment and disposal process had direct impacts on the environment. In order to reduce the environmental impacts, the use of waste hierarchy management can help to prevent the waste disposal which was high impacts than waste treatment. Therefore, it is necessary to select the treatment and disposal method that is suitable with the waste characteristic in order to reduce the environmental impacts.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The petroleum refinery wastes have various types and characteristics. This work, they were classified into hazardous wastes (76,755 tons) and non-hazardous wastes (16,181 tons). They need to manage properly through appropriate treatment and disposal methods to prevent their adverse impacts on the environments. Therefore, the objectives of this study were to evaluate the waste flow at the end-of-life and environmental impacts of the waste management options using material flow analysis (MFA) and life cycle assessment (LCA) as an assessment tool. The petroleum refinery wastes were separated into 20 categories and treated and disposed by 11 codes according to the data obtained from DIW. Both hazardous and non-hazardous waste treatment schemes were developed into 3 options, which are the base case or current waste disposal, zero wastes to landfill and reduce burning in the incinerator and enhancing recycling scheme.

The results from MFA using STAN software can clearly illustrate the waste flow of those 3 treatment options. For hazardous wastes, the waste management strategy of all three scenarios was mostly treated and obtained finally as energy. In the case of non-hazardous wastes, the favorable treatment method for the three options was sorting method. In addition, zero waste to landfill and incinerator option can decrease the wastes that were disposed of as emissions for hazardous wastes and greatly increased for the wastes theat sent to treat as material for non-hazardous. In case of enhancing recycling method, the final treatment of both hazardous and non-hazardous wastes that were obtained as material were increase. For enhancing recycling method with 70% recycling rate, both of hazardous and non-hazardous waste was increased the wastes that were sent to treat as energy and reduced the wastes that were sent to treat as material.

The environmental impacts from the petroleum refinery waste disposal were evaluated by LCA using SimaPro software as a tool. The results indicated that the base case and zero wastes to landfill and reduce burning in incinerator were not significantly different. For the waste management by enhancing recycling method, the impacts significantly reduced for both hazardous wastes and nonhazardous wastes.

Therefore, in order to reduce the environmental impact, the waste should be treated by the recycling method. Although the fuel blending method (Code 42) and co-material in cement kiln (Code 44) presented high impact value in some impact categories such as the global warming impact, terrestrial toxicity impact, and acidification potential but the total impact value of these methods are found to be less impact contributing to the environments and human health.

5.2 Recommendations

This study can be applied to other industries to manage the wastes with the proper method using LCA results to minimize the environmental impacts. Although the recycling option indicated a potential reduction in environmental impacts, the cost of treatment and disposal need to be further evaluated.

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APPENDICES

Appendix A The Petroleum Refinery Wastes in Thailand (2015)

The data of petroleum refinery waste obtained from 6 refineries in Thailand (2015) in Table A which compose of many issues such as waste characteristic (hazardous/non-hazardous waste), waste name, waste volume, and disposal code.

Where No. 1 = Storage in the refinery

No. 2 = Send to treatment plant or disposal

Hz = Hazardous waste

Non-Hz = Non-Hazardous waste

Table A1 The petroleum refinery waste data from Refinery A

No.	Hz/Non-HZ	Waste Code	Waste Name	Vol. (tons)	Disposal code
1	Hz	05 01 15	Spent clay	5	-
1	Hz	15 01 10	Contaminated material	3	-
1	Hz	15 02 02	Inert ball	30	-
1	Hz	15 02 02	Oil contaminated waste	1	-
1	Hz	16 06 01	Battery	4	-
1	Non-Hz	16 08 01	R-234 ccr catalyst	50	-
1	Hz	16 08 02	Activated alumina	40	-
1	Hz	16 08 02	Spent como catalyst	950	-
1	Hz	16 08 02	Spent nimo catalyst	20	-
1	Hz	17 06 03	Insulation	3	-
2	Hz	05 01 03	Oil sludge	2400	42
2	Non-Hz	05 01 14	Cooling tower packing	20	71
2	Hz	05 01 15	Spent clay	790	44
2	Non-Hz	05 01 16	Solid sulfur	200	71
2	Non-Hz	05 01 99	Agglomerated coke	40	42
2	Hz	13 02 06	Used lube oil	60	42
2	Non-Hz	15 01 03	Wood from construction	20	11
2	Hz	15 01 10	Contaminated material (บรรจุภัณฑ์ปนเปื้อน)	400	73
2	Hz	15 01 10	Empty cylinder	20	73
2	Hz	15 01 10	Empty drum	200	73
2	Hz	15 02 02	Activated carbon	90	42

Table A1 The petroleum refinery waste data from Refinery A (continued)

No.	Hz/Non-HZ	Waste Code	Waste Name	Vol. (tons)	Disposal code
2	Hz	15 02 02	Inert ball	120	44
2	Hz	15 02 02	Oil contaminated waste	200	42
2	Hz	15 02 02	Spent mercury absorbent	20	73
2	Hz	16 02 15	Used fluorescent lamp	10	73
2	Hz	16 05 06	Lab waste	10	73
2	Hz	16 05 08	Expired chemical	80	42
2	Hz	16 06 01	แบตเตอรี่เก่า	30	49
2	Non-Hz	16 06 04	Alkaline battery	4	73
2	Hz	16 08 02	Activated alumina	515	44
2	Hz	16 08 02	Cobalt Molybdenum (como) Type A (Used Catalyst KF-757)	40	81
2	Hz	16 08 02	R-234 ccr catalyst	50	81
2	Hz	16 08 02	Spent kf757 catalyst	636	81
2	Hz	16 08 02	Zeolite catalyst (em 1800)	40	81
2	Hz	16 08 07	Spent FCCU catalyst	750	44
2	Hz	16 08 07	Spent fccu catalyst	1500	44
2	Hz	16 08 07	Spent fccu catalyst	400	73
2	Hz	16 10 01	น้ำจากระบบบำบัดชีวภาพ	7200	42
2	Non-Hz	17 01 03	Concrete, Brick, Tiles and Ceramic	500	71
2	Non-Hz	17 02 01	Wood from construction	20	11
2	Non-Hz	17 02 01	Wood from Construction	40	71
2	Non-Hz	17 04 05	Scrap metal	2000	11
2	Non-Hz	17 04 07	Scrap metal	1150	11
2	Hz	17 04 09	Contaminated scrap metal	100	73
2	Hz	17 05 03	Contaminated soil	100	42
2	Hz	17 05 03	Soil contaminated sulfur	600	73
2	Hz	17 06 03	Insulation	200	73
2	Hz	17 06 05	วัสดุก่อสร้างที่มีแร่ใยหิน (Construction materials containing Asbestos)	60	73
Total (tons)				21721	-

Table A2 The petroleum refinery waste data from Refinery B

No.	Hz/Non-HZ	Waste Code	Waste Name	Vol. (tons)	Disposal code
1	Non-Hz	05 01 16	Contaminated sulphur	10	-
1	Hz	12 01 16	Copper slag	10	-
1	Hz	15 01 10	Contaminate bottle glass	8	-
1	Hz	15 01 10	Contaminated painting can	0.7	-
1	Hz	16 02 13	Electronics from office	1.7	-
1	Hz	16 02 15	Fluorescent lamps	6.6	-
1	Hz	16 05 06	Mixed chemical waste	2	-
1	Non-Hz	17 02 01	Wood	0.5	-
1	Hz	19 02 11	Coke	0.2	-
2	Hz	05 01 06	Oily sludge	500	42
2	Hz	05 01 06	Oily sludge	200	75
2	Hz	05 01 15	Spent filter clay	300	44
2	Hz	05 01 15	Spent filter clay	300	44
2	Non-Hz	05 01 16	Contaminated sulphur	70	75
2	Non-Hz	05 01 99	Coke	200	41
2	Hz	12 01 16	Copper slag	100	44
2	Hz	12 01 16	Copper slag	200	44
2	Hz	15 01 10	Contaminated painting can	10	73
2	Hz	15 02 02	Ceramic ball	150	44
2	Hz	15 02 02	Ceramic ball	150	44
2	Hz	15 02 02	Ceramic ball	100	44
2	Hz	15 02 02	Chloride guard	200	75
2	Hz	15 02 02	Contaminated material	150	42
2	Hz	15 02 02	Spent activated carbon	1000	42
2	Hz	16 02 15	Fluorescent lamps	5	73
2	Hz	16 02 15	เศษชิ้นส่วนอิเล็กทรอนิกส์ที่ไม่ใช้งานแล้ว	10	49
2	Hz	16 05 06	Mixed chemical waste	5	42
2	Hz	16 08 02	Spent KF757H Catalyst and KF758 Catalyst from HDS 2,3 Unit	250	81
2	Hz	16 08 07	High temp shift spent catalyst	50	44
2	Hz	16 08 07	R-264 reformer catalyst (ccr-1, ccr-2)	37	81
2	Hz	16 08 07	Spent sru catalyst	70	75
2	Hz	16 10 01	Wastewater or Oily Water	10	76
2	Hz	16 10 01	Wastewater or Oily Water	10	76
2	Hz	16 11 05	Refractory brick	200	44
2	Hz	16 11 05	Refractory brick	200	44
2	Non-Hz	17 02 01	Wood	100	42
2	Non-Hz	17 04 05	Metal scrap	500	11
2	Non-Hz	17 04 05	Metal scrap	500	11

Table A2 The petroleum refinery waste data from Refinery B (continued)

No.	Hz/Non-HZ	Waste Code	Waste Name	Vol. (tons)	Disposal code
2	Non-Hz	17 04 05	Metal scrap	100	11
2	Hz	17 05 03	Contaminated sand/stone	500	42
2	Hz	17 05 03	Contaminated sand/stone	200	44
2	Hz	17 05 03	Contaminated sand/stone	100	44
2	Non-Hz	17 06 04	Insulation	200	71
2	Non-Hz	19 09 05	Spent resin	10	41
2	Non-Hz	19 09 05	Spent resin	10	76
Total (tons)				6736.7	-

Table A3 The petroleum refinery waste data from Refinery C

No.	Hz/Non-HZ	Waste Code	Waste Name	Vol. (tons)	Disposal code
1	Non-Hz	12 01 17	ทรายขัดผิวใช้งานแล้ว	0.5	-
1	Hz	13 02 08	Used oil	10	-
Total (tons)				10.5	-

Table A4 The petroleum refinery waste data from Refinery D

No.	Hz/Non-HZ	Waste Code	Waste Name	Vol. (tons)	Disposal code
1	Hz	15 02 02	Spent salt	50	-
1	Hz	16 08 07	Spent Catalyst from HCU and NPU	313	-
1	Hz	16 08 07	Spent Catalyst from GO-HDS and DGO-HDS	368	-
2	Hz	05 01 03	Tank bottom sludge	100	42
2	Hz	05 01 06	Oily sludge	500	42
2	Hz	05 01 09	Wwtu sludge	50	42
2	Hz	05 01 09	Wwtu sludge	50	42
2	Hz	05 01 09	Wwtu sludge	300	76
2	Hz	05 01 11	Spent caustic	100	42
2	Non-Hz	05 01 16	Sulfur containing waste	100	42
2	Hz	13 02 08	น้ำมันหล่อลื่นใช้แล้ว	20	42
2	Hz	15 01 10	Contaminated container	10	42
2	Hz	15 01 10	ถังเหล็ก 200 ลิตร	60	49

Table A4 The petroleum refinery waste data from Refinery D (continued)

No.	Hz/Non-HZ	Waste Code	Waste Name	Vol. (tons)	Disposal code
2	Hz	15 02 02	Contaminated material	150	42
2	Hz	15 02 02	Spent salt	70	44
2	Hz	16 02 13	อุปกรณ์อิเล็กทรอนิกส์เสื่อมสภาพ	10	49
2	Hz	16 02 15	หลอดไฟเสื่อมสภาพ	5	49
2	Non-Hz	16 02 16	เศษสายไฟ	15	49
2	Hz	16 03 03	สารเคมีใช้งานแล้ว	30	42
2	Hz	16 06 01	แบตเตอรี่ใช้แล้ว	5	21
2	Hz	16 07 09	Wastewater treatment	500	75
2	Hz	16 08 02	Spent Catalyst for 2R-3701	54	81
2	Hz	16 08 02	Spent Catalyst for 3R-3701	116	81
2	Hz	16 08 02	Spent Catalyst for HCU (UF-210-1.3Q STARS CATALYST)	14	81
2	Hz	16 08 02	Spent catalyst รวม ceramic ball	200	42
2	Hz	16 08 02	Spent catalyst รวม ceramic ball	350	44
2	Hz	16 10 01	Chemical wastewater	100	42
2	Hz	16 10 01	Chemical wastewater	600	76
2	Hz	16 11 05	Refractory	150	44
2	Non-Hz	17 01 01	เศษคอนกรีตไม่ปนเปื้อน	800	82
2	Non-Hz	17 01 01	เศษปูนไม่ปนเปื้อน	800	82
2	Non-Hz	17 04 02	อลูมิเนียม	12	49
2	Hz	17 04 09	เศษเหล็ก 106	600	49
2	Non-Hz	17 06 04	Insulation	50	44
2	Non-Hz	17 06 04	Insulation	150	71
2	Non-Hz	19 09 04	Activated carbon	100	42
Total (tons)				6902	-

Table A5 The petroleum refinery waste data from Refinery E

No.	Hz/Non-HZ	Waste Code	Waste Name	Vol. (tons)	Disposal code
2	Hz	05 01 09	Oily sludge	500	42
2	Hz	05 01 09	Oily sludge	1000	76
2	Hz	05 01 09	Oily sludge	1000	76
2	Hz	05 01 15	Spent clay	500	44

Table A5 The petroleum refinery waste data from Refinery E (continued)

No.	**Hz/Non-HZ**	**Waste Code**	**Waste Name**	**Vol. (tons)**	**Disposal code**
2	Non-Hz	05 01 16	Sulfur scrubber waste	50	75
2	Non-Hz	05 01 99	Coke	50	41
2	Hz	06 02 04	Spent caustic	500	42
2	Hz	06 02 04	Spent caustic	3500	42
2	Hz	12 01 16	Copper slag	2000	44
2	Hz	12 01 16	Copper slag	2000	44
2	Hz	13 02 08	Used lube oil	100	42
2	Non-Hz	15 01 01	เศษกระดาษ	10	11
2	Non-Hz	15 01 01	เศษพลาสติก	10	11
2	Non-Hz	15 01 03	เศษไม้	20	11
2	Non-Hz	15 01 03	เศษไม้	50	11
2	Non-Hz	15 01 04	Empty contaminated drum	5	49
2	Hz	15 01 10	Empty contaminated drum	3	33
2	Hz	15 02 02	Activated carbon	100	41
2	Hz	15 02 02	Activated carbon	100	42
2	Hz	15 02 02	Spent chloride absorbent	150	75
2	Hz	15 02 02	Spent mercury absorbent	100	81
2	Non-Hz	15 02 03	Industrial oily debris	50	42
2	Hz	16 02 15	Used fluorescent	0.5	49
2	Hz	16 07 08	Oily tank cleaning	4500	42
2	Hz	16 07 08	Oily tank cleaning	1500	42
2	Hz	16 07 08	Oily tank cleaning	1500	76
2	Hz	16 07 08	Oily tank cleaning	3000	76
2	Hz	16 08 02	Zinc spent catalyst	20	81
2	Hz	16 08 07	Activated alumina	300	44
2	Hz	16 10 01	Condensate oil	1500	42
2	Hz	16 10 01	Condensate oil	1000	76
2	Hz	16 10 01	Condensate oil	1000	76
2	Hz	16 11 05	Refractory brick	100	44
2	Hz	16 11 05	Refractory brick	100	44
2	Non-Hz	17 04 07	เศษโลหะ	200	11
2	Non-Hz	17 04 07	เศษโลหะ	200	11
2	Non-Hz	17 04 07	เศษโลหะ	100	11
2	Hz	17 04 09	Stainless steel contaminated carbon	50	49
2	Hz	17 05 03	Industrial oily debris	100	42
2	Hz	17 05 03	Industrial oily debris	50	42
2	Hz	17 05 03	Oily sand	350	44

Table A5 The petroleum refinery waste data from Refinery E (continued)

No.	Hz/Non-HZ	Waste Code	Waste Name	Vol. (tons)	Disposal code
2	Hz	17 05 03	Oily sand	350	44
2	Hz	17 06 03	Insulation	100	42
2	Non-Hz	19 09 05	Ion exchange	60	41
2	Non-Hz	19 09 05	Ion exchange	5	76
Total (tons)				27883.5	-

Table A6 The petroleum refinery waste data from Refinery F

No.	Hz/Non-HZ	Waste Code	Waste Name	Vol. (tons)	Disposal code
2	Hz	05 01 06	Oily sludge	1500	41
2	Hz	05 01 06	Oily sludge	750	41
2	Hz	05 01 06	Oily sludge	1650	42
2	Hz	05 01 06	Oily sludge	500	42
2	Hz	05 01 06	Waste oily sludge	1100	42
2	Hz	05 01 09	Dry basin sludge(wet)	2000	41
2	Hz	05 01 09	Dry basin sludge	2000	41
2	Non-Hz	05 01 16	Sulfur waste	50	71
2	Non-Hz	05 01 16	Sulfur waste	20	73
2	Hz	05 07 01	Spent Catalyst (Mercury spent adsorbent)	100	52
2	Hz	07 01 10	Coke	20	41
2	Hz	12 01 16	Copper slag	1500	44
2	Hz	13 02 08	Used lube oil	100	49
2	Non-Hz	15 01 01	เศษบรรจุภัณฑ์กระดาษ	50	11
2	Non-Hz	15 01 03	เศษไม้	400	11
2	Hz	15 01 10	Empty contaminated container	20	33
2	Hz	15 01 10	Empty contaminated container	20	49
2	Hz	15 01 10	Empty contaminated container	50	73
2	Hz	15 01 10	Empty contaminated container	100	73
2	Hz	15 01 10	Empty contaminated lab bottles	20	73
2	Hz	15 01 10	Empty contaminated lab bottles	50	73
2	Hz	15 02 02	Activated carbon	100	41
2	Hz	15 02 02	Activated carbon	20	42
2	Hz	15 02 02	Activated carbon	50	42
2	Hz	15 02 02	Industrial oily debris	50	42

Table A6 The petroleum refinery waste data from Refinery F (continued)

No.	Hz/Non-HZ	Waste Code	Waste Name	Vol. (tons)	Disposal code
2	Hz	15 02 02	Industrial oily debris	100	42
2	Hz	15 02 02	Industrial oily Debris	200	42
2	Hz	15 02 02	Oily contaminated soil and gravel	200	42
2	Hz	15 02 02	Oily sand	100	42
2	Hz	15 02 02	Oily sand	450	44
2	Hz	15 02 02	Oily sand	100	44
2	Hz	15 02 02	Spent activated carbon	100	42
2	Hz	15 02 02	Spent amine filter	50	42
2	Non-Hz	15 02 03	Air filter from gt	50	71
2	Non-Hz	15 02 03	RO membrane	100	71
2	Non-Hz	15 02 03	Ro. Membrane	10	71
2	Hz	16 02 13	Electronic waste	20	73
2	Hz	16 02 13	Electronic waste	100	73
2	Hz	16 02 15	Fluorescent lamp	50	73
2	Hz	16 05 08	Asphalt	20	42
2	Hz	16 05 08	Asphalt	200	42
2	Hz	16 05 08	Chemical expired	20	42
2	Hz	16 05 08	Expired chemical	20	73
2	Hz	16 06 02	Alkaline battery	10	73
2	Hz	16 07 08	Oily tank Cleaning	1000	41
2	Hz	16 07 08	Oily tank cleaning	1000	41
2	Hz	16 07 08	Oily tank cleaning	800	42
2	Hz	16 07 08	Oily tank Cleaning	1000	42
2	Hz	16 07 08	Rust scale	300	42
2	Hz	16 08 07	Copper slag	300	44
2	Hz	16 08 07	RFCCU spent catalyst	2000	44
2	Hz	16 08 07	Spent catalyst	100	44
2	Hz	16 08 07	Spent catalyst	100	44
2	Hz	16 08 07	Spent catalyst	30	44
2	Hz	16 08 07	Spent catalyst	500	73
2	Hz	16 08 07	Spent rfccu catalyst	500	44
2	Hz	16 10 01	Spent caustic	200	42
2	Hz	16 11 05	Refractory brick	550	44
2	Hz	16 11 05	Refractory brick	700	44
2	Non-Hz	17 02 03	Rubber hose	20	71
2	Non-Hz	17 02 03	Rubber hose	30	71
2	Non-Hz	17 04 05	เศษโลหะสแตนเลส	40	11
2	Non-Hz	17 04 05	เศษเหล็ก	1700	11

Table A6 The petroleum refinery waste data from Refinery F (continued)

No.	Hz/Non-HZ	Waste Code	Waste Name	Vol. (tons)	Disposal code
2	Non-Hz	17 04 11	เศษสายเคเบิล	50	11
2	Non-Hz	17 05 04	Non-contaminated sand and soil	1500	71
2	Hz	17 06 03	Insulation	40	73
2	Hz	17 06 03	Insulation	250	73
2	Hz	17 09 01	Construction and demolition wastes containing mercury	100	52
2	Non-Hz	17 09 04	Asphalt concrete	1000	71
2	Non-Hz	17 09 04	Asphalt concrete	2500	71
2	Hz	19 08 11	Bio sludge	1000	73
2	Non-Hz	19 09 01	Silica	50	71
2	Non-Hz	19 09 05	Resin	50	71
2	Non-Hz	19 12 04	ยางและพลาสติก	40	11
Total (tons)				31570	-

Appendix B The Meaning of Waste Category Number and Treatment and Disposal Code

The petroleum refinery wastes were classified into 20 categories as illustrated in Table B1. The wastes were treated and disposed by treatment and disposal method based on DIW, Ministry of Industry, Thailand (2005) as shown in Table B2

Table B1 The meaning of waste category number

Number	Waste Category
1	Oily Sludge
2	Used Lube Oil
3	Oil Contaminated Materials
4	Spent Catalyst
5	Spent and Discarded Chemicals
6	Sulfur Waste
7	Copper Slag
8	Contaminated Container
9	Discarded Electronic Equipment
10	Battery
11	Aqueous Liquid Waste
12	Metal Waste
13	Contaminated Soil and Sand
14	Construction and Demolition Waste
15	Bio Sludge
16	Paper Waste
17	Wood Waste
18	Waste from Production Process
19	Waste from Water Preparation
20	Rubber and Plastic Wastes

Table B2 The meaning of treatment and disposal code

Code	Treatment and Disposal Method
11	Sorting
21	Storage
33	Reuse or refill
41	Fuel substitution
42	Fuel blending
44	Co-material in cement kiln
49	Recycle
52	Reclamation or regeneration of metal and metal compound
71	Sanitary landfill
73	Secure landfill of stabilized and/or solidified wastes
75	Burn in hazardous waste incinerator
76	Co-incineration in cement kiln
81	Collect and export
82	Land reclamation

Appendix C The Comparing of Base Case of Waste Management with Zero Waste to Landfill and Reduce Burning In Incinerator and Enhancing Recycling Method

After realignment of the petroleum refinery waste, the different of defined scenarios are shown in Table C1, C2, C3, and C4 by comparing with the base case of waste management.

Where Scenario 1 = Base case of waste management

Scenario 2 = The zero waste to landfill and reduce burning in incinerator

Scenario 3 = The enhancing recycling method

Δ = The difference of the compared scenario

Table C1 The comparing between base case of petroleum refinery waste management and minimization zero waste to landfill and reduce burning in incinerator for hazardous waste

Scenario	Disposal Code										
	21	33	41	42	44	49	52	73	75	76	81
1	5	23	8,470	32,705	18,325	885	200	4,245	1,120	9,420	1,357
2	5	23	8,470	32,935	18,325	2580	1,170	620	350	10,920	1,357
Δ	0	0	0	230	0	1695	970	-3625	-770	1500	0
%	0	0	0	0.7	0	191.5	485.0	-85.4	-68.8	15.9	0

Table C2 The comparing between base case of petroleum refinery waste management and minimization zero waste to landfill and reduce burning in incinerator for non-hazardous waste

Scenario	Disposal Code									
	11	41	42	44	49	71	73	75	76	82
1	7,160	320	390	50	32	6,470	24	120	15	1,600
2	13,100	320	390	50	216	250	20	120	115	1,600
Δ	5,940	0	0	0	184	-6,220	-4	0	100	0
%	82.96	0	0	0	575.0	-96.1	-16.7	0	666.7	0

Table C3 The comparing between base case of petroleum refinery waste management and enhancing recycling method for hazardous waste

Scenario	Disposal Code										
	21	33	41	42	44	49	52	73	75	76	81
1	5	23	8,470	32,705	18,325	885	200	4,245	1,120	9,420	1,357
3	5	23	8,470	32,935	18,325	11,200	4,727	620	350	0	100
Δ	0	0	0	230	0	10,315	4527	-3625	-770	-9420	-1257
%	0	0	0	0.70	0	1,165.54	2,263.50	-85.39	-68.75	-100.0	-92.63

Table C4 The comparing between base case of petroleum refinery waste management and enhancing recycling method for non-hazardous waste

Scenario	Disposal Code									
	11	41	42	44	49	71	73	75	76	82
1	7,160	320	390	50	32	6,470	24	120	15	1,600
3	13,100	320	390	50	2,321	0	0	0	0	0
Δ	5,940	0	0	0	2,289	-6,470	-24	-120	-15	-1,600
%	82.96	0	0	0	7,153.13	-100.0	-100.0	-100.0	-100.0	-100.0

Appendix D The Impact Category Meaning of SimaPro Software Results by European, CML-IA Method

The life cycle assessment results of refinery waste in this study are obtained from SimaPro software that are calculated under the European, CML-IA method (developed by CML: Center of Environmental Science of Leiden University,2001). CML-IA method is used for evaluating the environmental impacts with midpoint approach. This method consists of 10 impact categories which are explained the meaning and unit of each impact below

- Depletion of Abiotic Resources

Human health, human welfare, and ecosystem health are concerned in this impact category. It is related to the extraction of mineral and fossil fuels in the system and based on concentration reserves and rate of de-accumulation (kg antimony equivalents/kg extraction).

- Climate Change

This impact category is included the effect of human health, ecosystem health, and material welfare. It is related to emissions of greenhouse gases to air and global warming potential for time horizon 100 years (GWP100), in kg carbon dioxide/kg emission.

- Stratospheric Ozone Depletion

Despite of the fraction of UV-B radiation on earth surface, this impact category is covered the insidious effects on human health, terrestrial and aquatic ecosystems, animal health, and biochemical cycles and on materials. It shows the ozone depletion potential of different gases (kg CFC-11 equivalent/ kg emission).

- Human Toxicity

The effects of toxic substances on the human environment is concerned for this impact category but the risk on working environment are not included. Human toxicity potentials are showed as 1,4-dichlorobenzene equivalents/ kg emission.

- Fresh-Water Aquatic Eco-Toxicity

This impact category is referred to the emissions of toxic substances to air, soil, and water. The fate, exposure and effects of toxic substances are based on 1,4-dichlorobenzene equivalents/kg emission.

- Marine Ecotoxicity

The effects of toxicity substances on marine ecosystem are concerned in this impact category and it is expressed as 1,4-dichlorobenzene equivalents/kg emission.

- Terrestrial Ecotoxicity

This impact category means the impacts of toxicity substances on terrestrial ecosystem by showing the effects with 1,4-dichlorobenzene equivalents/kg emission.

- Photo-Oxidant Formation

Because the formation of reactive substances (mainly ozone) are pernicious to human health and ecosystems and included summer smog, this impact category will be concerned with photochemical ozone creation potential for emission of substances to air and evaluated in kg ethylene equivalents/kg emission.

- Acidification

Acidifying substances have effects on groundwater, soil, organisms, surface water, ecosystems and materials (buildings). Acidification potential for emission to air is evaluated in kg SO_2 equivalents/ kg emission.

- Eutrophication

This impact category causes by emissions of nutrients to water, soil, and air because of the excessive levels of macro-nutrients in the environment. Nitrification potential is measured by kg PO_4 equivalents per kg emission. (PRé, various authors, 2018)

Appendix E The Environmetal Impact Results of Petroleum Refinery Wastes from SimaPro Software

The petroleum refinery wastes were evaluated the environmental impacts using SimaPro software. The results are shown in Tables E1 to E8 which are followed by the impact categories and treatment and disposal methods.

Where Impact category No.1 = Depletion of abiotic resources (kg Sb eq)

Impact category No.2 = Depletion of abiotic resources fossil (MJ)

Impact category No.3 = Climate change (kg CO_2 eq)

Impact category No.4 = Stratospheric Ozone Depletion (kg CFC 11 eq)

Impact category No.5 = Human Toxicity (kg 1,4-DB eq)

Impact category No.6 = Fresh-Water Aquatic Eco-Toxicity (kg 1,4-DB eq)

Impact category No.7 = Marine Ecotoxicity (kg 1,4-DB eq)

Impact category No.8 = Terrestrial Ecotoxicity (kg 1,4-DB eq)

Impact category No.9 = Photo-Oxidant Formation (kg C_2H_4 eq)

Impact category No.10 = Acidification (kg SO_2 eq)

Impact category No.11 = Eutrophication (kg PO_4^{3-} eq)

These results included hazardous wastes (Hz) and non-hazardous (Non-Hz) wastes and 3 scenarios which were base case of waste management (BC), zero wastes to landfill and reduce burning in incinerator (ZB), and enhancing recycling method (RC).

Table E1 The SimaPro software results of base case of waste management for hazardous wastes scenario

No.	Treatment and Disposal Code									
	33	41	42	44	49	52	73	75	76	81
1	4.97	155.43	1256.10	10380.57	258.45	34.01	1368.76	60.43	417.42	80077.56
2	3715272.40	395815744.75	1385733365.24	749292507.71	86267601.91	74347020.83	494874321.25	88629392.91	452030243.92	991328371.81
3	363094.22	9928795.63	89269699.34	68064584.08	7759424.53	7333333.33	21249331.51	7829329.06	23591239.66	98309748.09
4	0.03	5.11	63.52	10.38	0.74	0.52	5.43	0.81	5.08	6.83
5	1980504.22	6800496.02	57899028.88	1739107873.26	21140346.61	15088648.70	81167592.85	9187387.97	22360751.01	6875291606.69
6	608032.51	7423054.45	77537829.33	727632794.13	7568468.88	4756031.82	26344998.28	5754109.32	20480585.25	4696801684.58
7	829622669.26	18377725159.08	163802614113.76	2042447168487.06	15807093814.35	8224613917.40	56089778112.49	10789634225.66	46126600203.33	13271847130566.40
8	2439.05	29240.01	1626702.84	2319044.01	45966.42	36340.66	128554.18	35978.30	88048.03	957298.63
9	228.99	4020.21	30180.12	135335.13	3004.99	2537.61	10536.89	2798.42	9141.95	37958.80
10	2013.18	95054.47	692064.29	3435584.36	36047.06	30583.89	137134.43	38848.92	185464.75	1793342.55
11	778.10	31678.16	264756.97	2711404.56	19108.18	10612.07	67970.40	15262.17	73964.85	18463713.52

Table E2 The SimaPro software results of base case of waste management for non-hazardous wastes scenario

No.	Treatment and Disposal Code									
	11	41	42	44	49	71	73	75	76	82
1	90.11	0.75	2.14	21.70	41.36	22.29	17.78	21.66	21.82	16.63
2	18795679.42	5928938.19	22098022.03	64457081.49	4738443.03	393557008.62	319978699.40	59506362.02	60340321.31	320350849.71
3	1348413.17	250415.33	2108459.71	6180255.09	408331.96	11189734.56	7870579.17	5949962.72	5999192.54	7964566.35
4	0.34	12.06	4.89	0.49	0.09	12.18	3.32	0.48	3.06	3.32
5	6559846.81	85060.24	604897.94	7347926.23	2201724.45	3450191.51	2848636.66	7314374.04	7331395.71	2759652.83
6	3708812.02	56116.74	2025567.41	3225998.43	1118276.03	1680111.44	1270453.67	3197485.98	3208998.64	1229309.49
7	9207993024.96	182830552.32	2221770991.12	5999817784.36	2765616501.30	6422392083.32	4477935754.90	5860569138.45	5897663532.51	4262124544.05
8	10775.97	389.23	142112.65	28142.61	3425.81	21797.39	18558.80	28022.09	28098.07	18640.75
9	1012.68	78.82	512.00	2428.50	392.09	5958.69	3041.57	2085.53	2099.71	3040.69
10	19867.18	1098.15	11904.82	22733.49	5891.76	71749.40	55928.83	21895.61	22083.42	55834.88
11	11858.71	276.72	3832.07	8531.55	3519.49	13842.91	11167.72	8395.42	8448.32	11037.73

Table E3 The SimaPro software results of zero wastes to landfill and incinerator for hazardous wastes scenario

No.	Treatment and Disposal Code									
	33	41	42	44	49	52	73	75	76	81
1	4.97	155.43	1256.30	10380.57	1680.04	50.53	16.14	21.81	456.19	80077.56
2	3715272.40	395815744.75	1397701134.93	749292507.71	214300490.88	115945325.82	321674635.59	62171744.81	468121632.27	991328371.81
3	363094.22	9928795.63	89426959.47	68064584.08	17305321.14	10722722.25	8026537.23	6196268.66	25120610.71	98309748.09
4	0.03	5.11	64.10	10.38	1.36	1.57	3.31	0.51	5.23	6.83
5	1980504.22	6800496.02	58005373.14	1739107873.26	96782448.98	11240610.12	2754944.18	7679961.56	23787268.52	6875291606.69
6	608032.51	7423054.45	77564697.97	727632794.13	29383129.89	7544358.48	1242525.27	3933771.51	22147869.04	4696801684.58
7	829622669.26	18377725159.08	163899198667.24	2042447168487.06	61456590997.74	14747070609.81	4357206173.09	6739597380.51	49977875845.64	13271847130566.40
8	2439.05	29240.01	1627015.99	2319044.01	140724.38	46791.20	18547.57	29959.15	93567.14	957298.63
9	228.99	4020.21	30255.41	135335.13	9485.96	3403.35	3076.42	2169.07	9720.52	37958.80
10	2013.18	95054.47	693382.78	3435584.36	94479.00	50987.46	56672.43	23844.30	199243.06	1793342.55
11	778.10	31678.16	265003.76	2711404.56	70845.52	17625.07	11195.36	8916.94	80088.31	18463713.52

Table E4 The SimaPro software results of zero wastes to landfill and incinerator for non-hazardous wastes scenario

No.	Treatment and Disposal Code									
	11	41	42	44	49	71	73	75	76	82
1	95.02	0.75	2.14	21.70	44.13	16.11	16.11	21.66	22.35	16.63
2	79578058.19	5928938.19	22098022.03	64457081.49	15975673.43	319620597.45	319611503.45	59506362.02	63155795.97	320350849.71
3	4131285.75	250415.33	2108459.71	6180255.09	920439.25	7842077.15	7841393.84	5949962.72	6166417.74	7964566.35
4	0.61	12.06	4.89	0.49	0.11	3.31	3.31	0.48	11.66	3.32
5	7119549.52	85060.24	604897.94	7347926.23	2761188.01	2705584.82	2705381.97	7314374.04	7389055.50	2759652.83
6	4103868.92	56116.74	2025567.41	3225998.43	1289230.91	1200626.14	1200529.82	3197485.98	3247851.03	1229309.49
7	11085512724.73	182830552.32	2221770991.12	5999817784.36	3487310699.01	4179071580.48	4178549953.70	5860569138.45	6023661795.47	4262124544.05
8	13583.96	389.23	142112.65	28142.61	3103.62	18348.80	18347.79	28022.09	28355.62	18640.75
9	3811.29	78.82	512.00	2428.50	446.01	3020.77	3020.50	2085.53	2148.08	3040.69
10	33718.55	1098.15	11904.82	22733.49	6611.53	55479.12	55469.90	21895.61	22738.71	55834.88
11	14302.38	276.72	3832.07	8531.55	4220.37	10910.26	10907.94	8395.42	8631.10	11037.73

Table E5 The SimaPro software results of enhancing recycling method for hazardous wastes scenario

No.	Treatment and Disposal Code									
	33	41	42	44	49	52	73	75	76	81
1	4.97	155.43	1256.30	10380.57	2026.87	80138.95	16.14	21.81		3.04
2	3715272.40	395815744.75	1397701134.93	749292507.71	532695686.86	1216214107.09	321674635.59	62171744.81		10341073.83
3	363094.22	9928795.63	89426959.47	68064584.08	37335161.38	109311944.38	8026537.23	6196268.66		929823.91
4	0.03	5.11	64.10	10.38	4.72	10.06	3.31	0.51		0.01
5	1980504.22	6800496.02	58005373.14	1739107873.26	114073153.47	6894031946.31	2754944.18	7679961.56		277539.66
6	608032.51	7423054.45	77564697.97	727632794.13	48352690.03	4705608525.24	1242525.27	3933771.51		224367.26
7	829622669.26	18377725159.08	163899198667.24	2042447168487.06	105295379582.96	13287622246379.00	4357206173.09	6739597380.51		930384631.05
8	2439.05	29240.01	1627015.99	2319044.01	212234.70	1012284.60	18547.57	29959.15		1190.83
9	228.99	4020.21	30255.41	135335.13	17234.66	41687.60	3076.42	2169.07		281.54
10	2013.18	95054.47	693382.78	3435584.36	269807.72	1851465.25	56672.43	23844.30		6035.66
11	778.10	31678.16	265003.76	2711404.56	141254.43	18482323.36	11195.36	8916.94		1457.21

Table E6 The SimaPro software results of enhancing recycling method for non-hazardous wastes scenario

No.	Treatment and Disposal Code									
	11	41	42	44	49	71	73	75	76	82
1	95.02	0.75	2.14	21.70	78.35					
2	79578058.19	5928938.19	22098022.03	64457081.49	22185499.82					
3	4131285.75	250415.33	2108459.71	6180255.09	1425167.72					
4	0.61	12.06	4.89	0.49	11.30					
5	7119549.52	85060.24	604897.94	7347926.23	2657212.40					
6	4103868.92	56116.74	2025567.41	3225998.43	1320273.90					
7	11085512724.73	182830552.32	2221770991.12	5999817784.36	5307784810.12					
8	13583.96	389.23	142112.65	28142.61	3882.47					
9	3811.29	78.82	512.00	2428.50	658.83					
10	33718.55	1098.15	11904.82	22733.49	10877.97					
11	14302.38	276.72	3832.07	8531.55	4462.68					

Table E7 Total emission of each impact category for hazardous wastes

Waste Category		Hz-BC	Hz-ZB	Hz-RC
Impact Category	**Unit**			
Abiotic depletion	kg Sb eq	94013.69	94099.53	94004.08
Abiotic depletion (fossil)	MJ	4722033842.74	4720066860.99	4689621907.98
Global warming (GWP 100a)	kg CO_2 eq	333698579.47	333464641.49	329583168.96
Ozone layer depletion (ODP)	kg CFC 11 eq	98.45	98.44	98.23
Human toxicity	kg 1,4-DB eq	8830024236.21	8823431086.69	8824711791.82
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	5574907588.54	5574281917.81	5572590458.34
Marine aquatic ecotoxicity	kg 1,4-DB eq	15634341981268.80	15634679186555.90	15630498529129.30
Terrestrial ecotoxicity	kg 1,4-DB eq	5269612.14	5264627.14	5251955.94
Photochemical oxidation	kg C_2H_4 eq	235743.10	235653.86	234289.02
acidification	kg SO_2 eq	6446137.90	6444603.59	6433860.15
Eutrophication	kg PO_4^{3-} eq	21659249.00	21661249.31	21654011.87

Table E8 Total emission of each impact category for non-hazardous wastes

Waste Category		Non-Hz-BC	Non-Hz-ZB	Non-Hz-RC
Impact Category	**Unit**			
Abiotic depletion	kg Sb eq	256.24	256.59	197.96
Abiotic depletion (fossil)	MJ	1269751405.22	1270282881.92	194247599.72
Global warming (GWP 100a)	kg CO_2 eq	49269910.61	49355272.93	14095583.61
Ozone layer depletion (ODP)	kg CFC 11 eq	40.22	40.22	29.34
Human toxicity	kg 1,4-DB eq	40503706.44	40792671.10	17814646.33
Fresh water aquatic ecotoxicity	kg 1,4-DB eq	20721129.84	20776584.88	10731825.40
Marine aquatic ecotoxicity	kg 1,4-DB eq	47298713907.29	47481219763.69	24797716862.64
Terrestrial ecotoxicity	kg 1,4-DB eq	299963.36	299047.11	188110.92
Photochemical oxidation	kg C_2H_4 eq	20650.29	20592.20	7489.45
acidification	kg SO_2 eq	288987.53	287484.75	80332.97
Eutrophication	kg PO_4^{3-} eq	80910.65	81045.54	31405.40

Table E9 The percentage of each environmental impact in each scenario for hazardous wastes

Impact Category	Hz-BC	Hz-ZB	Hz-RC
Abiotic depletion	33.3345	33.3345	33.3310
Abiotic depletion (fossil)	33.4094	33.4105	33.1801
Global warming (GWP 100a)	33.4704	33.4719	33.0577
Ozone layer depletion (ODP)	33.3581	33.3583	33.2836
Human toxicity	33.3400	33.3400	33.3199
Fresh water aquatic ecotoxicity	33.3378	33.3382	33.3240
Marine aquatic ecotoxicity	33.3360	33.3361	33.3278
Terrestrial ecotoxicity	33.3705	33.3707	33.2587
Photochemical oxidation	33.4019	33.4023	33.1958
acidification	33.3544	33.3548	33.2908
Eutrophication	33.3360	33.3361	33.3279

Table E10 The percentage of each environmental impact in each scenario for non-hazardous wastes

Impact Category	Non-Hz-BC	Non-Hz-ZB	Non-Hz-RC
Abiotic depletion	36.0498	36.0998	27.8504
Abiotic depletion (fossil)	46.4382	46.4576	7.1042
Global warming (GWP 100a)	43.7097	43.7854	12.5049
Ozone layer depletion (ODP)	36.6357	36.6403	26.7241
Human toxicity	40.8670	41.1586	17.9744
Fresh water aquatic ecotoxicity	39.6732	39.7794	20.5474
Marine aquatic ecotoxicity	39.5548	39.7074	20.7378
Terrestrial ecotoxicity	38.1089	37.9925	23.8986
Photochemical oxidation	42.3753	42.2561	15.3687
acidification	43.9990	43.7702	12.2309
Eutrophication	41.8442	41.9140	16.2418

Appendix F The Comparing of Environmental Impacts of Recycling Method between 100% and 70% Recycling Rate

The environmental impacts of 100% and 70% recycling rate for both hazardous and non-hazardous wastes are displayed in Table F1 and F2, respectively.

Table F1 The environmental impacts of hazardous wastes comparing between 100% and 70% recycling rate

Scenarios	Unit	Treatment and Disposal Codes										Total
		33	41	42	44	49	52	73	75	76	81	
Global Warming (GWP 100a)												
Hz-RC	kg CO2 eq	363094.22	9928795.63	89426959.47	68064584.08	37335161.38	109311944.38	8026537.23	6196268.66	0.00	929823.91	329583168.96
Hz-Rc 70%	kg CO2 eq	363094.22	8828023.51	88820090.14	68064584.08	31809671.17	79881826.18	8026537.23	6196268.66	11697825.14	30133932.29	333821852.63
Human Toxicity												
Hz-RC	kg 1,4-DB eq	1980504.22	6800496.02	58005373.14	1739107873.26	114073153.47	6894031946.31	2754944.18	7679961.56	0.00	277539.66	8824711791.82
Hz-Rc 70%	kg 1,4-DB eq	1980504.22	6442560.35	57854508.91	1739107873.26	109204306.26	4832000143.01	2754944.18	7679961.56	12252144.82	2062231450.51	8831508397.08
Terrestrial Ecotoxicity												
Hz-RC	kg 1,4-DB eq	2439.05	29240.01	1627015.99	2319044.01	212234.70	1012284.60	18547.57	29959.15	0.00	1190.83	5251955.94
Hz-Rc 70%	kg 1,4-DB eq	2439.05	25204.47	1626047.49	2319044.01	193191.62	724912.33	18547.57	29959.15	47666.58	287916.19	5274928.46
Acidification												
Hz-RC	kg SO2 eq	2013.18	95054.47	693382.78	3435584.36	269807.72	1851465.25	56672.43	23844.30	0.00	6035.66	6433860.15
Hz-Rc 70%	kg SO2 eq	2013.18	68308.09	687613.12	3435584.36	219746.60	1312284.02	56672.43	23844.30	75075.43	542070.46	6423211.99

Table F2 The environmental impacts of non-hazardous wastes comparing between 100% and 70% recycling rate

Scenarios	Unit	Treatment and Disposal Codes										Total
		11	41	42	44	49	71	73	75	76	82	
Global Warming (GWP 100a)												
Non-Hz-RC	kg CO2 eq	4131285.75	250415.33	2108459.71	6180255.09	1425167.72	0.00	0.00	0.00	0.00	0.00	14095583.61
Non-Hz-Rc 70%	kg CO2 eq	4131285.75	250415.33	2108459.71	6180255.09	1072070.96	7841557.24	7841352.25	5949713.16	6012996.79	7878304.00	49266410.28
Human Toxicity												
Non-Hz-RC	kg 1,4-DB eq	7119549.52	85060.24	604897.94	7347926.23	2657212.40	0.00	0.00	0.00	0.00	0.00	17814646.33
Non-Hz-Rc 70%	kg 1,4-DB eq	7119549.52	85060.24	604897.94	7347926.23	2554257.12	2705430.48	2705369.63	7314299.96	7336133.48	2721650.88	40494575.47
Terrestrial Ecotoxicity												
Non-Hz-RC	kg 1,4-DB eq	13583.96	389.23	142112.65	28142.61	3882.47	0.00	0.00	0.00	0.00	0.00	188110.92
Non-Hz-Rc 70%	kg 1,4-DB eq	13583.96	389.23	142112.65	28142.61	4443.20	18348.03	18347.72	28021.72	28119.23	18435.61	299943.96
Acidification												
Non-Hz-RC	kg SO2 eq	33718.55	1098.15	11904.82	22733.49	10877.97	0.00	0.00	0.00	0.00	0.00	80332.97
Non-Hz-Rc 70%	kg SO2 eq	33718.55	1098.15	11904.82	22733.49	8957.20	55472.10	55469.34	21892.24	22138.75	55578.83	288963.46

Appendix G The SimaPro Results of Enhancing Recycling Method with 70% Recycling Rate

The enhancing recycling method with 70% recycling rate was conducted to evaluate the environmental impacts from SimaPro software with functional unit ton of waste and each treatment and disposal method generated the impacts from different sources such as co-incineration in cement kiln method (Code 76) of hazardous wastes (Figure G1), collecting and exporting method (Code 81) of hazardous wastes (Figure G2), sanitary landfill method (Code 71) of non-hazardous wastes (Figure G3), and burning in hazardous waste incinerator method (Code 75) of non-hazardous wastes (Figure G4).

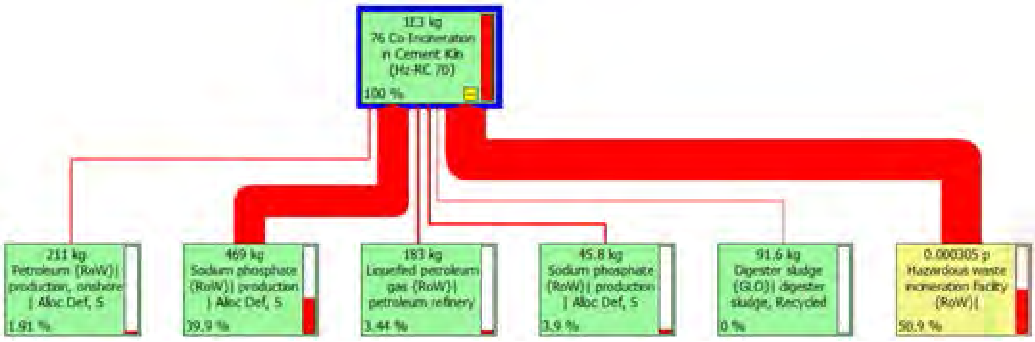

Figure G1 The contribution of global warming potential (GWP 100a) by co-incineration in cement kiln method (Code 76) of hazardous wastes of Enhancing Recycling Method with 70% Recycling Rate.

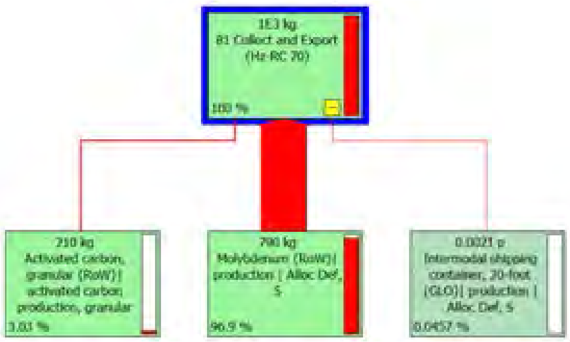

Figure G2 The contribution of global warming potential (GWP 100a) by collecting and exporting method (Code 81) of hazardous wastes of Enhancing Recycling Method with 70% Recycling Rate.

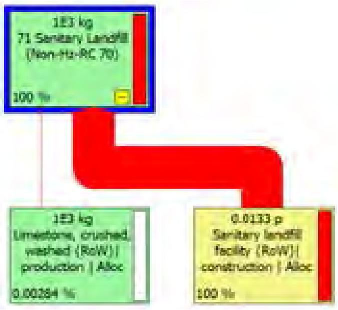

Figure G3 The contribution of global warming potential (GWP 100a) by sanitary landfill method (Code 71) of non-hazardous wastes of Enhancing Recycling Method with 70% Recycling Rate.

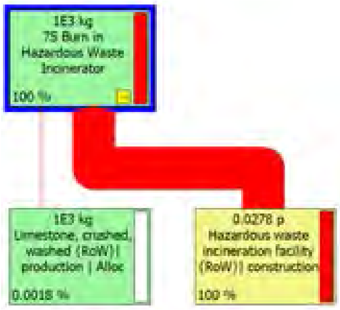

Figure G4 The contribution of global warming potential (GWP 100a) by burning in hazardous waste incinerator method (Code 75) of non-hazardous wastes of Enhancing Recycling Method with 70% Recycling Rate.

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