MASS FLOW ANALYSIS OF INFECTIOUS WASTE MANAGEMENT IN BANGKOK

Mr. Tech Sukprasert

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ปัจจุบัน ปริมาณขยะมูลฝอยติดเชื้อในกรุงเทพมหานครกำลังเพิ่มขึ้นอย่างต่อเนื่อง สาเหตุจากความเจริญก้าวหน้าในการให้บริการทางการแพทย์และการเพิ่มขึ้นของจำนวนประชากรที่อาศัยอยู่ในกรุงเทพมหานคร ปัจจัยเหล่านี้ส่งผลต่อการเพิ่มขึ้นของจำนวนสถานพยาบาลสาธารณสุข ปัญหาเหล่านี้กำลังเป็นสิ่งที่ท้าทายที่ต้องมีการพัฒนาระบบการจัดการและการเก็บรวบขยะมูลฝอยติดเชื้ออย่างเหมาะสมและมีประสิทธิภาพ ดังนั้นการศึกษานี้มีจุดประสงค์เพื่อที่จะพัฒนาแผนภาพการวิเคราะห์กระแสการไหล และ ประเมินปริมาณของก๊าซคาร์บอนไดออกไซด์ และ ประสิทธิภาพเชิงนิเวศเศรษฐกิจของการจัดการขยะมูลติดเชื้อในกรุงเทพมหานคร ยิ่งไปกว่านั้น งานวิจัยได้ทำการสำรวจข้อมูลในการจัดการขยะมูลฝอยติดเชื้อภายในโรงพยาบาลรัฐและโรงพยาบาลเอกชนในกรุงเทพมหานครด้วย ผลจาการศึกษาได้รวบรวมข้อมูลเป็นระยะเวลาหนึ่งปีตั้งแต่เดือนมิถุนายน 2555 จนถึงเดือนพฤษภาคม 2556 พบว่ามสถาพยาบาลสาธารณสุขจำนวน 2,409 แห่งและมีเตียงจำนวน 28,141 เตียงสำหรับรองรับผู้ป่วยในโรงพยาบาลรัฐและโรงพยาบาลเอกชน และมีขยะมูลฝอยติดเชื้อที่ถูกส่งไปกำจัดยังสถานที่รับกำจัดเป็นปริมาณ 871.33 ตันต่อเดือนโดยบริษัท กรุงเทพธนาคม จำกัดเป็นผู้ให้บริการในการจัดการขยะอันตรายทั้งในการเก็บขน บำบัดและกำจัด โดยวิธีการเผาไหม้ในเตาเผาขยะมูลฝอยติดเชื้อที่มีระบบควบคุมและบำบัดมลพิษทางอากาศและมลพิษทางน้ำ ผลจากการวิเคราะห์แผนภาพกระแสการไหลของการจัดการขยะมูลฝอยติดเชื้อในกรุงเทพมหานคร พบว่าจาก 871.33 ตันต่อเดือนของขยะมูลฝอยติดเชื้อถูกบำบัดในเตาเผาขยะมูลฝอยติดเชื้อ ขยะมูลฝอยติดเชื้อก็กลายเป็นมลพิษอากาศ 497.87 ตัน และไอน้ำ 281.35 ตัน และเถ้าหนัก 90 ตัน และองค์ประกอบในน้ำเสีย 2.11 ตัน มลพิษทางอากาศจากเตาเผาส่งผลอย่างมีนัยสำคัญต่อการเกิดผลกระทบสิ่งแวดล้อมโดยรวมเมื่อเทียบกับกระบวนการอื่น ๆ ในระบบการจัดการ ผลการประเมินก๊าซคาร์บอนไดออกไซด์ในการจัดการขยะมูลฝอยติดเชื้อทั้งหมด พบว่ามีการปล่อย 682.39 ตันของก๊าซคาร์บอนไดออกไซด์ต่อเดือน งานวิจัยได้เสนอแนวทางปรับปรุงการจัดการมูลฝอยติดเชื้อในเกรุงเทพมหานคร โดยการเสนอให้ปรับปรุงระบบการขนส่งใหม่พร้อมกับการประเมินประสิทธิภาพของการใช้พลังงานและการปล่อยก๊าซคาร์บอนไดออกไซด์และค่าใช้จ่ายในการบำบัดในแต่ละระบบการจัดการ ระบบการขนส่งใหม่สามารถช่วยลดปริมาณการปล่อยก๊าซคาร์บอนไดออกไซด์ได้ถึง 31.01% เมื่อเทียบกับระบบการขนส่งที่ใช้อยู่ในปัจจุบัน และรวมถึงวิธีการอื่น ๆ เพื่อเพิ่มประสิทธิภาพนอกเหนือไปจากการขนส่งคือประสิทธิภาพของเตาเผาขยะ ผลงานวิจัยสามารถเป็นประโยชน์ในการปรับปรุงประสิทธิภาพของการจัดการมูลฝอยติดเชื้อในแต่ละขั้นตอน ข้อมูลนี้จะเป็นประโยชน์สำหรับหน่วยงานที่รับผิดชอบในการพัฒนากลยุทธ์ในการจัดการและนโยบายเพื่อปรับปรุงประสิทธิภาพและส่งเสริมความยั่งยืนของการจัดการมูลฝอยติดเชื้อในกรุงเทพมหานครในอนาคต

สาขาวิชา การจัดการสิ่งแวดล้อม ลายมือชื่อนิสิต ....

ปีการศึกษา 2556 ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก ....

5587652420 : MAJOR ENVIRONMENTAL MANAGEMENT
KEYWORDS: MASS FLOW ANALYSIS / CARBON FOOTPRINT / ECO-EFFICIENCY / WASTE MANAGEMENT / INCINERATION / INFECTIOUS WASTE

TECH SUKPRASERT: MASS FLOW ANALYSIS OF INFECTIOUS WASTE MANAGEMENT IN BANGKOK. ADVISOR: ASST. PROF. CHANATHIP PHARINO, Ph.D., 166 pp.

Currently in Bangkok, the amount of infectious waste has been steadily increasing due to advancement in medical services and increasing number of patients in the metropolitan. This resulted in increasing numbers of public health facilities in many areas. It is very challenging to establish appropriate and efficient collection and treatment system to handle this infectious waste. Therefore, this research aims to develop the mass flow analysis (MFA) diagram, measure carbon footprint (CF) and evaluate eco-efficiency of infectious waste management in Bangkok. Furthermore, this research conducted the survey to gather information of infectious waste management within public and private hospitals in Bangkok. The results found that during June 2012 to May 2013, the total number of public health facilities and bed capacities was 2,409 places and 28,141 beds. Average amount of infectious waste sent to treatment facility was 871.33 ton/month. Krungthep Tanakom Company (KTC) is the service provider for infectious waste collection, transport, treatment (with two incinerators) and disposal. The MFA diagram found that when 871.33 tons of infectious waste was treated by two incinerators, it produced 497.87 tons of air pollutants, 281.35 tons of evaporated water, 90 tons of bottom ashes and 2.11 tons of wastewater components. Air pollutants emitted from both incinerators significantly contributed to overall environmental impacts compared to other processes in the management system. Total CO_2 emissions from the entire system were 682.39 ton/month. To improve infectious waste management in Bangkok, options to increase the efficiency of transportation system for waste collection were evaluated along with efficiency of energy consumption, CO_2 emissions and treatment costs in each management system. New transportation system could decrease CO_2 emissions around 31.01% compared to existing transportation system and include other approaches to increase efficiency in addition to transportation, i.e., efficiency of the incinerators. Furthermore, the results from surveys of public and private hospitals provide useful information to improve the efficiency of infectious waste management in each stage from segregation and collection at sources until disposal. These research findings can be very useful for responsible authorities to develop management strategies and policy to better improve the efficiency and promote sustainability of infectious waste management in Bangkok in the future.

Field of Study: Environmental Management Student's Signature ....

Academic Year: 2013 Advisor's Signature ....

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Very special thanks go to 65 respondents from 21 public hospitals and 44 private hospitals for their contribution to this survey.

Finally, I would like to thank my mother, elder sister and friends for their continuous support. This dissertation is dedicated to my late father who would have done this better than me.

CONTENTS

Page

Page

Page

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BMA	Bangkok Metropolitan Administration
CHP	Combined heat and power
CP	Clinics and polyclinics
CS	Collection and storage
ESCAP	Economic and Social Commission for Asia and the Pacific
EU	European Union
G	Government hospitals
HHMC	Home health and medical care
HHW	Hazardous household waste
HVNSs	Home-visit nursing stations
I	Incinerator
LCA	Life Cycle Assessment
MFA	Mass Flow Analysis
MOPH	Ministry of Public Health
MSEA	Ministry of State for Environmental Affairs
O	Others
OECD	Organization for Economic Co-operation and Development

P	Private hospitals
PATH	Program for Appropriate Technology in Health
PCBs	Polychlorinated biphenyls
PCD	Pollution Control Department
PET	Polyethylene terephthalate
POPs	Persistent Organic Pollutants
S	Secure landfill
TGO	Thailand Greenhouse Gas Management Organization
UNEP	United Nations Environment Programme
WBCSD	World Business Council for Sustainable Development
WHO	World Health Organization

CHAPTER I

INTRODUCTION

1.1 Rationale for the study

Currently, the number of public health facilities such as hospitals, health centers, clinics, polyclinics and others belonging to both government and private sectors has been increased in our society domestically and internationally. For instance from international statistics, during 2003 - 2005, the number of small clinics in Taiwan increased from 18,183 to 18,877 (Huang & Lin, 2008) while the number of hospitals operating in Greece was 317 places with 53,701 beds excluding military hospitals in 2006 (Sanida et al., 2010). In Thailand, total number of public health facilities and bed capacities was more than 37,000 places and total number of beds around 140,000 in 2012 (PCD, 2014). In particular, total average number of public health facilities and bed capacities in Bangkok was 2,352 places and 28,143 beds in 2012. These public health facilities were major sources of infectious waste generation.

Regarding the amount of infectious waste generation, in Taiwan during 2003 - 2005, infectious industrial waste accounted for 19.3%–21.9% of total medical wastes. The amount of infectious waste was around 19,350 tons in 2004 and increased over the previous year by 4,000 tons (Huang & Lin, 2008). In Greece, more than 14,000 tons of infectious hospital wastes were produced yearly (Sanida et al., 2010). In Jordan, average generation rates of total medical wastes in the hospitals in 2004 were estimated to be 6.10 kg/patient/day (3.49 kg/bed/day), 5.62 kg/patient/day (3.14 kg/bed/day) and 4.02 kg/patient/day (1.88 kg/bed/day) for public, maternity and private hospitals, respectively. For medical laboratories, waste generation rates were in the range of 0.053–0.065 kg/test-day for governmental laboratories and 0.034–0.102 kg/test-day for private laboratories (Bdour et al., 2007). Recently in 2012, the amount of infectious waste in Thailand was around 42,000 ton/year which around 28,000 ton/year generated by health facilities of the government, and around 14,000 tons/year generated by health facilities of the private sector (ThanOnline, 2013). In Bangkok, total average amount of infectious waste generated by public health facilities in 2012 was 849.13 ton/month or 10,189.55 ton/year (Thanakom, 2013). The amount of infectious waste in Bangkok accounted for 24.26% of infectious wastes in Thailand.

Several technologies for infectious waste treatment, consisting of mechanical, thermal, chemical and irradiation processes, are used in many countries. An incinerator as thermal processes is widely used to treat infectious waste generated from public health facilities because it yields very high disinfection efficiency and significantly reduces weight and volume of wastes (80 - 90%) (MSEA, 2013). On the other hand, a limitation of using the incinerator was that air pollution problems during operation could not be effectively controlled, and the ash from the incinerator has never been analyzed (Panyaping, 2006). These could lead to an adverse threat to human health and the environment including leaching of heavy metals found in bottom ashes to surface and ground water (Gidarakos et al., 2009).

Since the amount of infectious waste has been steadily increasing, it is essential to establish appropriate and efficient collection and treatment system to handle these wastes. However, infectious waste management in Thailand still faces many problems. Illegal dumping of infectious wastes often occurs in Thailand. This may become a public health threat such as causing outbreaks of diseases impacting on human health and the environment such as diarrhea, parasitic diseases, cholera, typhoid, tetanus, viral hepatitis, and AIDS.

The study aims to identify comprehensive flows of infectious wastes from generation sources and evaluate the efficiency of treatment and management system. The research applies Mass Flow Analysis (MFA) to develop MFA diagram and evaluate the eco-efficiency of infectious waste management in Bangkok. The research outcomes are expected to help identify the source of inefficiency and the approach to improve the effectiveness of infectious waste management in Bangkok.

1.2 Research objectives

1. To develop mass flow analysis (MFA) diagram of infectious waste management in Bangkok.
2. To evaluate eco-efficiency of infectious waste management in Bangkok and compare performance with other systems.
3. To recommend management strategies to better improve the efficiency of infectious waste management in Bangkok.

1.3 Research questions

1. How is the infectious waste management in Bangkok operated? What are the major sources of generators and the quantity of infectious wastes generation?

2. What is the efficiency level of the infectious waste management system? How can the infectious waste management system be sustainably improved?

1.4 Expected outcomes

1. Better understanding an overview of the origins and flow paths of infectious waste (in terms of quantity or changed forms) and the current situation about the efficiency of infectious waste management in Bangkok.
2. Recommending management strategies and policies to better improve the efficiency and promote sustainability of infectious waste management in the future.

1.5 The scope of the study

The scope of this study was to develop MFA diagram and evaluate eco-efficiency of infectious waste management at the beginning of sources of infectious waste generation (i.e., government and private hospitals, health centers, clinics and polyclinics and others), segregation and collection, storage, transportation, treatment and disposal in Bangkok during June 2012 to May 2013.

CHAPTER II

LITERATURE REVIEWS

This chapter presented all relevant data and background to provide understanding and information to conduct the research, regarding (1) current situations and characterizations of infectious waste, (2) generation rate of infectious waste, (3) infectious waste treatment technologies and (4) international and domestic policies and regulations about infectious waste management. Details of each section were described as follows:

2.1 Situations and characterizations of infectious waste

2.1.1 International situations

From the review of international situations of infectious waste, in Taiwan, the number of small clinics increased from 18,183 to 18,877 between 2003 and 2005. The majority of medical waste was general industrial waste, which accounted for 76.9%–79.4% of total medical waste between 2003 and 2005. In Taiwan, infectious industrial waste is any waste produced by medical organizations, medical testing centers, medical researcher centers, biotechnology organizations and other enterprises engaged in medicine, testing, research or manufacturing. Infectious industrial waste accounted for 19.3%–21.9% of total medical waste. The amount of infectious waste reached 19,350 tons in 2004, and it increased over the previous year of 4000 tons. It increased to be 20,105 tons in 2005. The management of infectious industrial waste was considered important due to potential environmental hazards and public health risks which could have a threat to a population about 22.7 million in Taiwan (Huang & Lin, 2008).

The number of hospitals and bed capacities operating in Greece was 317 places and 53,701 beds in 2006, respectively. These numbers of hospitals excluded military hospitals. In Greece, more than 14,000 tons of infectious hospital wastes are produced yearly. According to collected data by each the 21 hospitals in Central Macedonia, the total amount production of infectious wastes was estimated at 4,094 kg/day in 2002. These quantities of infectious waste are still mismanaged, and numerous problems are still encountered regarding waste segregation, collection, transportation and management, as well as often excessive entailed costs (Sanida et al., 2010).

In Irbid city (a major city in the northern part of Jordan), there was a total number of 14 healthcare facilities consisting of four hospitals and 10 clinical laboratories which served a total population of about 1.5 million in 2004. Average generation rates of total medical wastes in the hospitals were estimated to be 6.10 kg/patient/day (3.49 kg/bed/day), 5.62 kg/patient/day (3.14 kg/bed/day) and 4.02 kg/patient/day (1.88 kg/bed/day) for public, maternity and private hospitals, respectively. For medical laboratories, rates were in the range of 0.053–0.065 kg/test-day for governmental laboratories and 0.034–0.102 kg/test-day for private laboratories. Irbid city had no defined methods for handling and disposal of these wastes and no specific regulations or guidelines for segregation or classification of these wastes. This meant that medical wastes were mixed and disposed along with municipal solid wastes (Bdour et al., 2007).

In Iran, Nemazee hospital was found that there was improper segregation of infectious waste that was caused from health literacy consisting of lacks of training and sensitivity and management weakness consisting of poor planning and lacks of organizational resources and supervision and evaluation. Patients or their companions placed water bottles into yellow bins (reserved only for infectious medical waste) because they were not trained and did not have enough information regarding segregation. Nurses, medical and nursing students and cleaners were aware of the importance of segregation but they were sometimes careless and mistakenly mixed infectious medical waste with domestic waste (Oroei et al., 2014).

Fourteen different healthcare facilities in Tripoli, Misurata and Sirt located in the northwestern part of Libya had no guidelines for separation, collection and classification, including no methods for storage and disposal of generated waste. In some hospitals, the containers for collecting and transferring hospital waste were placed near the main street within the hospital buildings or were located outside at the street-side curb. In addition, these containers were mostly uncovered which created another potential hazard. Some hospitals had no temporary storage area, and waste was simply dumped in the corner of a hospital room until it could be transported off-site (Sawalem et al., 2009).

2.1.2 In Thailand and Bangkok

In Thailand, there are increased numbers of public health facilities such as hospitals, health centers, clinics, polyclinics and others belonging to both government and private sectors. Total numbers of public health facilities and bed capacities are more than 37,000 places and around 140,000 beds, respectively (PCD, 2014). In 2012, the amount of infectious waste in Thailand was around 42,000 tons/year which around 28,000 tons/year generated by public health facilities of the government sector, and around 14,000 tons/year generated by public health facilities of the private sector (ThanOnline, 2013). However, Thailand has still encountered problems regarding the mismanagement of infectious waste. This may cause outbreaks of diseases impacting on human health and the environment such as diarrhea, parasitic diseases, cholera, typhoid, tetanus, viral hepatitis and AIDS.

About a few years ago, Thailand had events regarding problems of illegal dumping of infectious waste in several provinces. On December 18, 2012, DSI staffs went to Village No.7, Ban Dan sub-district, Ban Dan district, Buri Ram province to investigate illegal dumping of infectious waste at an abandoned warehouse as shown in Figure 2-1(a). Around 70-100 tons of infectious wastes were illegally dumped by the enterprise which had the contract of services in collection, transfer and disposal of infectious waste (DailyNews, 2012).

On July 03, 2012, Bangkok Post reported news of illegal dumping of infectious waste in Ayutthaya province as shown in Figure 2-1(b). Government officials inspected 4 tons of infectious hospital waste in a paddy field in Ayutthaya province. Green Party Partnership or a waste disposal company was alleged to have been hired by the hospital to dump the infectious wastes from Lampang and Sukhothai provinces coming in Ayutthaya province (Bangkokpost, 2012).

(a)

(b)

Figure 2-1: Illegal dumping of infectious hospital waste in Buri Ram (a) and Ayutthaya (b) provinces (DailyNews & Bangkokpost, 2012)

Dr. Narong Saiwong who was the deputy director of Department of Health revealed that problems of illegal dumping of infectious waste in public areas were caused by infectious waste incinerators of hospitals which could not use or operate effectively. Other causes were a lack of budget or fund in maintenance of incinerators, and the costs of fuels used for incinerators were quite expensive (ThanOnline, 2013).

In Bangkok, The amount of infectious waste has been continuously increasing, and it is the major problem of infectious waste management in Bangkok. Bangkok Metropolitan area defines effective measures and policies for the management of infectious wastes generated by public health facilities in Bangkok. Since 1988, Bangkok had started services in collection, transfer, treatment and disposal of infectious waste. The service had been completely provided since 1999, and fee collections from public health centers began in 2003 (DE, 2012).

At the present, Bangkok Metropolitan Administration (BMA) contracts the Krungthep Thanakom Co., Ltd. to collect, transfer, treat and dispose infectious wastes by the incineration method. The capacity of infectious waste treatment and management is 30 ton/day. There are 2 incinerators with the capacity 15 ton/day/incinerator. The Krungthep Thanakom Co., Ltd. has 18 specialized vehicles for infectious waste collection and transportation which are refrigerated to control temperature not more than 10 degree Celsius. The Krungthep Thanakom Co., Ltd. can collect and dispose almost 100% of the amount of infectious waste generated by public health facilities. However, there is still the amount of infectious waste generated by clinics and polyclinics which cannot be completely collected and disposed.

During 2001 to 2008, generation rates of infectious waste had increased from 11.37 to 20.45 ton/day (Thanakom, 2009a). Numbers of public health facilities using the services of the Krungthep Thanakom Co., Ltd. had increased from 535 to 1,875 places (Thanakom, 2009b). During 2006 to 2010, the amount of infectious waste had been steadily increasing because more clinics used the services of the Krungthep Thanakom Co., Ltd. as shown in **Figure 2-2**. However, more than 50% of clinics did not use the services of the Krungthep Thanakom Co., Ltd (DE, 2012). This meant that infectious waste was still disposed along with general waste, and this might cause potential outbreaks of diseases impacting on human health and the environment.

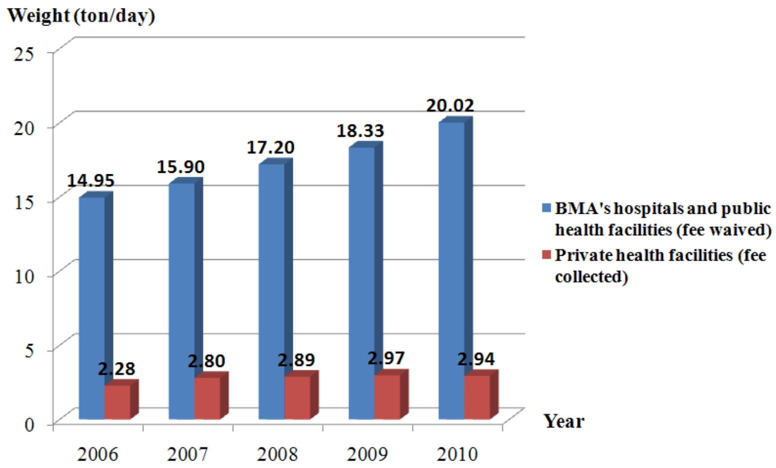


Figure 2-2: Amount of infectious waste collected during 2006-2010 (DE, 2012)

On May 2012, average amount of infectious waste was 27.13 ton/day, and total number of public health facilities using the services of the Krungthep Thanakom Co., Ltd. was 2,329 places excluding 1,381 places of clinics and polyclinics which did not use the services of the Krungthep Thanakom Co., Ltd (Thanakom, 2012).

2.1.3 Definition and types of infectious waste

The definition of infectious waste is specified by foreign or international organizations. World Health Organization defined the meaning and categories of infectious waste as follows (WHO, 1999):

Infectious waste is suspected to contain pathogens (e.g., bacteria, viruses, parasites or fungi) in sufficient concentration or quantity to cause diseases in susceptible hosts. This category includes:

1. Cultures and stocks of infectious agents from laboratory work

2. Waste from surgery and autopsies on patients with infectious diseases (e.g., tissues and materials or equipment that have been in contact with blood or other body fluids)
3. Waste from infected patients in isolation wards (e.g. excreta and dressings from infected or surgical wounds and clothes heavily soiled with human blood or other body fluids)
4. Waste that has been in contact with infected patients undergoing hemodialysis (e.g. dialysis equipment such as tubing and filters, disposable towels, gowns, aprons, gloves and laboratory coats)
5. Infected animals from laboratories
6. Any other instruments or materials that have been in contact with infected persons or animals

In Japan, infectious wastes are defined as the waste materials generated in medical institutions as a result of medical care or research which contain pathogens that have the potential to transmit infectious diseases (Miyazaki et al., 2007).

In Ethiopian, infectious waste is any waste generated from health and health related facilities that are capable of producing infectious diseases. Infectious waste can be classified into ten categories as follows (Alemayehu et al., 2005):

1. Cultures and stocks of infectious agents and associated biological, including without limitation, specimens cultures, cultures and stocks of

infectious agent, waste from production of biological and discarded live and attenuated.

2. Laboratory wastes that were, or are likely to have been, in contact with infectious agents that may present a substantial threat to public health if improperly manage .
3. Pathological wastes, including, without limitation, human and animal tissues, organs, and body parts, and body fluid and excreta that are contaminated with or are likely to be contaminated with infectious agents, removed or obtained during surgery or autopsy or to diagnostic evaluation, provided that, with regard to pathological wastes from animals, the animals have or likely to have been exposed to a zoonotic or infectious agents.
4. Waste materials from the rooms of humans, or the enclosures of animals, that have been isolated because of diagnosed communicable diseases that are likely to transmit infectious agent. Also included are waste materials from rooms of patients who have been placed on blood and body fluids.
5. Human and animal specimens and blood products that are being disposed of, provided that with regard to blood specimens and blood products from animals, the animals were or are likely to have been exposed to a zoonotic or infectious agent.

6. Patients care waste such as bandages or disposable gowns that are lightly spoiled with blood or other body fluids, unless such wastes are spoiled to the extent that the generator of the waste determines that they should be managed as infectious wastes.
7. Sharp used in the treatment, diagnosis, or inoculation of human beings or animals or that have, or are likely to have, come in contact with infectious agents in medical, research, or individual laboratories, including, without limitation, hypodermic needles and syringes, scalpel blades, and glass articles that have been broken. Such wastes hereinafter referred to as “sharp infectious waste” or sharps.
8. Contaminated carcasses, body parts, and bedding of animals that were intentionally exposed to infectious agents from zoonotic or human diseases during research, production of biological, or testing of pharmaceuticals, and carcasses and bedding of animals otherwise infected by zoonotic or infectious agents that may represents a substantial threat to public health if improperly managed.
9. Any other waste materials generated in the diagnosis, treatment and immunization of human beings or animals, in research pertaining these, or in the production or testing of biological.
10. Any other waste materials the generator designates an infectious waste.

In Thailand, the definition of infectious waste is specified in laws or regulations from agencies, organizations or institutes related to infectious waste management.

The regulation of MOPH B.E. 2545 defined the meaning and types of infectious waste as follows (MOPH, 2002):

Infectious waste is any waste that contains pathogens (e.g., bacteria, viruses, parasites or fungi) in sufficient concentration and quantity to cause diseases in susceptible hosts. The term of infectious waste includes as follows:

1. Body parts or carcasses of humans and animals generated from surgery, autopsies and researches
2. Sharps such as needles, blades, syringes, vials, glass wares, slides and cover slides
3. Discarded materials contaminated with blood, blood components, and body fluids from humans or animals, or discarded live and attenuated vaccines, such as cotton, other cloths and syringes
4. Wastes from wards as specified by Ministry of Public Health

2.1.4 Sources of infectious waste generation

Infectious waste is produced during treatment, diagnosis, immunization of humans and/or animals at healthcare facilities, veterinary clinics, health-research centers, medical laboratories, clinics, polyclinics, government and private hospitals, educational institutions, The Red Cross Society, detention centers, medical units, medical institutes, biotechnology units, home health cares, medical manufacturing and others (Huang & Lin, 2008; Thanakom, 2012).

2.1.5 Impacts of infectious waste

a. Public health impacts of infectious waste

For serious virus infections such as HIV/AIDS and hepatitis B and C, health-care workers are at risk of infection through injuries from contaminated sharps (largely hypodermic needles). Needle stick injuries are caused by recapping of hypodermic needles before disposal into containers. Certain infections spread through other media and may lead to a significant risk to the general public and to patients; for example, uncontrolled discharges of sewage from field hospitals treating cholera patients have been strongly implicated in cholera epidemics in some countries. In developing countries, many cases of infections with a wide variety of pathogens are suspected that have resulted from exposure to improperly managed infectious wastes (Alemayehu et al., 2005).

b. Epidemiology of infections from infectious waste

Most infections occur in health facilities which are called nosocomial infections that are not present in the patient at the time of admission to health facilities but they develop during the course of the stay in health facilities. Healthy people are naturally contaminated by infectious waste. Feces contain about 1,013 bacteria per gram, and the number of microorganisms on skin varies between 100 and 10,000 per cm^2. Many species of microorganisms live on mucous membranes where they form a normal flora. Microorganisms that can penetrate the skin or the mucous membrane barrier reach subcutaneous tissue, muscles, bones, and body cavities (e.g. peritoneal cavity, pleural cavity and bladder), which are normally sterile (i.e. contain no detectable organisms). If a general or local reaction to this contamination develops with subclinical and clinical symptoms, there is an infection (Alemayehu et al., 2005).

2.2 Infectious waste generation

Based on information regarding the amount of infectious waste in June 2000 in Bangkok, the generation rate of infectious waste of 75 hospitals was 0.31 kg/bed/day which was not different from the generation rate of 32 kg/bed/day surveyed in 1996. Average amount of infection waste of 148 health centers and 248 clinics and polyclinics was 1.10 and 1.51 kg/place/day, respectively which were lower than the generation rates of 6.50 and 4.60 kg/place/day surveyed in 1996. These results might be caused by Bangkok using services in collection, transfer, treatment and disposal of infectious waste from the private sector.

The Krungthep Thanakom Co., Ltd. provided services in collection, transfer, treatment and disposal of infectious waste generated from public health facilities in Bangkok. In May 2012, total numbers of public health facilities using services by the Krungthep Thanakom Co., Ltd. was 2,329 places, and average amount of infectious waste was 814 ton/month as shown in **Table 2-1** (Thanakom, 2012).

Table 2-1: Providing of services in collection, transfer, treatment and disposal of infectious waste for public health facilities in Bangkok 2012

Types of public health facilities	Total (per month)		Service (per month)		Percentage	
	Number of public health facilities	Amount of infectious waste (ton)	Number of public health facilities	Amount of infectious waste (ton)	Collection and transfer	Disposal
Government hospital	36	380	36	380	100	100
Private hospital	107	323	107	323	100	100
Health center	145	6	145	6	100	100
Clinic and polyclinic	3,264	56	1,883	37	57.69	2.27
Others	158	68	158	68	100	100
Total	3,710	833	2,329	814	62.78	97.83

2.3 Current treatment technologies

There are several technologies for infectious waste treatment, namely, mechanical, thermal, chemical and irradiation processes (Panyaping, 2006).

1. **Mechanical process** is used to change the physical form of the waste to facilitate waste handling. It consists of compaction and shredding. Compaction involves compressing of the waste into containers to reduce its volume. Shredding is used to break the waste into smaller pieces.

2. **Thermal process** is designed to use heat at low temperature (150 °C) and high temperature (600 - 5,500 °C) to decontaminate infectious waste. The thermal processes include autoclaving and incineration.

2.1 Incineration

Incineration processes use high temperature (800 - 1,050 °C) combustion under controlled conditions to convert wastes containing infectious and pathogenic materials to inert material residues and gases. It gives a significant volume and weight reduction, and it sterilizes the waste. There is limitation of the temperature of incineration due to the occurring pollution during operation. It is needed to control its temperature. Incineration is the burning of waste at high temperature. In high temperature with modern incinerators, waste is fed into a primary chamber and exposed to lower temperatures (800-900 °C) under oxygen-starved conditions causing pyrolysis. The pyrolysis gases then pass into a second chamber where they are burned at higher temperatures (+/- 1000°C) resulting in the formation of carbon dioxide and water (PATH, 2005).

2.2 **Autoclave**

Autoclave is a steam sterilization technique that uses steam to directly contact with the waste to disinfect the waste. Steam under pressure is used to obtain a temperature of at least 121°C. The moist heat increases heat transfer and penetrates the waste load. Shredding will increase the exposure of waste to steam, as well as reduce waste volume (PATH, 2005).

3. **Chemical process** involves the use of chemicals (e.g., ozone [gas], chlorine, formaldehyde, ethylene oxide [gas], propylene oxide [gas] and periacetic acid) for disinfection. The effectiveness of each chemical agent depends on temperature, pH, and the presence of compounds which can interfere with disinfection. With proper exposure conditions, waste is sterilized. The process often includes shredding in order to reduce waste volume, increase complete exposure of waste to chemical disinfectant, and render waste unrecognizable before landfill.

4. **Irradiation process** is designed to use ultraviolet or ionizing radiation for irradiating and sterilizing infectious waste. This method includes microwave irradiation. Microwave irradiation is designed to use the electromagnetic radiation spectrum lying in frequencies between the 300 and 300,000 MHz to inactivate microbial organisms. The microwave process uses radiant energy to heat moisture within the waste and/or heat water that is added to the waste. Microwaving units kill infectious agents through heat and pressure, not as a result of exposure to the microwaves. Shredding can be combined with microwaving to reduce volume. Waste is heated between 95°C–100°C and maintained for a regimented period.

5. Among these technologies, autoclaves and incinerators are mostly used for treatment and disposal of infectious waste. Each type of treatment technologies for infectious waste has different advantages and disadvantages as described in **Table 2-2** (MSEA, 2013).

Table 2-2: Advantages and disadvantages of each type of treatment technologies

Types of treatment technologies	Advantages	Disadvantages
Thermal process - Autoclave	- Tested and proven technology with extensive use - On-site or regional treatment of various sizes - Low capital operating cost - No hazardous emissions since combustion is not involved - Complies with current rules in most industrialized countries - Quality control procedures are well established through extensive use - Less manpower required - No pre- or post-treatment required	- Shredding may be required to make treated waste unrecognizable - Only 30 to 35% volume reduction - If autoclave does not have proper drying mechanism, foul odors can be emitted - Requires plastic liners or bags - Cannot treat all types of medical waste - Disposal areas may have a concern about disinfection quality control

- Incineration	- Can accept the greatest variety of waste - Treated waste is unrecognizable and exists as ash - Significant reduction of weight and volume of waste (80 to 90%) - Waste totally sterilized - Very high disinfection efficiency - Energy recovery potential in larger systems	- High investment and operating costs - Incinerators convert biological problem into potential air quality emission problems - Acid gases and heavy metals in air emissions - Heavy metals found in ash residues - Identified as a major source of dioxin and furan emissions
Chemical process	- Economical with low capital investment - Some chemical disinfectants are relatively inexpensive - Reduction in waste volume - Highly efficient disinfection under good operating conditions	- Only for surface contaminated or penetrable waste - Inadequate for pharmaceutical, chemical, and some types of infectious waste - Shredding required for most medical waste - Environmental risk to air and water associated with the chemical use - Uses hazardous substances that require comprehensive safety measures and safe disposal - Requires highly qualified technicians for operation of the process
Irradiation process - Microwave irradiation	- Hi-tech state-of-art technology - Shredding makes biomedical waste unrecognizable - On site treatment of varying capacities - No hazardous emissions since combustion is not involved - Complies with current rules in most industrialized countries - Proven technology with world-wide installations including larger regionally-based systems	- High capital cost. - Pre-shredding and wetting of waste required - All waste cannot be processed - Highly skilled manpower required - High operating and maintenance cost

2.4 Mass flow analysis

2.4.1 Concepts and theory

Material flow analysis (MFA) is a systematic assessment of the flows and stocks of materials within a system defined in space and time. It connects the sources, the pathways, the intermediate and final sinks of a material. Because of the law of the conservation of matter, the results of an MFA can be controlled by a simple material balance comparing with all inputs, stocks, and outputs of a process. It is the distinct characteristic of MFA that makes the attractive method as a decision-support tool in resource management, waste management and environmental management (Brunner & Rechberger, 2004).

2.4.2 Applications

MFA has been applied as a basic tool in such diverse fields as economics, environmental, resource and waste management. MFA is used in fields of waste management for investigating the substance management of recycling or treatment facilities. For instance, substance control by an incinerator is different from substance control by a mechanical-biological treatment facility. MFA can contribute to the design of better products which are more easily recycled or treated once they become obsolete and turn into waste. These practices are known as design for recycling, design for disposal or design for the environment.

2.4.3 Publications about MFA

According to Binder & Mosler (2007), the research investigated waste-resource flows of short-lived goods in households of Santiago de Cuba. The research applied the method of material flow analysis to analyze the consumption and waste mass flows of short-lived goods and understand the waste management behavior of households in Santiago de Cuba. The analyzed goods were glasses, aluminum, organic materials and PET. The necessary data were gathered in personal interviews with 1,171 households using a standardized questionnaire. The households were asked how many PET bottles, aluminum, and glass containers which they consumed per month, and how they disposed of the different kinds of garbage. The results showed the material flows for glass, PET and aluminum, respectively (in kg/household and year). Regarding weight, glasses were the most widely used packaging material with a yearly consumption of 22 kg/household as shown in Figure 2-3 and followed by PET with 3.3 kg/household and aluminum with 1.3 kg/household.

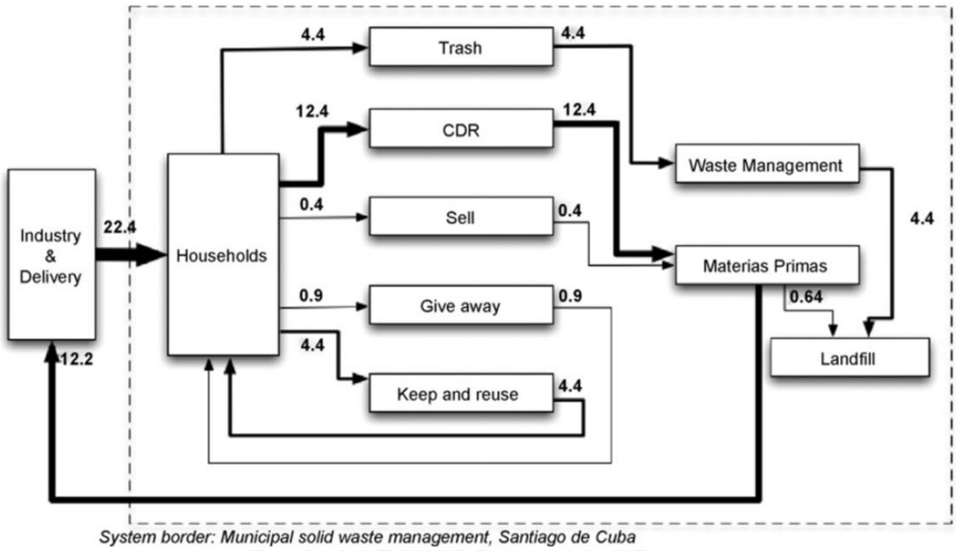


Figure 2-3: Material flow analysis for glass in kg/capita and year for 2004 in Santiago De Cuba

According to Asari et al., (2008), the research investigated life-cycle flow of mercury and analyzed recycling scenario of fluorescent lamps in Japan. The research summarized the mercury flow of mercury-containing products from their manufacture to their disposal in Japan and discussed the current management of mercury-containing hazardous household waste (HHW). The mercury flow originating from these products was estimated to be about 10-20 tons annually, and around 5 tons of which was attributable to fluorescent lamps. Fluorescent lamps were the major mercury-containing products in Japan. The mercury flow for end-of-life fluorescent lamps (excluding backlights) was analyzed under three scenarios for Kyoto, Japan in 2003: the present condition scenario, the improved recycling scenario, and the complete recycling scenario. Under the present condition scenario, mercury flow was calculated to be 34 kg Hg for incineration, 17 kg Hg for crushing, 21 kg Hg for landfill, and only 4 kg Hg for recycling as shown in **Figure 2-4**. Incinerated and landfilled mercury from end-of-life fluorescent lamps contributed to residential waste, and crushed lamps contributed to commercial and industrial waste.

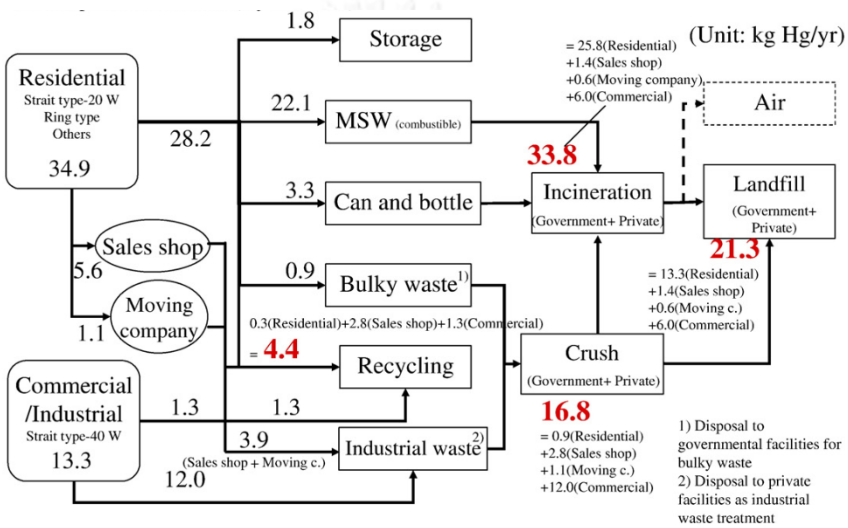


Figure 2-4: Estimated flow of mercury for one scenario for end-of-life fluorescent lamps in Kyoto (2003) under the present condition scenario

2.5 Gashouse gas (GHG) emissions

2.5.1 Concepts and theory

Greenhouse gas footprint refers to the amount of GHG that are emitted through transport, land clearance and the production and consumption of food, fuels, manufactured goods, materials, wood, roads, buildings and services. For simplicity of reporting, it is often expressed in terms of the amount of carbon dioxide or its equivalent of other GHGs emitted. There are six recognized GHGs including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) (Wikipedia, 2014).

GHG footprint analysis is a measurement of an organization's direct and indirect GHG emissions. Greenhouse gases contribute to climate change and global warming through the greenhouse effect. A GHG report will measure an entity's direct and indirect emissions of the various gases, and they convert the data to CO_2 equivalents. The final result is the tons of CO_2 equivalents released over the year. This is a number to be managed (GreenCPA, 2008).

2.5.2 Applications

GHG accounting and reporting are widely used in the business sector to show the commitment and demonstrate social responsibility of the organization, and they result in raising an environmental awareness to the organization's employees, enhancing energy efficiency or saving natural resources and energy leading to less production costs. To manage GHG risks and identify reduction opportunities, the organization can identify the major GHG sources and thus prioritize the implementation to reduce the risks.

Unilever Co., Ltd. has used the concept of GHG footprint to measure the GHG impact across the lifecycle of their products to find the biggest opportunities for reducing GHG emissions. They have developed a metric which measures the GHG emissions associated with the lifecycle of a product, such as the GHG emissions from drinking a single cup of tea. They used the insights and knowledge of Unilever experts to develop individual metrics (e.g., greenhouse gas emissions, water and waste) and to apply these to their portfolio of products. The metric covers the GHG emissions related to raw materials, manufacture, transport, consumer use and disposal of their products. They aim to capture the most significant areas of impact across the product lifecycle to identify where we can have an influence and where it is feasible to measure the outcome. They conducted an extensive baseline measurement of their global product portfolio. Setting a baseline helps them understand the size and scale of their impacts enabling them to prioritize and put in place actions to address these through innovation or actions in the marketplace such as improving waste management practices. To set the baseline, they assessed the GHG emissions across the lifecycle of more than 1,600 representative products in 2008. They calculated it at an absolute level as well as on a 'per consumer use' basis in 14 countries. The calculation covers 70% of their volumes (Unilever, 2014).

2.5.3 Publications about GHG emissions

According to Pirlo et al., (2014), the carbon footprint (CF) of milk produced in six Italian Mediterranean Buffalo farms was estimated through life cycle assessment (LCA). The farms were characterized by high levels of inputs (e.g., purchased feeds, chemical fertilizers and fossil fuels). The forage system was based mainly on maize silage and followed by Italian ryegrass and/or whole cereal silage. The CF assessment was from cradle to farm gate. The greenhouse gases (GHG) that were taken into account were CH_4 from enteric fermentations, CH_4 from manure in the stable and the tank, N_2O from nitrification and denitrification processes in the manure before application into the soil and N_2O produced after organic and synthetic fertilizer application, direct emissions of CO_2 from the fossil fuels combustion within the farms and indirect emissions of CO_2 deriving from production of electricity, off- farm feeds, synthetic fertilizers and other minor inputs. Carbon footprint of 1 kg of fat and protein corrected milk (FPCM) was 3.75 kg CO_2eq. Main sources of GHG were enteric CH_4 (45%) and indirect CO_2eq (25%). Besides enteric CH_4, the farm activity that gives the highest contribution to milk CF was on-farm feed production with 34% on total greenhouse gas emissions (TGE). Carbon footprint with economic allocation (CFea) was estimated by considering the live-weight of male calves and culled cows, and its value was 3.60 kg CO_2eq. If the economic value of the increase of the herd size is considered in the assessment, CFea will decrease to 3.45 or 3.27 kg CO_2eq with an increase of 10 % or 20 % of the number of mature buffalos.

According to Monni (2012), the research assessed GHG emissions of different actors from landfilling to waste incineration. The EU policies promoted material and energy recovery from waste and the production of energy from renewable sources. In the energy system, the replacement of another energy production plant with a waste to energy plant (WTE) may either increase or decrease the total emissions. Cities and companies calculated their GHG emissions or carbon footprint using various calculation protocols, and a change from landfilling to waste incineration affected the emissions of these actors in various ways depending on the system boundaries. In this contribution, impact of a change from landfilling to WTE on the emissions of different actors was calculated for the case in which WTE replaces separated production of district heat (DH) by natural gas and electricity by coal. In the case of a waste management company, emissions decreased from about 51 kt CO_2eq in 2009 (before introduction of the WTE) to −33 kt CO_2eq in 2030. Emissions of DH company decreased by 40%, whereas at the city-level the combined emissions of waste management and district heat consumption decreased 60% between 2009 and 2030. The significance of the energy source to be replaced by energy from WTE on the potential GHG emission reductions was also calculated for different options. The emissions of electricity and district heat produced by WTE were 35–60% smaller than emissions from separating production of district heat by oil or natural gas and production of electricity by natural gas or coal. When electricity and DH produced by the WTE replaced those produced by alternative CHP plants, the impact varied from increase of emissions by 50% to decrease of emissions by 40% depending on the fuel of the CHP plant and electricity source used to cover the smaller electricity generation by the WTE. However, in all the cases, when the avoided emissions from landfilling were taken into account, the emissions of WTE were smaller than those of alternative waste management and energy generation options over time.

2.6 Eco-efficiency

2.6.1 Concepts and theory

Eco-efficiency is one of the main analysis frameworks to promote a transformation from unsustainable development to one of sustainable development. It is based on the concept of creating more goods and services while using fewer resources and creating less waste and pollution. Eco-efficiency indicator is measured as the ratio between the added value of what has been produced (e.g., GDP) and the added environmental impacts of the product or service (e.g., SO_2 emissions). According to World Business Council for Sustainable Development (WBCSD) definition, eco-efficiency is achieved through the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing environmental impacts of goods and resource intensity throughout the entire life-cycle to a level at least in line with the Earth's estimated carrying capacity. In short, it is concerned with creating more value with less impact (WBCSD, 2000).

2.6.2 Applications

The WBCSD has developed a set of eco-efficiency indicators to help measure progress towards economic and environmental sustainability in the business sector (EllipsonAG, 2000). Elements of eco-efficiency in the business sector are reduction of material requirements and energy intensity of goods and services, reduction of toxic dispersion, enhancing of material recyclability, maximizing of the sustainable use of renewable resources, extending of product durability, and increase of the service intensity of goods and services. For example, the government of Japan applied the concept of eco-efficiency to assess its own eco-efficiency relative to the performance of OECD countries (Organization for Economic Co-operation and Development) in terms of CO_2 emissions, final energy consumption, gross domestic product (GDP) and the amount of municipal solid waste generated. The eco-efficiency is expressed in terms of environmental load per unit of economic activity (e.g., CO_2 per GDP) which is used as standard in comparing the performance of countries as shown in **Figure 2-5**, and it provides policy and strategic directions in management to improve the overall eco-efficiency performance and quality of growth (ESCAP, 2009).

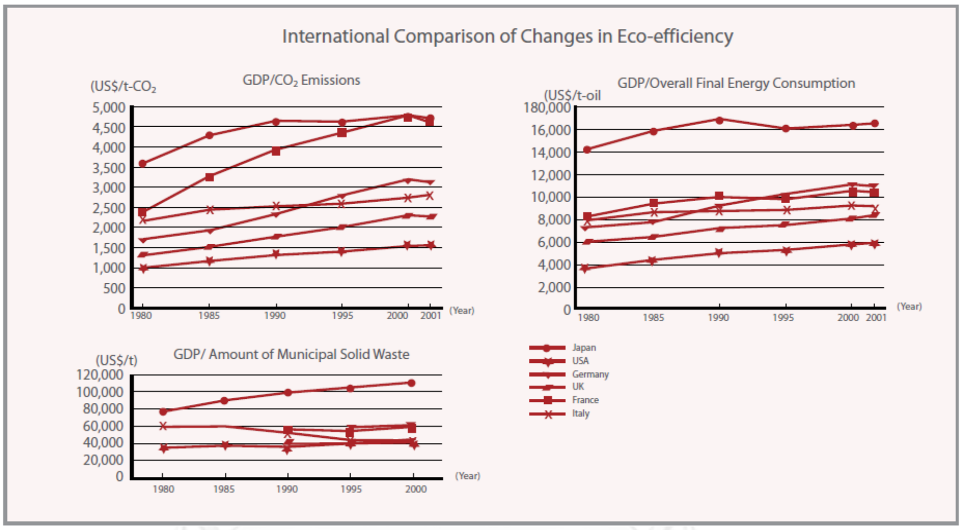
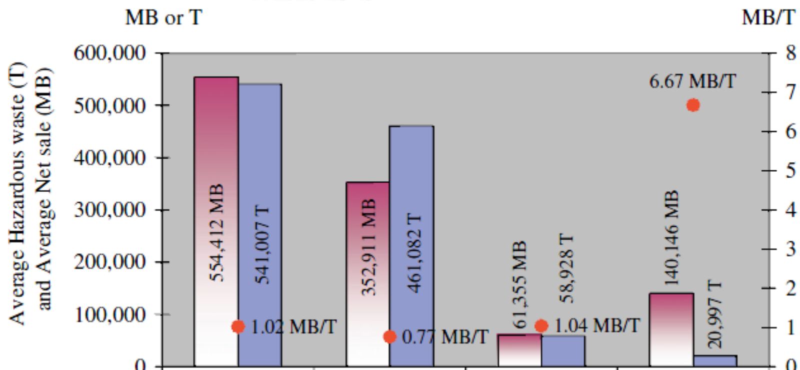


Figure 2-5: Applications of eco-efficiency at the macro level in Japan (ESCAP, 2009)

2.6.3 Publications about eco-efficiency

According to Charmondusit & Keartpakpraek (2011), the research summarized the use of eco-efficiency indicators focusing on the sector level. The eco-efficiency of the petroleum and petrochemical group in the MTPIE was evaluated as the ratio of economic value to specific environmental influences. Net sale and gross margin in unit of baht (B) were selected as the economic performance indicator. The environmental performance indicator consisted of four specific indicators which were materials consumption in tons (T), energy intensity in giga joules (GJ), water use in cubic meters (m3), and hazardous waste generation in tons (T). In term of eco-efficiency indicators, average hazardous waste eco-efficiency indicator in net sale term calculated from the ratio of average net sale (MB) to average waste (T) after that the eco-efficiency indicator was in term of MB/T as shown in Figure 2-6.



	PP group	Upstream	Intermediate stream	Downstream
Average Net sale (MB)	554,412	352,911	61,355	140,146
Average Waste (T)	541,007	461,082	58,928	20,997
Eco-efficiency in MB/T	1.02	0.77	1.04	6.67

Figure 2-6: Hazardous waste eco-efficiency indicators of the petroleum and petrochemical group in term of net sale value (Charmondusit & Keartpakpraek, 2011)

2.7 Current policies for infectious waste management

2.7.1 International laws and regulations

I. Stockholm convention 1 and 2 on persistent organic pollutants

United Nations Environment Programme (UNEP) reported that chemicals in POPs group were the most harmful pollutants comparing with other pollutants discharged into the environment by human activities, industries, and others. There are 12 types of Persistent Organic Pollutants (POPs) such as aldrin, chlordane, DDT, dieldrin, endrin, heptachlor, mirex, toxaphene, polychlorinated biphenyls (PCBs), hexachlorobenzene, dioxins, and furans. These pollutants kill and damaged life of humans and animals by damaging nervous, reproductive, and immune systems and causing cancer, birth defects, and disabilities. Therefore, Stockholm Convention is very useful to prevent human health and the environment because governments had obligation with Stockholm Convention on cancelling the production and the discharge of these chemical pollutants to the environment. Stockholm Convention defines criteria to promote the use of the best available techniques and the best environmental practices that can reduce or eliminate emissions of dioxins and furans to the environment. This convention is used to prevent and monitor dioxins and furans generated from infectious waste incineration to the environment (Thanakom, 2013).

II. Air emission regulations and performance standards for infectious waste incinerators

United State Environmental Protection Agency (USEPA) defines air emission standards to control the release of air pollutants (e.g., sulfur dioxide (SO2), nitrogen oxide (Noxas NO2), hydrogen chloride (HCl), hydrogen fluoride (HF), PCDD/Fs as international toxic equivalent; I-TEQ, total suspended particulate, opacity, mercury (Hg), cadmium (Cd), and lead (Pd)) from infectious waste incinerator to the environment (Thanakom, 2013).

2.7.2 Domestic laws and regulations

There is the use of ministerial regulations, Acts, commandments and notification of various ministries of Thailand to control and manage collection, transfer, treatment and disposal of infectious waste including fee rates of services and the release of air pollutants from infectious waste incinerator (Thanakom, 2013).

I. Notification of Ministry of Public Health on the determination of site and container characteristics for infectious waste

From notification of Ministry of Public Health on the determination of site and container characteristics for infectious waste in volume 122, special section 52 (IV), it was promulgated in the Royal Government Gazette on July 14, 2005. There is determination of site characteristics for storage of infectious waste containers where has to locate within hospitals, the specific site, no moisture, and convenience for transferring infectious waste to disposal facilities. Containers for storage of infectious waste have to be made of strong materials which have resistance to chemicals, no leaks, and sealed lids. These containers must have enough capacity that can store infectious waste at least 2 days and in case of storage of infectious waste more than 7 days at not exceeding 10 ° C. These containers have to be visibly labeled.

II. Bangkok regulations, B.E. 2545 on solid waste and sewage management of buildings, places and public health facilities

There was the determination of regulations in managing solid waste and sewage of a building, places, and public health facilities. They were under the authority according to section 49 of Bangkok Administration Act, B.E. 2528 along with article 7 and 14 of Bangkok Commandment, B.E. 2544 on collection, transfer, treatment and disposal of garbage or solid waste. These regulations were notified by the governor of Bangkok.

2.7.3 Management mechanisms and operating structures

In Thailand, there are 4 classifications of infectious waste disposal in public hospitals and processes of infectious waste management consisting of segregation and collection, storage, transportation, treatment and disposal.

I. Classifications of infectious waste disposal of public hospitals in Thailand

Infectious waste management in public hospitals can be classified into 4 methods as follows (Hansakul, 2009).

1. **Onsite hospitals:** Some hospitals treat their infectious wastes by their own incinerators.

2. **Local Administrative Organizations:** Some hospitals and some public health facilities which have no incinerators will transport their infectious wastes to incinerators of Local Administrative Organizations.

3. **Other hospitals:** Some hospitals and some public health facilities which have no incinerators will transport their infectious wastes to incinerators of onsite hospitals.

4. **Private sector disposal:** some hospitals and some public health facilities employ private sectors in collection, transportation, treatment and disposal of their infectious wastes.

II. Processes of Infectious Waste management

In Thailand, Ministry of Public Health introduces processes of infectious waste management in segregation and collection, storage, transportation, treatment and disposal of infectious waste.

i. Segregation and Collection

Infectious waste must be segregated and collected at sources of generation to containers for infectious waste storage as follows:

1. Containers (e.g., red plastic bags, boxes or drums) must be visibly labeled with "Infectious Waste" and biohazard symbol as shown in **Figure 2-7**. Red boxes and drums must be made of strong materials which are resistant to perforation and erosion of chemical solution including prevention of fluid leakages inside red boxes or drums. Red bags must have opacity, resistance to chemicals, laceration, leakages, and loading capacity.
2. All types of infectious waste excluding sharps will be packed in the red bags which do not exceed to 2/3 of the total volume.
3. Sharps will be packed in red boxes or drums which do not exceed to 3/4 of the total volume.

Figure 2-7: Labeling of infectious waste and biohazard symbol on red plastic bags, boxes and drums

ii. Storage

After segregating and collecting infectious waste, the next step is transfer of infectious waste to gathering or storage areas to wait transfer for further disposal.

1. Workers

Workers must pass training programs of prevention and inhibition of outbreaks of harmful diseases caused from infectious waste, and workers must wear personal protective equipment such as thick rubber gloves, aprons, masks and boots throughout the operation.

2. Methods for transfer

Transfer of infectious waste must be operated everyday as specified in schedule by infectious waste containing trolleys and have certain routes for transferring infectious waste to gathering or storage areas. During transferring infectious waste, infectious waste containing vehicles do not stop or pause anywhere. Infectious waste containers do not throw and drag. In case of infectious waste or containers dropped during transferring, workers do not pick by empty hands, but they must use pliers or thick rubber gloves in picking up.

3. Characteristics of carts or trolleys using for transfer

Carts or trolleys using for transferring infectious waste must be made of materials which are easy to clean up, and they can be cleaned with water. They must have opaque floors and walls. When infectious waste containers are put into carts or trolleys, their lids must be tightly closed to prevent animals and insects. They must be visibly labeled with only transferring infectious waste.

4. Characteristics of gathering or storage areas

Gathering or storage areas must have enough loading capacity, smooth floors and walls, no moisture, rails or sewers connecting to wastewater treatment systems, and it must be easy to transfer infectious waste and clean up. It must be visibly labeled with gathering or storage area for only infectious waste.

iii. Transportation

This is transportation of infectious waste from gathering or storage areas to disposal facilities by infectious waste containing vehicles which have controlled temperature not more than 10 °C. Drivers and workers must pass training programs of prevention and inhibition of outbreaks of harmful diseases caused from infectious waste.

iv. Treatment and disposal

Most technologies using for treatment and disposal of infectious waste are incinerators and autoclaves as described in **Section 2.3**. Within 30 days after collecting and transporting from sources, infectious waste should be disposed. Monitoring and operating reports should be monthly submitted to the local government. After disposal of infectious waste by aforementioned technologies, there is examination that infectious waste passed elimination of pathogens as specified in biological standards and regulations.

2.7.4 Publications about infectious waste management

According to Panyaping (2006), the research investigated medical waste management practices in Thailand. Waste management practices (WMPs) in hospitals were considered in terms of similarity and difference of medical WMPs comprising of infectious waste, solid waste, hazardous waste, and wastewater. The amount of infectious waste generated from different size of hospitals in Chiang Mai was a rate of 0.17 to 0.97 kg/day/bed. Most of big hospitals had an incinerator where medical waste was burned. The ash from incinerating medical waste was buried in a landfill. Solid waste in hospitals was sent to a municipal landfill, but some hospitals had an advanced recycling program. Some hazardous waste was either buried or sent to a private secured landfill. All hospitals had wastewater treatment plants (WWTP), but some WWTP needed advice for coping effectively with the WWTP problems. A standard operating procedure (SOP) and regulations for segregation of infectious waste, solid waste, and hazardous waste were improved to provide more effective WMPs in hospitals. The SOP should outline the method for handling hospital wastes, how to collect, segregate, treat, and dispose of these wastes. Incinerators and WWTPs in the hospitals should regularly be visited and inspected by the agency responsible for regulating these facilities to improve their efficiency and to solve problems.

According to Miyazaki et al., (2007), the research investigated the treatment of infectious waste arising from home health and medical care services: present situation in Japan. Because home health and medical care waste materials (HHMC waste materials) are collected in a mixed form, transported and disposed along with municipal solid wastes, municipal workers are suffering needle-prick accidents which may cause infection. This research emphasized to describe the present situation regarding HHMC waste materials and to determine the safe and effective management strategies for municipal workers dealing with such waste materials. In order to evaluate the fate of HHMC waste materials, a questionnaire was mailed to medical institutions, home-visit nursing stations (HVNSs), and regional pharmaceutical associations (RPAs). The results found that 87.5% of medical institutions reported that their patients transported used needles to medical institutions. These recovery rates were 61.2% of HVNSs and 30.6% of RPAs. Non-sharp objects were not separately collected. 33.9% of municipal governments reported accidents by collection and transportation of HHMC waste materials, while 95.0% of 20 municipal governments experienced needle stick accidents. Main obstacles in the appropriate management of HHMC waste materials are high cost of management and no establishment of handling, treatment and disposal methods in home. An appropriate method of collection of sharp objects is separation of wastes with sharp objects from other HHMC wastes to prevent injury. Sharp objects need to be put in a container with a lid to prevent a prick. The containers for disposal of sharp objects are collected and transported separately from general-household waste materials.

According toYong et al., (2009), the research investigated medical waste management in China: a case study of Nanjing. Because infectious and hazardous nature of medical wastes can cause undesirable effects on humans and the environment, medical waste management is very essential to reduce and prevent a risk of these effects. 15 hospitals, 3 disposal companies, and 200 patients were surveyed to analyze and evaluate the present situation of medical waste management in Nanjing. Information regarding different medical waste management aspects, including medical waste generation, segregation and collection, storage, training and education, transportation, disposal, and public awareness was collected by using field visits and a questionnaire survey method. The results found that the average generation rate of medical waste generated from the 15 hospitals is between 0.5 and 0.8 kg/bed day with a weighted average of 0.68 kg/bed day. 73% of the hospitals use segregated collection of various types of medical waste as follows: infectious waste was collected in yellow bags; municipal waste was collected in black bags; sharps were collected in plastic containers. 20% of the hospitals still use unqualified staffs for medical waste collection, and 93.3% of the hospitals have temporary storage areas. In medical waste transportation, the hospitals have the responsibility for providing on-site transportation of medical waste, while off-site transportation to the final disposal site is handled by disposal companies. The centralized disposal system by incineration technology has been constructed to treat these medical wastes, and the disposal cost of medical waste is about 580 US$/ton. There is proposal of some recommendations and management strategies to minimize potential health and environmental risks of medical wastes including increasing efficiency of medical waste management in Nanjing.

CHAPTER III

RESEARCH METHODOLOGY

Chapter III described the steps of research methodology. The research methodology was divided into five main sections as follows: (i) review and collection of relevant data for developing and analyzing the thesis, (ii) development of the MFA diagram of infectious waste management in Bangkok, (iii) account of greenhouse gas (GHG) emissions from infectious waste management in Bangkok, (iv) evaluation of efficiency of infectious waste management in Bangkok by using eco-efficiency indicators and (v) development and recommendations of management strategies for better improving the efficiency of infectious waste management in Bangkok.

3.1 Review and collection of relevant data

There were a review and collection of data regarding infectious waste management in Bangkok used this study from various sources as described below:

3.1.1 Materials of infectious waste management

Secondary data of materials of infectious waste management in Bangkok used in this study was collected and supported by the Krungthep Thanakom Co., Ltd. Materials were infectious waste, fuel (e.g., diesel, NGV and LPG), electricity, air pollutants (e.g., sulfur dioxide (SO_2), nitrogen oxide (NO_x as NO_2), hydrogen chloride (HCL) , carbon dioxide (CO_2), carbon monoxide (CO) and particulate matter and wastewater components (e.g., Total Dissolved Solids (TDS), Total Suspended Solids (TSS), Total Kjeldahl Nitrogen (TKN), settleable solids, sulfide and oil and grease). This data was collected as used to develop mass flow analysis and evaluate eco-efficiency of infectious waste management in Bangkok.

3.1.2 Material **flow analysis related to the thesis**

The theory, concepts, applications and research about material flow analysis of waste management were reviewed to be a guideline or background in determining involved processes, stocks, mass flows, subsystems and spatial and temporal boundaries of the MFA model of infectious waste management in Bangkok.

3.1.3 Eco-efficiency **indicators related to the Thesis**

The theory, concepts, applications and research about eco-efficiency used in evaluation of environmental and economic performance in the business sector were reviewed to be a guideline or background for evaluating eco-efficiency of infectious waste management in Bangkok.

3.1.4 Laws, regulations and policies for infectious waste management

International and domestic laws and regulations about infectious waste management were reviewed to understand proper and improper infectious waste treatment and disposal systems, segregation and collection practices of infectious waste and enforcement of laws and regulations in each country. These showed situations of infectious waste management in Thailand and other countries before there was development of recommendations applied to improve efficiency of infectious waste management in Bangkok.

3.2 Development of MFA diagram of infectious waste management in Bangkok

The MFA diagram of infectious waste management in Bangkok was developed by adopting methods according to Brunner and Rechberger (2004). To analyze the amount of infectious waste and the quantity of changed forms (e.g., air pollutants, wastewater components and bottom ashes) of infectious waste management system in Bangkok, the following four steps of MFA are essential guideline to establish the model as follow: (i) analysis of the system and the involved processes and materials (model building stage), (ii) measurement of the material or mass flows (data collection), (iii) calculation of materials and mass flows and (iv) interpretation of the results. Therefore, details in each step were explained below.

3.2.1 Analysis of the system, the involved processes and materials (Model building stage)

This step was a building stage described about determination of the system, materials used in the system, the involved processes, stocks and mass flows, spatial and temporal boundaries of the system and the mass balance equation.

a. Material flow analysis

Material flow analysis (MFA) is a method for describing and analyzing the material balances of a system as described in **Section 2.4**. The MFA model was defined by the system boundary, internal and external balance volumes, materials and its flows between different processes of infectious waste management in Bangkok to analyze total average amount of infectious waste over time and total average quantity of changed forms (e.g., air pollutants, wastewater components and bottom ashes).

b. Selection of materials

There are various approaches to choose relevant materials for the MFA model. They depend on the purpose of the MFA model, and on the other hand, they depend on the kind of a system on which the MFA model is based. Materials considered in this MFA model were a bulk of infectious waste and changed forms (e.g., air pollutants, wastewater components and bottom ashes) after it passed treatment and disposal system.

c. System definition in space and time

Space or a spatial boundary is usually determined by the scope of the study, and it is an administrative boundary (e.g., municipalities, cities or nations). This study aims to develop material flow analysis of infectious waste management in Bangkok which consisted of 20 pre-established routes for infectious waste collection and transportation to the disposal company covering total number of public health facilities in 50 districts of Bangkok. Total amount of infectious waste was treated by two incinerators of the Krunthep Thanakom CO., Ltd. which was BMA's enterprise. The spatial boundary used in this MFA model was infectious waste management in Bangkok.

Time or a temporal boundary depends on the kind of an inspected system and the given problem. It is the time span which the system is investigated and balanced. Data availability review was conducted as an initial step to define a period and frequency of data collection from various sources. Data of the amount of infectious waste and use of fuel (e.g., diesel, NGV and LPG), water supply and electricity was monthly collected by BMA's enterprise. Data of the quantity of air pollutants and wastewater components was quarterly collected by the disposal company. Data availability used for developing MFA diagram of infectious waste management in Bangkok was data collection during June 2012 and May 2013 that all data was averaged in unit of kg/month of mass flows.

d. Identification of relevant flows, stocks and processes

This section described identification of relevant flows, stocks and processes of the MFA model. In order to understand some technical terms of MFA according to Brunner and Rechberger (2004), they are described as follows:

Stocks are defined as material reservoirs (mass) within the analyzed system and have the physical unit of kilograms, tons or other units. A stock is a part of a process comprising of the mass that is stored within the process. Stocks are essential characteristics of metabolism of a system. For steady-state conditions (input equals output), the mean residence time of a material in the stock can be calculated by dividing the mass in the stock by the material flow in or out of the stock. Stocks can stay constant, or they can increase (accumulation of materials or decrease (depletion of materials) in a size.

Processes are linked by flows (mass per time) or fluxes (mass per time or cross section) of materials. Flows or fluxes across system boundaries are called imports or exports. Flows or fluxes of materials entering a process are named inputs while those exiting are called outputs.

Transfer coefficients (TC) are used to describe the partitioning of a substance in a process and to divide flows when a process has multiple outputs. Mass flows between different processes are modeled by transfer coefficients (TC) which define the fraction of total inputs into the process transferred to other processes.

e. Mass balance equation

According to the mass balance principle, the mass of all inputs into a process equals those of outputs plus a storage term that considers accumulation or depletion of materials in the process as illustrated in Figure 3-1 and Equation 3-1. The mass balance principle applies to check the mass balance in systems and processes. If inputs and outputs have no balance including accumulation and depletion rate, one or several flows are missing, or they have been incorrectly determined.

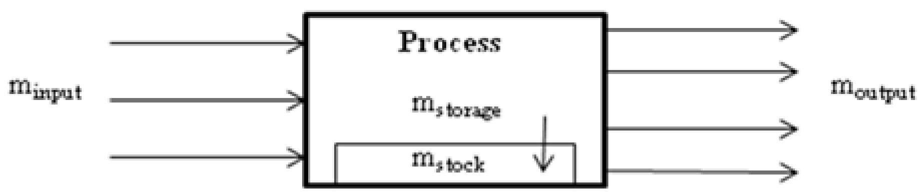


Figure 3-1: Consideration of a process's stock

$$\sum M_{input} = \sum M_{output} + M_{storage} \qquad \text{(Eq. 3-1)}$$

3.2.2 Measurement of the materials or mass flows

a. Determination of mass flows, stocks and quantities

All data of total average amount of infectious waste, total average number of public health facilities, total average quantity of bottom ashes, wastewater components and air pollutants and processes of infectious waste management were collected to determine mass flows, stocks and a process. Types of mass flows, origin and destination processes, stocks, data sources and units of mass flows were described in **Table 3-1**.

Table 3-1: Determination of mass flows, stocks and quantities for developing the MFA diagram

Flow types	Description	Units	Sources
F_{GCS}	The flow of infectious waste from government hospitals (G) to collection and storage (CS)	Kg/month	Secondary data: average amount of infectious waste during June 2012 and May 2013 (Krungthep Thanakom, 2013)
F_{PCS}	The flow of infectious waste from private hospitals (P) to collection and storage (CS)	Kg/month	Secondary data: average amount of infectious waste during June 2012 and May 2013 (Krungthep Thanakom, 2013)
F_{HCS}	The flow of infectious waste from health centers (H) to collection and storage (CS)	Kg/month	Secondary data: average amount of infectious waste during June 2012 and May 2013 (Krungthep Thanakom, 2013)
F_{CPCS}	The flow of infectious waste from clinics and polyclinics (CP) to collection and storage (CS)	Kg/month	Secondary data: average amount of infectious waste during June 2012 and May 2013 (Krungthep Thanakom, 2013)

F_{OCS}	The flow of infectious waste from others (O) to collection and storage (CS)	Kg/month	Secondary data: average amount of infectious waste during June 2012 and May 2013 (Krungthep Thanakom, 2013)
F_{CSI}	The flow of infectious waste from collection and storage (CS) to incinerator (I)	Kg/month	Calculation: $F_{CSI} = F_{GCS} + F_{PCS} + F_{HCS} + F_{CPCS} + F_{OCS}$
F_{IA1}	The flow of air pollutants (e.g., particulate, SO_2, NO_x as NO_2, HCL , CO and CO_2) from incinerator (I) to atmosphere (A1)	Kg/month	Secondary data: average quantity of air pollutants in August 2012, November 2012, February 2013 and May 2013 (Krungthep Thanakom, 2013)
F_{IA2}	The flow of moisture content in infectious waste from incinerator (I) to atmosphere (A2)	Kg/month	Calculation: $F_{IA2} = F_{CSI} - F_{IA1} - F_{IW1} - F_{IS}$
F_{IW1}	The flow of wastewater components (e.g., TDS, TSS, settleable solids, sulfide, TKN, oil and grease) from incinerator (I) to wastewater treatment plant 1 (W1)	Kg/month	Secondary data: average quantity of wastewater components in September 2012, November 2012, February 2013 and May 2013 (Krungthep Thanakom, 2013)
F_{W1W2}	The flow of treated wastewater components (e.g., TDS, TSS, settleable solids, sulfide, TKN, oil and grease) from wastewater treatment plant 1 (W1) to wastewater treatment plant 2 (W2)	Kg/month	Calculation: $F_{W1W2} = F_{IW1} - M_{storage}$
F_{IS}	The flow of bottom ashes from incinerator (I) to secure landfill (S)	Kg/month	Calculation: FIS = capacity of 1.5 tons of side loading trucks for collecting bottom ashes from incinerator to secure landfill x 60 trips per month (Krungthep Thanakom, 2013)

b. System analysis and model description

The material flow model used in this study was designed according to the following system analysis and was depicted in **Figure 3-2**.

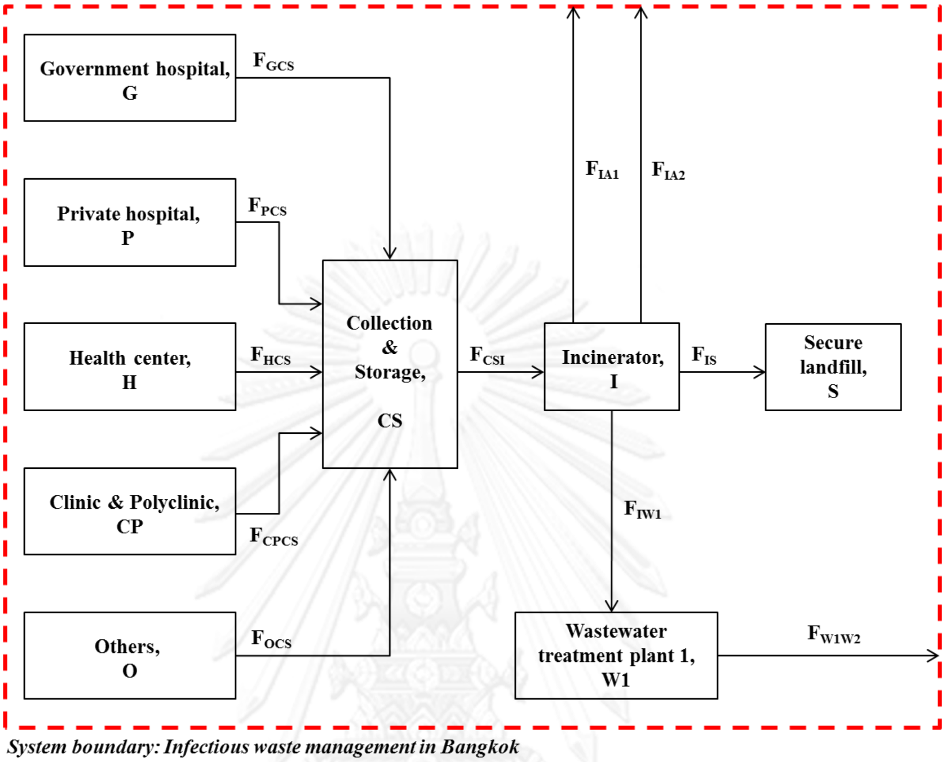


Figure 3-2: The system boundary and processes of the material flow analysis model used in this study (G, P, H, CP, O and other capital letters: processes and stocks; Fij: flows from process i to process j)

- *System components*

A system comprises of a set of material flows, stocks and processes within the defined boundary. The system consisted of five system components of public health facilities, collection and storage, two incinerators, wastewater treatment plant1 and secure landfill.

i. Public health facilities

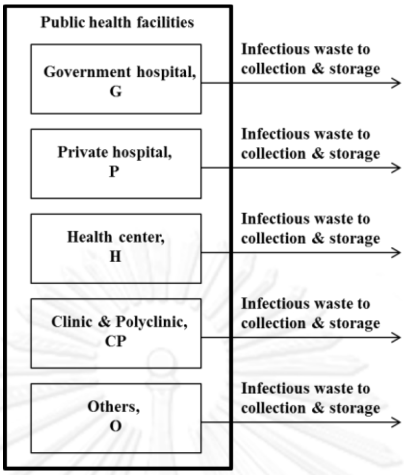


Figure 3-3: Model structure of public health facilities

Public health facilities consisted of average number of 36 government hospitals, 108 private hospitals, 145 health centers, 1,953 clinics and polyclinics and 167 others (e.g., the Red Cross Society, educational institutions and companies) as shown in **Figure 3-3**. Infectious waste outflows were average amount of infectious waste generated by each public health facility, and they were collected and transferred into a temporary storage area at the infectious waste incinerator factory.

ii. Collection and storage

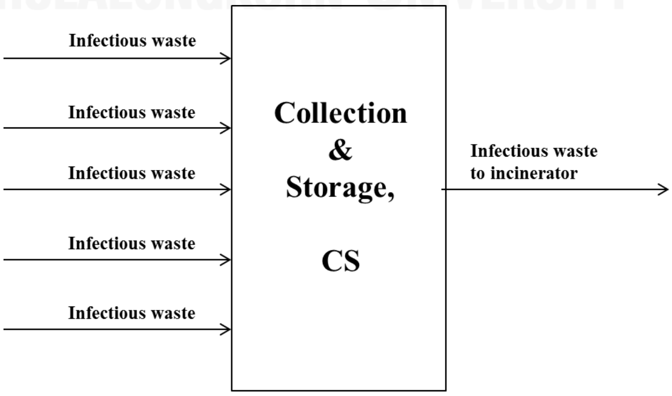


Figure 3-4: Model structure of collection and storage

Infectious waste inflows were average amount of infectious waste generated by each public health facility, and they were collected and transferred into a temporary storage area at the infectious waste incinerator factory. An infectious waste outflow was total average amount of infectious waste generated from all public health facilities which was treated and loaded into two incinerators. Inflows and an out flow of collection and storage were shown in **Figure 3-4**.

iii. Incinerators

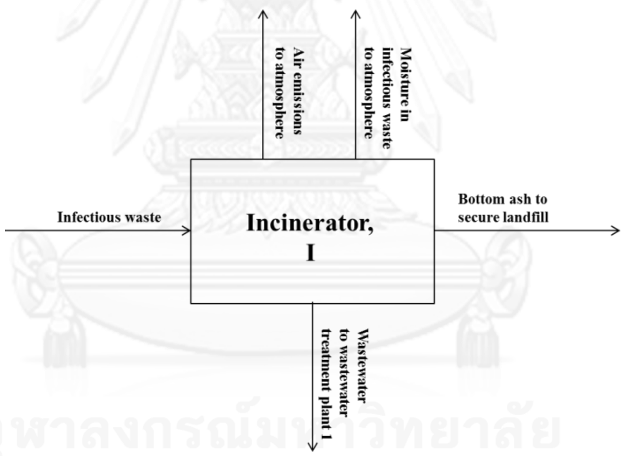


Figure 3-5: Model structure of two incinerators

An infectious waste inflow was total average amount of infectious waste generated from all public health facilities which was treated and loaded into two incinerators. An air emission outflow was total average quantity of air pollutants (e.g., particulate matter, SO_2, NO_x as NO_2, HCL, CO and CO_2) which were emitted from two incinerators to the atmosphere. A moisture outflow was total amount of moisture content in infectious waste which was evaporated from infectious waste incineration to the atmosphere. A wastewater outflow was total average quantity of total dissolved solids (TDS), suspended solids (SS), settleable solids, sulfide, total Kjeldahl nitrogen (TKN), oil and grease in wastewater which were discharged into wastewater treatment plant 1. A bottom ash outflow was total quantity of bottom ashes from infectious waste incineration. An inflow and outflows of two incinerators were shown in **Figure3-5**.

iv. Wastewater treatment plant 1

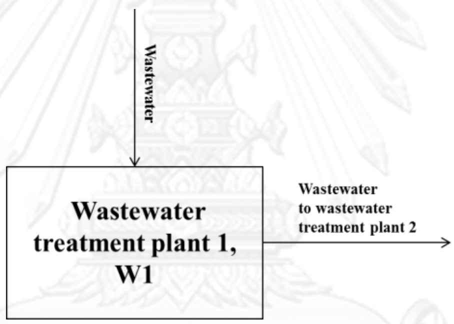


Figure 3-6: Model structure of wastewater treatment plant 1

A wastewater inflow was total average quantity of TDS, SS, settleable solids, sulfide, TKN, oil and grease in wastewater which were treated at wastewater treatment plant 1. A wastewater outflow was total average quantity of TDS, SS, settleable solids, sulfide, TKN, oil and grease in wastewater after they were treated at wastewater treatment plant1 and discharged into wastewater treatment plant 2 at Onnut transfer station. An inflow and an outflow of wastewater treatment plant 1 were shown in **Figure3-6**.

v. Secure landfill

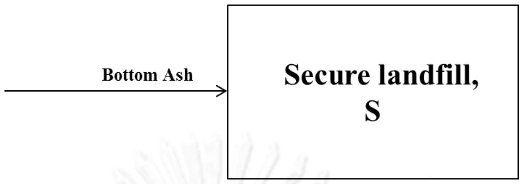


Figure 3-7: Model structure of secure landfill

A bottom ash inflow was total quantity of bottom ashes from infectious waste incineration which was collected and transferred to secure landfill as shown in **Figure 3-7**.

3.2.3 Calculation of materials and mass Flows

a. Quantity of public health facilities, infectious waste, and occupancy rates of hospital beds and trips

All data of total number of public health facilities, occupancy rates of hospital beds and trips of infectious waste collection and transfer and total amount of infectious waste were monthly collected by the waste management company.

For calculation of the number of public health facilities, hospital beds and trips, there was data collection during June 2012 and May 2013 which was averaged in units of place per month for public health facilities, bed per month for occupancy rate of hospital beds and trip per month for trips of infectious waste collection and transfer as calculated in **Table 3-2**. Public health facilities were divided into five categories of government and private hospitals, health centers, clinics and polyclinics and others (e.g., the Red Cross Society, educational institutions, laboratories, and companies). The number of public health facilities in each category was calculated by total number of public health facilities in each category in each month during June 2012 and May 2013 which was averaged in unit of place per month.

For calculation of the number of hospital beds, there was data collection of the number of hospital beds from government and private hospitals. The number of hospital beds in each category of hospitals was calculated by total number of hospital beds in each month during June 2012 and May 2013 which was averaged in unit of bed per month. The number of trips of infectious waste collection and transfer was calculated by total number of trips in each month during June 2012 and May 2013 which was averaged in a unit of bed per month.

For calculation of mass flows of infectious waste generated from five categories of public health facilities, the amount of infectious waste generated from each category of public health facilities during was collected during June 2012 and May 2013. Mass flows of the amount of infectious waste generated from each category of public health facilities were calculated by total amount of infectious waste in each month during June 2012 and May 2013 which was averaged in a unit of kg per month as described in **Table 3-2**.

Table 3-2: Calculation of average quantity of public health facilities, occupancy rates of hospital beds, trips and infectious wastes

Title	Categories	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Average
The number of public health facilities (place/month)	Government hospitals	36	36	36	36	36	36	36	36	36	36	37	37	36 ± 0.39
	Private hospitals	107	107	107	107	107	109	109	108	108	108	107	106	108 ± 0.90
	Heath centers	145	145	145	145	145	145	145	145	145	145	145	145	145 ± 0.00
	Clinics and polyclinics	1,898	1,923	1,916	1,935	1,949	1,951	1,962	1,972	1,980	1,992	1,983	1,971	1,953 ± 29.47
	Others	159	162	160	163	164	164	164	170	171	176	177	173	167 ± 6.20
	Total	2,345	2,373	2,364	2,386	2,401	2,405	2,416	2,431	2,440	2,457	2,449	2,432	2408 ± 35.61
The number of hospital beds (bed/month)	Government hospitals	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400	13,400 ± 0.00
	Private hospitals	14,743	14,743	14,743	14,743	14,743	14,743	14,743	14,743	14,743	14,743	14,743	14,713	14,741 ± 8.66
	Total	28,143	28,143	28,143	28,143	28,143	28,143	28,143	28,143	28,143	28,143	28,143	28,113	28,141 ± 8.66
The number of trips of infectious waste collection and transfer (trip/month)	Trips	652	678	669	666	700	668	704	681	636	661	846	679	686.67 ± 53.55
The amount of infectious waste (kg/month)	Government hospitals	394,518	415,719	412,628	405,344	414,437	382,876	393,271	390,604	381,263	422,587	384,757	402,918	400,077 ± 14,149.94
	Private hospitals	333,814	360,301	357,223	356,138	365,365	355,122	368,085	367,325	331,139	365,773	354,177	369,800	357,022 ± 12,684.36
	Health centers	5,739	5,727	6,364	5,717	6,828	6,448	5,924	5,748	6,313	5,318	5,000	5,023	5,846 ± 567.52
	Clinics and polyclinics	39,743	40,633	41,385	39,176	43,286	42,037	38,676	41,734	39,609	42,580	39,566	46,676	41,258 ± 2,242.85
	Others	68,256	69,520	63,000	68,785	66,784	70,467	67,834	65,509	61,256	69,472	62,860	71,723	67,122 ± 3,309.37
	Total	842,070	891,900	880,600	875,160	896,700	856,850	873,790	870,920	819,580	905,730	846,360	896,140	871,325 ± 25,826.30

b. Quantity of air pollutants

All data of the quantity of air pollutants emitted from two incinerators was quarterly collected by the disposal company. For calculation of mass flows of air pollutants, there was calculation of mass flows of air pollutants emitted from incinerators A and B. Mass flows of air pollutants emitted from incinerators A and B were divided into five categories of particulate matter, sulfur dioxide (SO_2), nitrogen dioxide (NO_x as NO_2), hydrogen chloride (HCL) and carbon monoxide (CO) which were measured concentration of each type of air pollutants before emitting to the atmosphere. Concentration of particulate matter reported in a unit of milligram of air pollutants per cubic meter of air at 25 °C (mg/Nm^3), and concentration of sulfur dioxide (SO_2), nitrogen dioxide (NO_x as NO_2), hydrogen chloride (HCL) and carbon monoxide (CO) reported in a unit of part per million (ppm). Mass flows of air pollutants emitted from incinerator A were calculated from the quantity of each type of air pollutants monitored on 31 August 2012, 13 November 2012, 15 February 2013 and 7 May 2013, and mass flows of air pollutants emitted from incinerator B were calculated from the quantity of each type of air pollutants monitored on 24 August 2012, 7 November 2012, 8 February 2013 and 17 May 2013. Concentration of air pollutants in a unit of part per million (ppm) was converted to a unit of milligram of air pollutants per cubic meter of air at 25 °C (mg/Nm^3) by using the following equation:

$$\frac{mg}{Nm^3} = ppm \times \frac{Mw}{25.4} \qquad \text{(Eq. 3-2)}$$

(Sutiwatanakun, 2013)

Where mg/Nm^3 = milligram of air pollutants per cubic meter of air at 25 °C

ppm = part per million

Mw = molecular weight of each type of air pollutants

Mass flows of air pollutants were calculated by concentration of air pollutants (mg/Nm^3) x air flow rate (Nm^3/s) x 60 (s/min) x 60 (min/hr.) x 24 (hr. /day) x 1 (g/1000mg) x 1 (kg/1000g) x 31 (day/month) as showed in **Table 3-3**. After calculation of mass flows of air pollutants emitted from incinerators A and B in each month, they were averaged in a unit of kg per month of each incinerator as showed in **Table 3-3**. The air flow rates used for calculation were 11.05 Nm^3/s for incinerator A and 11.45 Nm^3/s for incinerators B.

A mass flow of CO_2 emissions from infectious waste incineration was estimated according to the IPCC guidelines as the following equation (IPCC, 2006):

$$CO_2 \text{ emissions (kg/month)} = (IW_i * CCW_i * FCF_i * EF_i * 44/12)$$

Where: i = CW: clinical waste

IW_i = Amount of incinerated waste of type i (kg/month)

CCW_i = Fraction of carbon content in waste of type i

FCF_i = Fraction of fossil carbon in waste of type i

EF_i = Burn out efficiency of combustion of incinerators for waste of type i (fraction)

44 / 12 = Conversion from C to CO_2

From default data for estimation of CO_2 emissions from clinical waste according to the IPCC guidelines, CCW and FCF for clinical waste are 50% and 40%, respectively, and clinical waste contains mainly paper and plastics. The carbon in clinical waste is of both biogenic and fossil origin. The fossil carbon may be reduced if it includes carbon from packaging materials and similar materials. EF for clinical waste ranges from 50-99.5% (IPCC, 2006). Because infectious waste incinerators in Bangkok have been operated for 18 years, the efficiency of combustion may reduce in each year, and it depends on plant design, maintenance and age. Therefore, the research chose 75% of EF for calculation that was averaged from EF ranges of 50-99.5%. The different percent of CCW, FCF and EF for calculation results in estimation of different quantity of CO_2 emissions from infectious waste incineration. Therefore, the research assumed that CCW, FCF and EF of infectious waste in Bangkok were the same to clinical waste disposed from all sources.

The mass balance was the quantity of other pollutants in a unit of kg/month from infectious waste incineration comprising of moisture content in infectious waste plus five types of air pollutants (particulate matter, SO_2, NO_2, HCL and CO) plus wastewater components from air pollution treatment plus bottom ashes.

A mass flow of total moisture content in infectious waste was estimated from the quantity of other pollutants minus the quantity of five types of air pollutants minus the quantity of wastewater components minus the quantity of bottom ashes.

Table 3-3: Calculation of mass flows of air pollutants emitted from incinerators A and B

Incinerator A	Mass flow of air pollutants (kg/month)				Average (kg/month)
	31-Aug-12	13-Nov-12	15-Feb-13	7-May-13	
Particulate	1,335.85	408.24	1,840.91	5,332.16	2,229.29 ± 2,151.98
SO_2	28.37	26.08	574.79	43.12	168.09 ± 271.24
NO_x as NO_2	3,546.64	3,244.90	2,070.07	7,325.99	4046.90 ± 2,276.97
HCL	321.74	18.39	12.61	150.15	125.72 ± 145.30
CO	4,931.07	1,080.45	6,334.39	3,473.46	3,954.84 ± 2,244.19
Total A	10,163.68	4,778.06	10,832.78	16,324.88	10,524.85 ± 4,721.98
Incinerator B	**Mass flow of air pollutants (kg/month)**				**Average (kg/month)**
	24-Aug-12	**7-Nov-12**	**8-Feb-13**	**17-May-13**	
Particulate	1,227.64	4,398.36	261.27	1,397.16	1,821.11 ± 1,789.53
SO_2	422.33	35.27	326.27	850.16	408.51 ± 337.30
NO_x as NO_2	4,650.94	5,673.10	3,162.07	6,627.72	5,028.46 ± 1,483.14
HCL	934.16	523.02	182.99	765.74	601.48 ± 326.06
CO	730.14	202.94	40.02	40.76	253.46 ± 326.89
Total B	7,965.22	10,832.70	3,972.62	9,681.55	8,113.02 ± 3,001.20
Total A+B	18,128.90	15,610.76	14,805.40	26,006.43	18,637.87 ± 5,112.27

c. Quantity of wastewater components

All data of the quantity of wastewater components was quarterly collected by the disposal company. For calculation of mass flows of wastewater components, there was calculation of mass flows of wastewater components before (influents) and after (effluents) primary treatment. Mass flows of wastewater components were divided into six categories of total dissolved solids (TDS), total suspended solids (TSS), settleable solids, sulfides, total Kjeldahl nitrogen (TKN), oil and grease. Mass flows of influents and effluents of wastewater components were calculated by total average quantity of each type of wastewater components in a unit of milligram per liter (mg/L) in September 2012, November 2012, February 2013 and May 2013 multiplying volume of water supply use in unit of liter per month (L/month) as described in **Table 3-4**.

Table 3-4: Calculation of mass flows of wastewater components before and after primary treatment

Types of wastewater components	Influents (kg/month)	Effluents (kg/month)	Influents (kg/month)	Effluents (kg/month)	Influents (kg/month)	Effluents (kg/month)	Influents (kg/month)	Effluents (kg/month)	Average	
									Influents (kg/month)	Effluents (kg/month)
Sampling date	3-Sep-12	3-Sep-12	14-Nov-12	14-Nov-12	20-Feb-13	20-Feb-13	21-May-13	21-May-13		
TDS (mg/ L)	2,882.22	1,036.17	1,419.60	808.08	1,401.40	535.08	1,689.80	724.20	1,848.26 ± 701.81	775.88 ± 207.72
SS (mg /L)	136.97	20.25	103.74	12.01	71.34	11.47	84.49	14.48	99.13 ± 28.51	14.55 ± 4.02
Settleable Solids (ml/ L)	2.38	1.19	1.09	0.11	1.40	0.13	1.21	0.12	1.52 ± 0.59	0.39 ± 0.54
Sulfide (mg/ L)	4.17	0.13	3.06	0.15	2.68	0.15	3.02	0.12	3.23 ± 0.65	0.14 ± 0.02
TKN (mg/ L)	142.92	28.58	122.30	20.75	166.89	28.03	173.81	43.45	151.48 ± 23.53	30.20 ± 9.53
Oil & Grease (mg/ L)	9.53	2.38	6.55	1.09	6.37	1.27	7.24	2.41	7.42 ± 1.45	1.79 ± 0.71
Total									2,111.04 ± 756.54	822.95 ± 222.52

d. Quantity of bottom ashes

The disposal company had no record on the quantity of bottom ashes generated from two infectious waste incinerators. Therefore, the research estimated the quantity of bottom ashes from the capacity of 1.5 tons of side loading trucks for collecting and transferring bottom ashes twice a day to secure landfill. The quantity of bottom ashes was equal to the capacity of 1.5 tons of side loading trucks for collecting and transferring bottom ashes from two incinerators to secure landfill multiplying with 60 trips per month.

3.2.4 Interpretation of the Results

This step was important to interpret the MFA results. It presented what was the relative contribution of processes to certain flows and position where hotspots and potential control points located. It presented a possibility of problem shifting when certain flows would be restricted.

3.3 Account of GHG emissions from infectious waste management in Bangkok

3.3.1 Development and design of account of GHG emissions

The steps of developing and designing account of GHG emissions were divided into three steps as follows: a) setting organization boundaries, b) setting operational boundaries and c) calculating the quantity of GHG emissions (TGO, 2011).

a. Setting organization boundaries

The organization may comprise of one or more facilities which consolidate its GHG emissions and removals from one of these following approaches:

Equity share: the organization accounts for its portion of GHG emissions and/or removals from respective facilities according to its equity share which is usually based on business interest and ownerships.

Control: the organization accounts for all quantified GHG emissions and/or removals from facilities which have financial or operational control.

b. Setting operational boundaries

In setting operational boundaries, there must be specifying of activities of GHG emissions and/or removals related to the organization's operation which can be divided into three scopes as follows: i) scope 1: direct GHG emissions, ii) scope 2: energy indirect GHG emissions and iii) scope 3: other indirect GHG emissions.

i. Scope 1: direct GHG emissions

The organization should quantify direct GHG emissions from facilities within its organization boundary. Direct GHG emissions from electricity, heat and steam generated and exported or distributed by the organization may be separately reported, but it should not be deducted from the organization's total direct GHG emissions. GHG sources of direct GHG emissions are divided into four types as follows:

- ***Stationary combustion***

These emissions result from combustion of fuels in stationary sources (e.g., boilers, furnaces and turbines).

- ***Mobile combustion***

These emissions result from combustion of fuels in mobile combustion sources (e.g., trucks, trains, ships, airplanes, buses and cars).

- ***Process emissions***

Most of these emissions result from manufacturing or processing of chemicals and materials (e.g., cement aluminum and ammonia).

- ***Fugitive emissions***

These emissions result from intentional or unintentional releases (e.g., equipment leaks from joints, seals, packing and gaskets). These emissions are generated from waste management within the organizational boundary (e.g., methane emitted from wastewater treatment system).

ii. Scope 2: energy indirect GHG emissions

The organization should quantify indirect GHG emissions from the generation of imported electricity, heat or steam consumed by the organization. "Imported" refers to electricity, heat or steam that is supplied from outside the organization boundaries.

iii. Scope 3: other indirect GHG emissions

The organization may quantify other indirect GHG emissions based on requirements of the applicable GHG program, internal reporting needs or the intended use for the GHG inventory.

c. Calculating the quantity of GHG emissions

The quantity of GHG emissions could calculate as the following equation:

Greenhouse gas emissions = activity data x GHG emission factors (Eq. 3-3)

3.3.2 Calculation of CO_2 emissions from activities of infectious waste management

In this study, there was calculation of CO_2 emissions from infectious waste management system in Bangkok. There was calculation of CO_2 emissions from fuel combustion (e.g., diesel and NGV) in infectious waste collection vehicles, LPG combustion in two infectious waste incinerators, wastewater treatment plant 1 and electricity use. CO_2 emissions from infectious waste management system were equal to data of activities multiplying with CO_2 emission factors.

a. Collection and transportation

There was calculation of CO_2 emissions from fuel combustion (e.g., diesel and NGV) in infectious waste collection vehicles. The amount of diesel and NGV was averaged in units of L/month for diesel and kg/month for NGV as shown in **Appendix A**. Due to fuel combustion in vehicles as mobile combustion, CO_2, CH_4 and N_2O emission factors used for calculating CO_2 emissions were 2.70E+00 kg CO_2/L diesel, 1.42E-04 kg CH_4/L diesel and 1.42E-04 kg N_2O/L diesel and 2.13E+00 kg CO_2/kg NGV, 3.49E-03 kg CH_4/kg NGV and 1.14E-04 kg N_2O/kg NGV, respectively. 100-years global-warming potential (GWP) of CH_4 and N_2O was 25 kg CO_2/kg CH_4 and 298 kg CO_2/kg N_2O, respectively which were used to convert units of kg CH_4/month and kg N_2O/month to a unit of kg CO_2/month. CO_2 emissions from collection and transportation were equal to the amount of diesel and NGV used in infectious waste collection vehicles multiplying with CO_2 emission factors of each type of fuels.

b. Two Incinerators

There was calculation of CO_2 emissions from LPG combustion in two infectious waste incinerators and transformation of combustible infectious waste in incineration processes. LPG was used as fuel for infectious waste incineration, and the amount of LPG was averaged in a unit of kg LPG/month. Due to LPG combustion in two incinerators as stationary combustion, CO_2, CH_4 and N_2O emission factors used for calculating CO_2 emissions were 3.11E+00 kg CO_2/kg LPG, 4.93E-06 kg CH_4/kg LPG and 4.93E-06 kg N_2O/kg LPG, respectively. 100-years global-warming potential (GWP) of CH_4 and N_2O was 25 kg CO_2/kg CH_4 and 298 kg CO_2/kg N_2O, respectively which were used to convert units of kg CH_4/month and kg N_2O/month to a unit of kg

CO_2/month. CO_2 emissions from LPG combustion in two incinerators were equal to the amount of LPG used in infectious waste incineration multiplying with CO_2 emission factors of LPG. CO_2 emissions from transformation of combustible infectious waste in incineration processes were the results of the MFA model which were total quantity of CO_2 from incinerating 871,325 kg/month of infectious waste. Total CO_2 emissions from two incinerators were equal to CO_2 emissions from LPG combustion plus CO_2 emissions from incinerating 871,325 kg/month of infectious waste.

c. Electricity use

There was calculation of CO_2 emissions from electricity use in the infectious waste incinerator factory. The amount of electricity use was averaged in a unit of kWh/month as shown in **Appendix A**. The CO_2 emission factor of electricity use was 0.5813 kg CO_2/kWh. CO_2 emissions from electricity use in the infectious waste incinerator factory were equal to the amount of electricity use in operation multiplying with the CO_2 emission factor of electricity use.

d. Wastewater treatment plant 1

There was calculation of CO_2 emissions from wastewater treatment plant 1 at the infectious waste incinerator factory, and they were calculated from converting the quantity of CH_4 emissions from wastewater treatment. Total CH_4 emissions from wastewater treatment plant 1 were calculated as the following equation:

$$CH_4 \text{ emissions} = \sum [(TOW_i - S_i) * EF_i - R_i] \qquad \text{(Eq. 3-4)}$$

Where TOW_i = total organically degradable materials in wastewater from industry i in inventory month, kg COD/month

i = industrial sector

S_i = organic components removed as sludge in inventory month, kg COD/month

EF_i = emission factor for industry i. kg CH_4/ kg COD for treatment/discharge pathway or system(s) used in inventory month. If more than one treatment practice is used in an industry, this factor would need to be a weighted average.

R_i = amount of CH_4 emissions recovered in inventory month, kg CH_4/month

S_i and R_i were not used for calculation of total CH_4 emissions from wastewater treatment plant 1 because there were no recovery process of the quantity of CH_4 emissions and no report of the quantity of organic components removed as sludge in inventory month in wastewater treatment processes.

The CH_4 emission factor for industrial wastewater was calculated as the following equation:

$$EF_j = B_0 * MCF_j \qquad \textbf{(Eq. 3-5)}$$

where B_0 = maximum CH_4 producing capacity, 0.25 kg CH_4/kg COD for industrial wastewater

MCF_j = methane correction factor

j = each treatment or discharge pathway or system

Because wastewater treatment plant 1 was an aerobic treatment plant and not well managed or overloaded, default MCF value for industrial wastewater ranged from 0.2 to 0.4. Because the research focused on the lowest quantity of CH_4 emissions from wastewater treatment plant1, the research chose to use MCF value of 0.2 and maximum CH_4 producing capacity of 0.25 kg CH_4/kg COD for industrial wastewater in calculating the CH_4 emission factor for industrial wastewater. The CH_4 emission factor used in calculating total CH_4 emissions from wastewater treatment plant 1was 0.05 kg CH_4/kg COD as described in **Table 3-5**. The amount of water supply use for the operation of the infectious waste incinerator factory was averaged in a unit of m^3/month as shown in **Appendix A**.

CO_2 emissions from wastewater treatment plant 1 were equal to total CH_4 emissions multiplying with global-warming potential of CH_4 (GWP_CH_4) which was equal to 25 kg CO_2/kg CH_4 as shown in **Table 3-5**.

Table 3-5: Calculation of CO_2 emissions from wastewater treatment plant 1

	Influent pond 1 (COD) (mg/L)	Effluent pond 2 (COD) (mg/L)	Water supply (m^3/ month)	Water supply (L/ month)	TOW_i (kg $COD_{removed}$/ month)	EF_j (kg CH_4/kg COD)	CH_4 emissions (kg CH4/ month)	GWP_CH_4 (kg CO_2e)	Kg CO_2/ month
Sampling date	20-Feb-13	20-Feb-13	Feb-13						
	1,420	98	1,274	1,274,000	1,684.23	0.05	84.21	25	2,105.29
Sampling date	21-May-13	21-May-13	May-13						
	1,650	105	1,207	1,207,000	1,864.82	0.05	93.24	25	2,331.02
Sampling date	3-Sep-12	3-Sep-12	Oct 12-May 13						
	840	90	1,191	1,191,000	893.25	0.05	44.66	25	1,116.56
Sampling date	14-Nov-12	14-Nov-12	Nov-12						
	220	18	1,092	1,092,000	220.58	0.05	11.03	25	275.73
Average									1457.15 ± 947.89

e. The entire system

Total CO_2 emissions from infectious waste management in Bangkok were equal to CO_2 emissions from collection and transportation plus CO_2 emissions from two incinerators plus CO_2 emissions from electricity use plus CO_2 emissions from wastewater treatment plant 1.

3.4 Evaluation of efficiency of infectious waste management in Bangkok

3.4.1 Evaluating eco-efficiency indicators of infectious waste management

Eco-efficiency indicators were divided into two dimensions of economic and environmental performances. The economic performance was used to assess economic input and benefits. Economic indicators were quantity of products and net sale. The environmental performance was used to assess influence of the system to surroundings and material consumption. Environmental indicators were material, energy and water consumption or wastewater and solid waste production or greenhouse gas emissions.

Evaluation of efficiency indicators of infectious waste management in Bangkok was divided into three categories as follows: (i) the energy efficiency, (ii) CO_2 emission efficiency and (iii) efficiency of treatment costs.

a. The energy efficiency

i. Incinerators

Energy efficiency of two incinerators was evaluated in the ratio of average amount of infectious wastes in kg/month and average quantity of lower heating values of LPG used for infectious waste incineration in MJ/month.

ii. Transportation

Energy efficiency of transportation was evaluated in the ratio of average amount of infectious wastes in kg/month and average quantity of lower heating values of diesel and NGV of 18 special vehicles used for collecting and transferring infectious wastes and one private vehicle in MJ/month.

iii. The entire system

Energy efficiency of the entire system was evaluated in the ratio of average amount of infectious wastes in kg/month and average quantity of lower heating values of LPG used for infectious waste incineration in MJ/month plus average quantity of lower heating values of diesel and NGV of 18 special vehicles used for collecting and transferring infectious wastes and one private vehicle in MJ/month plus average quantity of electrical energy used for operating the entire system of infectious waste management in MJ/month.

b. The CO_2 emission efficiency

i. Incinerators

CO_2 emission efficiency of two incinerators was evaluated in the ratio of average amount of infectious wastes in kg/month and average quantity of CO_2 emissions from LPG combustion used for infectious waste incineration in kg/month plus average quantity of CO_2 emissions from transformation of combustible infectious wastes in treatment processes (with incineration) in kg/month.

ii. Transportation

CO_2 emission efficiency of transportation was evaluated in the ratio of average amount of infectious wastes in kg/month and average quantity of CO_2

emissions from diesel and NGV combustion of 18 special vehicles used for collecting and transferring infectious wastes and one private vehicle in kg/month.

iii. The entire system

CO_2 emission efficiency of the entire system was evaluated in the ratio of average amount of infectious wastes in kg/month and average quantity of CO_2 emissions from LPG combustion used for infectious waste incineration in kg/month plus average quantity of CO_2 emissions from transformation of combustible infectious wastes in treatment processes (with incineration) in kg/month plus average quantity of CO_2 emissions from diesel and NGV combustion of 18 special vehicles used for collecting and transferring infectious wastes and one private vehicle in kg/month plus average quantity of CO_2 emissions from electricity used for operating the entire system of infectious waste management in kg/month plus average quantity of CO_2 emissions from wastewater treatment in kg/month.

c. Efficiency of treatment costs

i. Incinerators

Efficiency of treatment costs of two incinerators was evaluated in the ratio of average amount of infectious wastes in kg/month and average costs of LPG used for infectious waste incineration in baht/month.

ii. Transportation

Efficiency of treatment costs of transportation was evaluated in the ratio of average amount of infectious wastes in kg/month and average costs of diesel and NGV of 18 special vehicles used for collecting and transferring infectious wastes and one private vehicle in baht/month.

iii. The entire system

Efficiency of treatment costs of the entire system was evaluated in the ratio of average amount of infectious wastes in kg/month and average costs of LPG used for infectious waste incineration in baht/month plus average costs of diesel and NGV of 18 special vehicles used for collecting and transferring infectious wastes and one private vehicle in baht/month plus average costs of electricity and water supply used for operating the entire system of infectious waste management in baht/month.

3.4.2 Scenario analysis for improving efficiency of infectious waste management

The research proposed and analyzed a scenario for better improving efficiency of infectious waste management by modifying 12 diesel engine vehicles for infectious waste collection and transportation to 12 NGV engine vehicles (dedicated retrofit). Improvement of transportation system was evaluated efficiency indicators, the cost saving rate and the payback period as described below:

a. Improving the efficiency of the transportation system

i. The energy efficiency

Energy efficiency of improving the efficiency of the transportation system was evaluated in the ratio of average amount of infectious wastes in kg/month and average quantity of lower heating values of NGV of 12 new NGV engine vehicles used for collecting and transferring infectious wastes in MJ/month plus average quantity of lower heating values of diesel and NGV of 7 vehicles staying the same in MJ/month.

ii. The CO_2 emission efficiency

CO_2 emission efficiency of improving the efficiency of the transportation system was evaluated in the ratio of average amount of infectious wastes in kg/month and average quantity of CO_2 emissions from NGV combustion of 12 new NGV engine vehicles used for collecting and transferring infectious wastes in kg/month plus average quantity of CO_2 emissions from diesel and NGV combustion of 7 vehicles staying the same in kg/month.

iii. The efficiency of treatment costs

Efficiency of treatment costs of improving the efficiency of the transportation system was evaluated in the ratio of average amount of infectious wastes in kg/month and average costs of NGV of 12 new NGV engine vehicles used for collecting and transferring infectious wastes in baht/month plus average costs of NGV and diesel of 7 vehicles staying the same in baht/month plus averagely fixed costs of NGV engine installation of 12 new NGV engine vehicles in baht/month.

iv. Cost saving and payback period

The fuel combustion rates of diesel and NGV engine vehicles were 6.369 km/L and 11.905 km/kg, respectively. Retail prices of diesel and NGV were 29.99 baht/L and 10.50 baht/kg, respectively (PTT, 2013). The cost rates of diesel and NGV in a unit of baht/km were calculated from retail prices of diesel and NGV divided by the fuel combustion rates of diesel and NGV engine vehicles, respectively. The cost saving rate of 12 NGV engine vehicles in a unit of baht/month were calculated from (the cost rate of diesel in a unit of baht/km minus the cost rate of NGV in a unit of baht/km) multiplying with average distances of 12 diesel engine vehicles in a unit of km/month. The payback period (month) of NGV engine installation was calculated from total equipment installation prices (baht) of 12 NGV engine vehicles divided by the cost saving rate in a unit of baht/month.

3.5 Recommendations of strategies for better improving the efficiency of infectious waste management in Bangkok

To develop recommendations for improving the efficiency of infectious waste management in Bangkok, the research created questionnaires about increasing the efficiency of infectious waste management in Bangkok as shown in **Appendix A**. The questionnaires were mailed to 37 government hospitals and 106 private hospitals covering 50 districts of Bangkok. Based on questionnaires, there were two parts of information obtained from a survey as follows: (i) the first part was to investigate infectious waste management systems within public and private hospitals and (ii) the second part to evaluate satisfaction of public and private hospitals from services in collection, transfer, treatment and disposal of infectious waste provided by The Krungthep Thanakom Co., Ltd.

CHAPTER IV

MASS FLOW ANALYSIS AND ECO-EFFICIENCY INDICATORS

In this Chapter IV, the research results analyzed from the case study in Bangkok were presented and discussed. The results were divided into three main sections: (i) mass flow analysis of infectious waste management in Bangkok, (ii) greenhouse gas (GHG) emissions from infectious waste management in Bangkok and (iii) evaluation of eco-efficiency indicators of infectious waste management in Bangkok. Details in each section are as follows:

4.1 Mass flow analysis of infectious waste management in Bangkok

4.1.1 Analysis at each stage of infectious waste management processes

For infectious waste management in Bangkok during June 2012 to May 2013, the results of analysis at each stage of infectious waste management processes were presented and discussed, including the following sections: infectious waste generation, segregation and collection, storage, transportation, treatment and disposal of infectious waste.

a. Infectious waste generation

The generation rate of infectious waste depended on several factors such as different sizes of public health facilities, occupancy rates of hospital beds, infectious waste segregation and collection programs, locations of public health facilities, types of public health facilities and types of services provided. The study found that average amount of infectious waste generation was 400,077 kg/month or 0.83 kg/bed/month/place of 36 government hospitals (G) with 13,400 beds, 357,022 kg/month or 0.23 kg/bed/month/place of 108 private hospitals (P) with 14,741 beds, 5,846 kg/month or 40.32 kg/month/place of 145 health centers (HC), 41,258 kg/month or 21.13 kg/month/place of 1,953 clinics and polyclinics (CP) and 66,122 kg/month or 402.13 kg/month/place of 167 others (O) (e.g., the Red Cross Society, educational institutions, laboratories and companies) as summarized in **Table 4.1**.

Table 4-1: Infectious waste generation rates in Bangkok for different types of facilities

Types	Abbreviations	Number of beds	Generation rate	
			kg/month	kg/month/place
Government hospitals	G	13,400	400,077	11,062.03
Private hospitals	P	14,741	357,022	3,321.13
Health centers	HC	-	5,846	40.32
Clinics and polyclinics	CP	-	41,258	21.13
Others	O	-	67,122	402.13

These results were compared with the generation rates of infectious waste among different types of public health facilities. The total generation rate of infectious waste of both P and G was higher than the total generation rate of infectious waste of HC, CP and O by 642,872 kg/month or 562.81%. On the other hand, the total number of HC, CP and O was higher than the total number of both G and P by 2,121 place/month or 1,472.92%.

From analyzing the generation rates of infectious waste in each public health facility, it indicated that G was ranked at the first in the term of infectious waste generation rate, and P was the second infectious waste generator. Therefore, the segregation and collection practices are very important to be implemented in the hospitals to reduce and prevent infectious wastes mixed along with municipal wastes which cause outbreaks of diseases impacting on human health and the environment.

b. Segregation and collection

According to regulations of MOPH B.E. 2545, infectious waste has been classified into four categories: (i) body parts or carcasses of humans and animals, (ii) sharps (e.g., needles, blades and glass wares), (iii) discarded materials contaminated with blood components and body fluids and (iv) wastes from wards as specified by Ministry of Public Health. Infectious waste should be segregated at sources and collected by using colored bags and containers (e.g., plastic, stainless or paper) which should be visibly labeled with "Infectious Waste" or biohazard symbols as stated in the regulations. Infectious waste was segregated by workers of public health facilities and collected in colored bags and containers. The segregation practices have been applied as follows: ***all types of infectious waste excluding sharps*** are collected in ***red bags*** with no exceeding capacity to 2/3 of the total volume; ***sharps*** are collected in ***red boxes*** and containers with no exceeding capacity to 3/4 of the total volume. In particular, containers for sharp collection should be strong and resistant to laceration and perforation.

c. Storage

After infectious wastes were segregated and collected, workers of public health facilities transferred them from where infectious wastes were generated to temporary storage areas at public health facilities waiting for collection and transportation to the disposal facility. Temporary storage areas were located within public health facilities where infectious wastes were gathered from sources within those public health facilities. After being transported to the treatment and disposal facility, there is a temporary storage area for containing infectious wastes before they were loaded into two incinerators. According to scientific standards, infectious wastes in tropical areas can be kept in a temporary storage area for 24 hours during the hot season and up to 48 hours in cooler seasons (Prüess et al., 1999).

d. Transportation

Bangkok Metropolitan Administration (BMA) has contracted with the Krungthep Thanakom Co., Ltd. for collection, transportation, treatment and disposal of infectious waste by the incineration method. Regarding transportation of the infectious wastes in Bangkok, public health facilities had the responsibility for providing on-site collection and storage while off-site transport to the disposal site was handled by the disposal company. During June 2012 to May 2013, 871,325 kg/month of infectious wastes were transported through 20 pre-established routes covering total numbers of public health facilities in 50 districts of Bangkok.

The infectious waste collection was divided into two groups as follows: (1) routes 1-8 and 18-20 for GH and PH, and (2) route 9-17 for HC, CP and O. The infectious waste collection time was the schedule to be 4 time sets (1) 8.00 to 12.00 pm for routes 1, 2, 4, 6 and 18, (2) 2.00 to 7.00 am for routes 3, 5, 7, 8, 19 and 20, (3) 8.30 am to 2.00 pm for routes 1 and 19, and (4) 5.00 to 12.00 pm for route 9. The infectious waste collection time was determined by the transport distances and the amount of infectious waste. The disposal company arranged for 18 special trucks and 40 qualified workers to collect infectious wastes from public health facilities and transport to the treatment facility. There are 3 types of trucks with various waste handling capacities as follows: two trucks with capacity of 4 tons **(a)**, seven trucks with capacity of 3 tons as shown in **Figure 4-1 (a)**, and nine trucks with capacity of 1 ton as shown in **Figure 4-1 (b)**. The workers obtained proper training for infectious wastes collection and transfer. They wear personal protective equipment (e.g., thick rubber gloves, aprons, masks and boots) throughout the operation. Infectious wastes generated from GH and PH were collected every day and transported to a temporary storage area in the disposal facility, while infectious wastes generated from HC, CP, and O were collected and transported to treatment once to twice a week. The amount of infectious waste generated from each public health facility was weighed at sources before they were transported onto special trucks. When special trucks containing infectious wastes reached at the disposal facility, total amount of infectious waste was weighted again by a weighing machine of the disposal facility.

(a) (b)

Figure 4-1: Special trucks for infectious waste collection and transportation (Thanakom, 2013)

e. Treatment and disposal

i. Infectious waste incineration

After infectious wastes were transported to a temporary storage area at the disposal company, they were loaded into two incinerators for treatment as shown in **Figure 4-2**. The capacity of infectious waste treatment and management was 30 ton/day with two incinerators. When 871,325 kg/month of infectious wastes were treated by two incinerators with high temperature (800-1,050 °C) combustion, they transformed into air pollutants, wastewater components and bottom ashes. These pollutants were transferred into further treatment and disposal processes.

Figure 4-2: Two incinerators for infectious waste treatment (Thanakom, 2013)

ii. Air pollution treatment

According to air pollution emission regulations and performance standards for an infectious waste incinerator, Ministries of Natural Resource and Environment and Industry of Thailand define air pollution emission standards to control the release of air pollutants (e.g., sulfur dioxide (SO_2), nitrogen oxide (NO_x as NO_2), hydrogen chloride (HCl), hydrogen fluoride (HF) and total suspended particulate) from an infectious waste incinerator to the environment as shown in **Appendix B**. Based on the data collected during the study period, after infectious wastes were treated with the incineration, there were approximately 497,867 kg/month of air pollutants from incinerating 871,325 kg/month of infectious wastes of two incinerators. The quantity of each type of air pollutants was divided into 479,229 kg/month of carbon dioxide (CO_2) emitted from both incinerators, 10,525 kg/month of other air pollutants (e.g., particulate matter, SO_2, NO_2, HCL and CO) emitted from incinerator A, 8,113 kg/month of other air pollutants emitted from incinerator B as shown in **Table 4-2** and 281,347 kg/month of moisture content in infectious waste evaporated by incineration processes to atmosphere.

Each incinerator had wet scrubber as the air pollution treatment system before air pollutants were emitted into atmosphere. The air pollutants were quarterly monitored according to the USEPA method. Average quantity of each type of air pollutants emitted from incinerator A was 2,229.29 kg/month of particulate matter, 168.09 kg/month of sulfur dioxide (SO_2), 4,046.90 kg/month of nitrogen dioxide (NO_2), 125.72 kg/month of hydrogen chloride (HCl) and 3,954.84 kg/month of carbon monoxide (CO). Average quantity of air pollutants emitted from incinerator B was 1,821.11 kg/month of particulate matter, 408.51 kg/month of sulfur dioxide (SO_2), 5,028.46 kg/month of nitrogen dioxide (NO_2), 601.48 kg/month of hydrogen chloride (HCl) and 253.46 kg/month of carbon monoxide (CO).

Table 4-2: Average quantity of each type of air pollutants emitted from Incinerators A and B

Types of air pollutants	Incinerator A (kg/month)	Incinerator B (kg/month)
Particulate matter	2,229.29	1,821.11
SO_2	168.09	408.51
NO_X as NO_2	4,046.90	5,028.46
HCL	125.72	601.48
CO	3,954.84	253.46
Total	10,524.85	8,113.02
Total A+B	18,637.87	

The different quantity of each type of air pollutants generated from infectious waste incineration may depend on the proportion of elemental compositions in infectious wastes as inputs for each incinerator. Most compositions of infectious wastes consisted of many types of plastics (e.g., polyvinyl chloride (PVC), polyethylene (PE) and polyurethane (PU)). When each type of plastics was burned, it produced different quantity of each type of air pollutants (e.g., SO_2, NO_2 and HCl). The different quantity of CO emitted was due to incomplete combustion in each incinerator.

iii. Wastewater treatment

According to the notification of Ministry of Industry No.2 (1996) on the determination of wastewater quality discharged from factories, there is specification of standard values (e.g., Total Dissolved Solids (TDS), Total Suspended Solids (TSS) Total Kjeldahl Nitrogen (TKN), Chemical Oxygen Demand (COD) and Biochemical Oxygen Demand (BOD)) to control and monitor the quantity of wastewater components before they are discharged into the environment as shown in **Appendix B**. As an output from incinerating infectious wastes, wastewater from wet scrubber as air pollution treatment system was treated with activated sludge in wastewater treatment system. Wastewater quality was quarterly monitored before and after treatment as required by the notification of Ministry of Industry. **Table 4-3** showed that average quantity of wastewater components before treatment was 2,111.04 kg/month consisting of 1,848.26 kg/month of TDS, 99.13 kg/month of TSS, 1.52 kg/month of settleable solids, 3.23 kg/month of sulfide, 151.48 kg/month of TKN and 7.42 kg/month of oil and grease. Average quantity of wastewater components after treatment was 822.95 kg/month consisting of 775.88 kg/month of TDS, 14.55

kg/month of TSS, 0.39 kg/month of settleable solids, 0.14 kg/month of sulfide, 30.20 kg/month of TKN and 1.79 kg/month of oil and grease.

According to the mass balance principle, the mass of wastewater components before treatment (2,111.04 kg/month) was equal to the mass of wastewater components after treatment (822.95 kg/month) plus the mass of wastewater components stored in sludge (1,288.09 kg/month).

Table 4-3: Average quantity of each type of wastewater components before and after treatment

Types of wastewater components	Influents (kg/month)	Effluents (kg/month)
TDS	1,848.26	775.88
TSS	99.13	14.55
Settleable Solids	1.52	0.39
Sulfide	3.23	0.14
TKN	151.48	30.20
Oil & Grease	7.42	1.79
Total	2,111.04	822.95

The removal efficiency percentage of wastewater components treated by the activated sludge system was 58.02% for TDS, 85.32% for TSS, 74.54% for settleable solids, 95.68% for sulfide, 80.06% for TKN and 75.88% for oil and grease. The removal efficiency percentage of total quantity of wastewater components was 61.02% which was used as food sources for bacterial growth in the wastewater treatment system.

f. Disposal of bottom ashes

Incinerating infectious wastes produced approximately 90,000 kg/month of bottom ashes. Bottom ashes from two infectious waste incinerators were transported and disposed twice a day to secure landfill by side loading trucks with capacity of 1.5 tons.

Bottom ashes generated from infectious waste incineration consisted of incombustible and combustible materials. Combustible materials became bottom ashes, but incombustible materials were still visible in original or melted forms (e.g., glass tubes and bottles and hypodermic needles).

4.1.2 Mass flows of infectious wastes at each management stage

Data from each stage of infectious waste management processes in Bangkok during June 2012 to May 2013 was analyzed to develop mass flow analysis (MFA) diagram to comprehensively understand an overview of the origins and flow paths of infectious wastes (in terms of quantity and changed forms) from the sources of generation to the disposal.

Figure 4-3 showed mass flows of infectious waste quantities and changed forms in kg/month in Bangkok during June 2012 to May 2013. Total average amount of infectious wastes generated from all public health facilities was 871,325 kg/month. Average amount of infectious wastes was 400,007 kg/month from government hospitals (G), 357,022 kg/month from private hospitals (P), 5,846 kg/month from health centers (H), 41,258 kg/month from clinics and polyclinics (CP) and 67,122 kg/month from others (O) which were collected and transported to a temporary storage area in the infectious waste treatment facility. All of these wastes were loaded into two incinerators. When the infectious waste was incinerated at high temperature, it transformed into 497,867 kg/month of air pollutants, 281,347 kg/month of evaporated water (H_2O), 2,111 kg/month of wastewater components and 90,000 kg/month of bottom ashes. The amount of infectious waste generated from G, P, H, CP, and O accounted for 45.92%, 40.97%, 0.67%, 4.74% and 7.70%, respectively of total infectious waste in the system; therefore, Both G and P were two main factors influencing on the MFA.

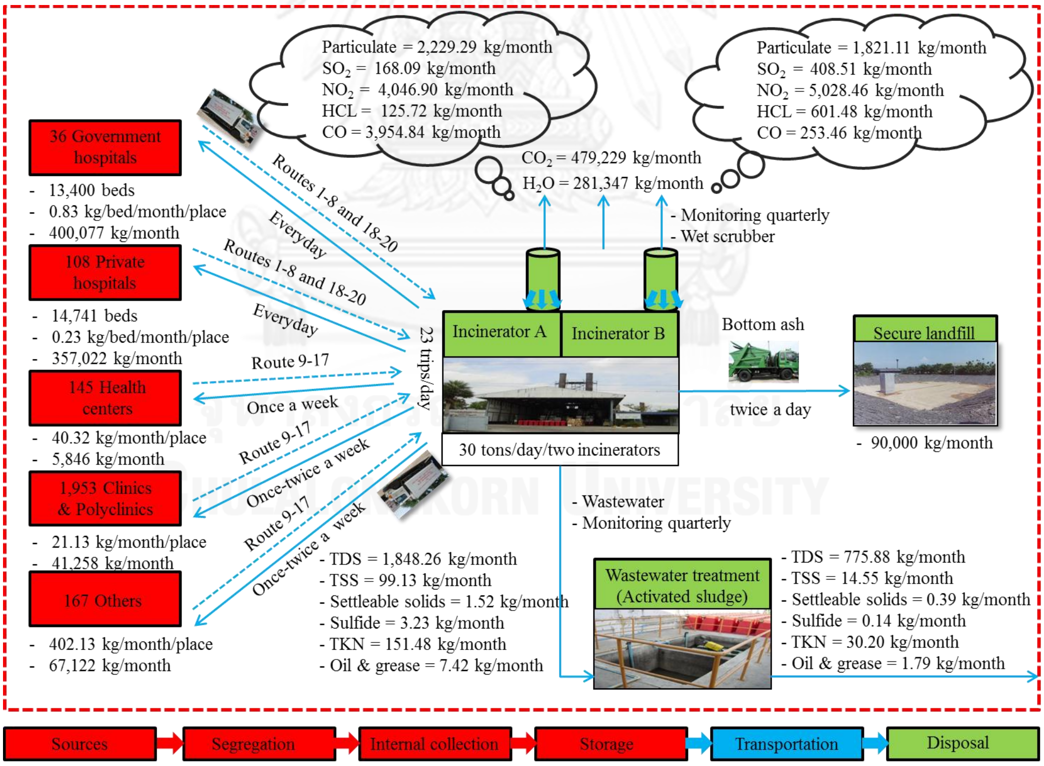


Figure 4-3: Mass flow analysis for infectious waste quantities and changed forms in kg/month in Bangkok during June 2012 to May 2013

When 100% of infectious waste was incinerated at high temperature, it became air pollutants (57.14%) (Where 55% of CO_2 and 2.14% of other air pollutants), evaporated water (32.29%), wastewater components (0.24%) and bottom ashes (10.33%). Therefore, in comparing the weights of pollutants from infectious waste flows, air pollutants were emitted at the highest masses into the environment. The disposal company has to install efficient air pollution treatment system to minimize and prevent these air pollutants to atmosphere as possible.

From medical waste incineration, it transformed into air pollutants (45.47%), evaporated water (44.13%) and bottom ashes (10.4%), and these quantities depended on combustible and elemental compositions of medical waste (Xie & Li, 2009). The MFA results indicated that air pollutants and evaporated water were two main quantities from infectious waste incineration which were according to these quantities from the mentioned study.

4.1.3 The ratio of infectious waste and generated pollutants

Table 4-4 showed the ratio of total amount of infectious waste treated and average quantity of each type of pollutants produced in the unit of kg/kg. Based on the analysis of 871,325 kg/month of infectious waste and types of air pollutants produced, the ratio of amount of infectious waste treated and the quantity of air pollutants produced was 1.82 kg/kg for CO_2, 96.01 kg/kg for NO_2, 207.05 kg/kg for CO, 215.12 kg/kg for particulate matter, 1,198.19 kg/kg for HCL, 1,511.13 kg/kg for SO_2 and 1.75 kg/kg for total air pollutants, respectively. For example, the interpretation of the result is that 215.21 kg of incinerated wastes generated about 1 kg of particulate matter. For overall, approximately 1.75 kg of incinerated wastes generated about 1 kg of air pollutants.

Regarding wastewater components, the ratio of the amount of infectious waste treated and the quantity of wastewater components produced was 471.43 kg/kg for TDS, 8,789.30 kg/kg for TSS, 573,013.94 kg/kg for settleable solids, 269,780.94 kg/kg for sulfide, 5,752.02 kg/kg for TKN, 117,381.79 kg/kg for oil and grease and 412.75 kg/kg for total wastewater components, respectively.

Regarding bottom ash generation, the ratio of the amount of infectious waste treated and the quantity of bottom ashes produced was 9.68 kg/kg.

Table 4-4: The ratio of infectious waste and each type of produced pollutants

Types of pollutants	Ratio of infectious waste and produced pollutants
CO_2	1.82
NO_X as NO_2	96.01
CO	207.05
Particulate matter	215.12
HCL	1,198.19
SO_2	1,511.13
Total air pollutants	1.75
TDS	471.43
TKN	5,752.02
TSS	8,789.30
Oil & grease	117,381.79
Sulfide	269,780.94
Settleable solids	573,013.94
Total wastewater components	412.75
Bottom ashes	9.68

These results indicated that when infectious waste was incinerated at high temperature, they mostly became CO_2 because of most compositions of infectious wastes as combustible materials and NO_2 because of LPG combustion at high temperature (1000 °C) in high quantity used as fuel in incinerators. For production of bottom ashes, it indicated that infectious wastes mostly became bottom ashes after treatment because they consisted of needles, glasses and some plastics which were resistant to high temperature. Needles, glasses and some plastics were melted as another form.

The ratio of incinerated infectious waste and produced pollutants can be applied as a benchmark when is compared with the ratio of other incinerated wastes (e.g., hazardous and municipal waste incineration and produced pollutants.

4.2 Greenhouse Gas (GHG) emissions from infectious waste management in Bangkok

From the MFA model, it indicated that when infectious waste was treated by the incineration method, they mostly became CO_2 emitted to atmosphere. Moreover, the disposal company used LPG as fuel for two incinerators in burning infectious wastes and diesel and NGV as fuel for special vehicles in collecting and transferring infectious wastes. LPG, diesel and NGV combustion is the major source of greenhouse gases from infectious waste management processes emitted to atmosphere causing climate change. Therefore, GHG emissions from activities of infectious waste management are challenging to be appropriately handled to minimize environmental impacts.

4.2.1 CO_2 emissions based on activities of infectious waste management

a. Collection and transportation

The operational boundary and GHG sources of infectious waste collection and transportation were in scope 1 and mobile combustion (type M), respectively. The operational boundary of infectious waste collection and transportation was in scope 1 because it was direct GHG emissions from logistics of the disposal company. GHG sources of infectious waste collection and transportation was type M because they were produced from fuel combustion in vehicles.

CO_2 emissions from diesel and NGV combustion of 19 vehicles were 25,181.58 kg/month. Nineteen vehicles consisted of 18 special vehicles for collecting and transferring infectious wastes and one private vehicle. Eighteen special vehicles comprised of 12 diesel engine vehicles, 4 diesel dual fuel engine vehicles (diesel + NGV) and 2 bi-fuel engine vehicles (gasoline + NGV). One private vehicle was diesel engine system. Total quantity of diesel and NGV used in the 19 vehicles was averagely 5,264.72 L/month and 4,764.24 kg/month, respectively.

b. Two incinerators

The operational boundary of two incinerators was in scope 1, and GHG sources were stationary combustion (types S). The operational boundary of two incinerators was in scope 1 because it was direct GHG emissions from infectious waste treatment at incinerators. GHG is type S because it is produced from infectious waste and fuel combustion in incinerators.

CO_2 emissions from two incinerators were divided into two processes as follows: (i) CO_2 emissions from NGV combustion used in incinerating were 165,290.68 kg/month and (ii) CO_2 emissions from transformation of combustible infectious waste into CO_2 after incinerating were 479,229 kg/month that this fraction of the amount of CO_2 was estimated from the MFA diagram as shown in **Figure 4-3**. Total CO_2 emissions from two incinerators were 644,519.68 kg/month. Total quantity of NGV used in infectious waste incineration was 53,102 kg/month.

c. Electricity use

The indirect CO_2 emissions from electricity consumption were 11,227.40 kg/month. Total amount of electricity used for operating the entire system of infectious waste management was 19,314.29 kWh/month.

The operational boundary of electricity use was in scope 2 because it was indirect GHG emissions from fuel combustion (e.g., fuel oil, natural gases and coal) for electricity production which was not directly generated by the infectious waste incinerator factory. However, electricity used for the operation was purchased from metropolitan electricity authority (MEA). MEA has purchased grid electricity from electricity generating authority of Thailand (EGAT) for selling and distributing it to customers. The GHG sources were type S because they were produced from fuel combustion in turbines of EGAT for electricity production.

d. Wastewater treatment

The operational boundary and GHG sources of wastewater treatment were in scope 1 and fugitive emissions (type F), respectively. CO_2 emissions from wastewater treatment were 1,457.15 kg/month. Total amount of water supply used for operating the entire system of infectious waste management was 1,190,875 L/month.

The operational boundary of wastewater treatment was in scope 1 because it was direct GHG emissions from biodegradable processes in the wastewater treatment plant 1. The GHG sources were type F because they leaked from the wastewater treatment plant 1.

Since the disposal company's wastewater treatment system was aerobic treatment processes, but it was not well managed or overload. Therefore, some areas of wastewater treatment wells had anaerobic treatment processes causing methane emissions (CH_4) produced in less quantity which was converted in a unit of kg of CO_2 with less quantity.

4.2.2 CO_2 emissions based on operational boundaries

CO_2 emissions from each scope and type of GHG emission sources of infectious waste management in Bangkok during June 2012 to May 2013 were described as shown in **Table 4-5**.

Table 4-5: Types of operational boundaries and GHG emission sources and total CO_2 emissions from the entire system

Emission sources	Scope 1		Scope 2		Total
	Emission (kg CO_2/month)	Percentage (%)	Emission (kg CO_2/month)	Percentage (%)	Emission (kg CO_2/month)
Stationary combustion	644,519.68	94.45	11,227.40	1.65	655,747.08
Mobile combustion	25,181.58	3.69	0	0	25,181.58
Fugitive emissions	1,457.15	0.21	0	0	1,457.15
GHG emissions	671,158.41	98.35	11,227.40	1.65	682,385.81

Table 4-5 summarized the CO_2 emission results from all sources and scopes. Total CO_2 emissions from scope 1 were 671,158.41 kg/month or 98.35% which was emitted from two infectious waste incinerators, logistics and wastewater treatment plant 1. Total CO_2 emissions from scope 2 were 11,227.40 kg/month or 1.65% which was emitted from EGAT's fuel combustion in turbines for electricity production. Total CO_2 emissions from two scopes of the entire system of infectious waste management in Bangkok were 682,385.81 kg/month.

From the evaluation of total CO_2 emissions from the entire system, it indicated that most CO_2 emissions from transformation of combustible infectious waste into CO_2 in treatment processes (with incineration) were the main source causing climate change. Therefore, reduction of CO_2 emissions from this system was necessary to reduce CO_2 emissions to atmosphere by increasing the efficiency of air pollution treatment systems of two infectious waste incinerators.

4.3 Eco-efficiency analysis of infectious waste management in Bangkok

The results of eco-efficiency evaluation were presented and discussed in the following two sections: (i) eco-efficiency analysis of infectious waste management in Bangkok, (ii) scenario analysis for improving the efficiency of infectious waste management in Bangkok. In the eco-efficiency analysis, there were 3 main indicators which were energy consumption, CO_2 emissions and treatment costs. Scenario analysis focused on improving the energy efficiency system for the transport trucks.

4.3.1 The energy efficiency

i. Incinerators

Energy efficiency of incinerator was presented as the ratio of average amount of infectious waste in kg/month and average quantity of lower heating values of LPG used for infectious waste incineration in MJ/month. The result found that energy efficiency of two incinerators was 0.35 kg of infectious waste/MJ.

ii. ***Transportation***

Energy efficiency of transportation was evaluated as the ratio of average amount of infectious waste in kg/month and average quantity of lower heating values of diesel and NGV of 18 special vehicles used for collecting and transferring infectious wastes and one private vehicle in MJ/month. The energy efficiency of transportation systems was 2.14 kg of infectious waste/MJ.

iii. ***The entire system***

Energy efficiency of the entire system was analyzed as the ratio of average amount of infectious waste in kg/month and the sum of energy from incinerators plus transportation plus electricity use in MJ/month. The energy efficiency of the entire system was 0.30 kg of infectious waste/MJ.

4.3.2 The CO_2 emission efficiency

i. Incinerators

Evaluation of CO_2 emission efficiency in the ratio of average amount of infectious waste in kg/month and average quantity of CO_2 emissions from LPG combustion used for infectious waste incineration in kg/month plus average quantity of CO_2 emissions from transformation of combustible infectious wastes in treatment processes (with incineration) in kg/month illustrated that CO_2 emission efficiency of two incinerators was 1.35 kg of infectious waste/kg of CO_2.

ii. Transportation

Evaluation of CO_2 emission efficiency in the ratio of average amount of infectious waste in kg/month and average quantity of CO_2 emissions from diesel and NGV combustion of 18 special vehicles used for collecting and transferring infectious wastes and one private vehicle in kg/month illustrated that CO_2 emission efficiency of transportation systems was 34.60 kg of infectious waste/kg of CO_2.

iii. The entire system

Evaluation of CO_2 emission efficiency in the ratio of average amount of infectious waste in kg/month and total quantity of CO_2 emissions in kg/month illustrated that CO_2 emission efficiency of the entire system was 1.28 kg of infectious waste/kg of CO_2.

4.3.3 The efficiency of treatment costs

i. Incinerators

Efficiency of treatment costs of incinerators was evaluated as the ratio of infectious waste in kg/month and costs of LPG used for infectious waste incineration in baht/month. The efficiency of treatment costs of two incinerators was 1.46 kg of infectious waste/baht.

ii. Transportation

Efficiency of treatment costs of transportation in the ratio of average amount of infectious waste in kg/month and average costs of diesel and NGV of 18 special vehicles used for collecting and transferring infectious wastes and one private vehicle in baht/month illustrated that efficiency of treatment costs of transportation systems was 4.19 kg of infectious waste/baht.

iii. The entire system

Efficiency of treatment costs of the entire system in the ratio of average amount of infectious waste in kg/month and the sum of costs from incinerators plus transportation plus the use of electricity and water supply in baht/month illustrated that efficiency of treatment costs of the entire system was 0.96 kg of infectious waste/baht.

4.3.4 Comparison between efficiency indicators among three stages of management

i. Comparison between energy efficiency

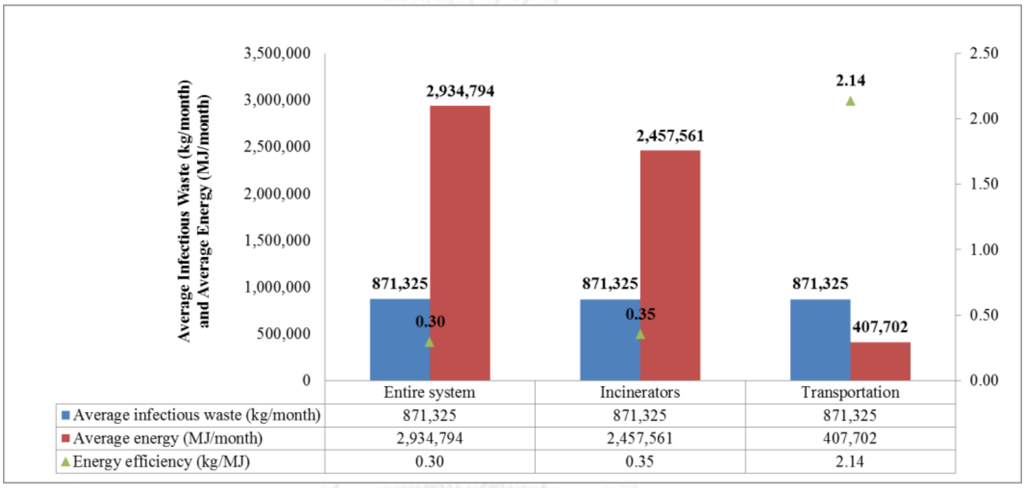


Figure 4-4: Energy efficiency indicators of infectious waste management

Figure 4-4 showed that energy efficiency was 0.30 kg/MJ for the entire system, 0.35 kg/MJ for the incinerators and 2.14 kg/MJ for the transportation. These results indicated that the transportation has higher energy efficiency than that of incinerators by 511.43%. The differences between energy efficiency of the incinerators and the transportation resulted in increase and decrease of energy efficiency of the entire system. Regarding all energy efficiency using the entire system efficiency as a benchmark, the incinerators and the transportation were two indicators to analyze for the hotspot to better improve energy efficiency of the entire system. Comparison of energy efficiency between the incinerators and the transportation indicated that the incinerators were the hotspot because they used higher energy in infectious waste management than the transportation by 502.78%. In the same time, the transportation was efficiently managed when it was compared with the incinerators. Therefore, the incinerators should better be improved to increase their energy efficiency to increase energy efficiency of the entire system. However, efficiency of transportation should be better improved as well.

ii. Comparison between CO_2 emission efficiency

CO_2 emission efficiency was evaluated in the ratio of infectious waste treatment in kg/month and average CO_2 emission generated during collection, transportation, treatment and disposal of infectious wastes in kg/month was assessed. As illustrated in **Figure 4-5**, the CO_2 emission efficiency was 1.28 kg waste/kg CO_2 for the entire system, 1.35 kg waste/kg CO_2 for the incinerators and 34.60 kg waste/kg CO_2 for the transportation.

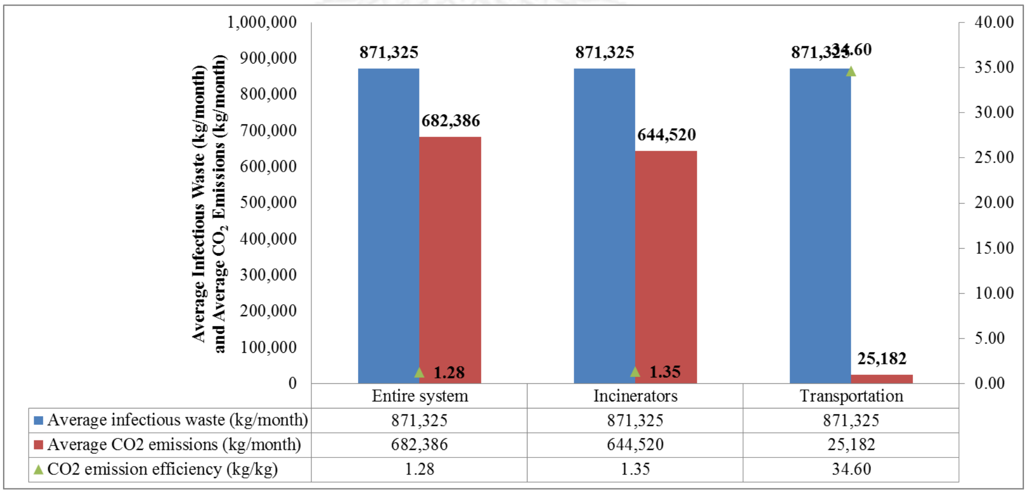


Figure 4-5: CO_2 emission efficiency indicators of infectious waste management

These results indicated that the transportation has higher CO_2 emission efficiency than that of the incinerators by 2,462.96%. The differences between CO_2

emission efficiency of the incinerators and the transportation resulted in increase and decrease of CO_2 emission efficiency of the entire system. Into consideration of all CO_2 emission efficiency using the entire system efficiency as a benchmark, the incinerators and the transportation were two indicators to analyze for the hotspot to better improve CO_2 emission efficiency of the entire system. Comparison of CO_2 emission efficiency of the incinerators and the transportation indicated that the incinerators were the hotspot because they had higher CO_2 emissions in infectious waste treatment than the transportation by 2,459.45%. In the same time, the transportation was still efficiently managed when it was compared with the incinerators. Therefore, the incinerators should be better improved to increase their CO_2 emission efficiency to increase of CO_2 emission efficiency of the entire system. However, the efficient transportation could be better improved as well.

iii. Comparison between efficiency of treatment costs

Efficiency of treatment costs was evaluated in the ratio of treated infectious wastes and average economic value (costs) in baht/month. **Table 4-6** showed that efficiency of treatment costs was 0.96 kg/baht for the entire system, 1.46 kg/baht for the incinerators and 4.19 kg/baht for the transportation.

Table 4-6: Efficiency indicators of treatment costs of infectious waste management

Types of stages	Entire system	Incinerators	Transportation
Efficiency of treatment costs (kg/baht)	0.96	1.46	4.19

These results indicated that the transportation has higher efficiency of treatment costs than that of incinerators by 186.99%. Into consideration of all efficiency of treatment costs using the entire system efficiency as a benchmark, the incinerators and the transportation were two indicators to analyze for the hotspot to better improve efficiency of treatment costs of the entire system. Comparison of efficiency of treatment costs of the incinerators and the transportation indicated that the incinerators were the hotspot because they had higher costs in infectious waste management than the transportation by 186.43%. In the same time, the transportation was still efficiently managed when it was compared with the incinerators. Therefore, the incinerators should be better improved to increase their efficiency of treatment to increase efficiency of treatment costs of the entire system. However, the efficient transportation could be better improved as well.

4.4 Scenario analysis for improving efficiency of infectious waste management

4.4.1 Efficiency improvement in the transportation system

Analysis of energy, CO_2 emission and cost efficiency of the existing system indicated that the incinerators should be better improved to increase their all efficiency of the entire existing system. However, the existing transportation could be better improved to increase its efficiency of the entire new system as well. Therefore, the research proposed a scenario for improving the efficiency of infectious waste management by modifying 12 diesel engine vehicles for infectious waste collection and transportation to 12 NGV engine vehicles (dedicated retrofit) as shown in **Figure 4-6**.

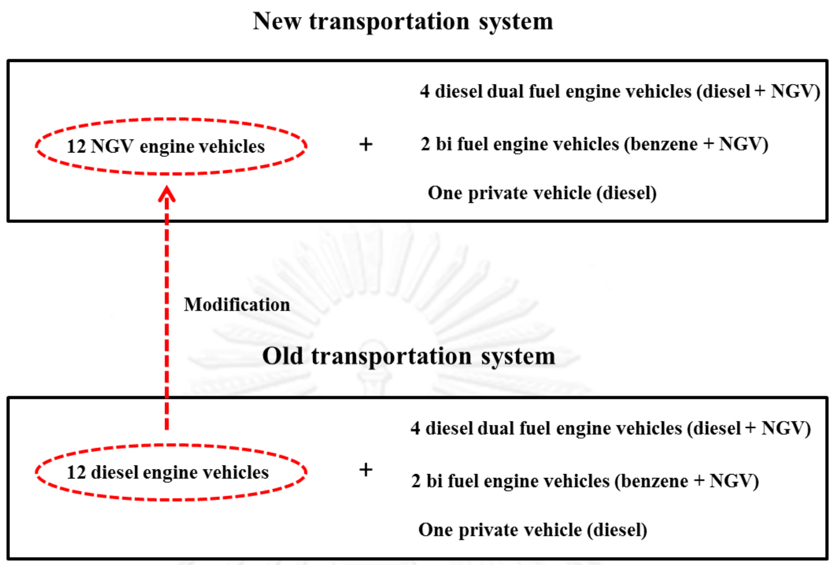


Figure 4-6: The diagram of modifying 12 diesel engine vehicles to 12 NGV engine vehicles

After modification of 12 diesel engine vehicles for infectious waste collection and transportation to 12 NGV engine vehicles (dedicated retrofit), the results of efficiency of new transportation were presented and discussed below:

i. The energy efficiency

Energy efficiency was evaluated as the ratio of average amount of infectious waste in kg/month and the sum of energy consumption from 12 new NGV engine vehicles plus 7 vehicles staying the same in MJ/month. The result found that energy efficiency of the new transportation system was 2.49 kg of infectious waste/MJ.

ii. The CO_2 emission efficiency

CO_2 emission efficiency was evaluated as the ratio of average amount of infectious waste in kg/month and the sum of CO_2 emissions from fuel combustion in 12 new NGV engine vehicles plus 7 vehicles staying the same in kg/month. CO_2 emission efficiency of the new transportation system was 50.16 kg of infectious waste/kg of CO_2.

iii. The efficiency of treatment costs

Efficiency of treatment costs was evaluated as the ratio of average amount of infectious waste in kg/month and the sum of costs from fuels plus NGV engine modification and installation in baht/month. Efficiency of treatment costs of the new transportation system was 7.72 kg of infectious waste/baht.

iv. Cost saving and the payback period

From analysis of efficiency of treatment costs, the new transportation system had to pay high fixed costs for NGV engine modification and installation. Therefore, the cost saving rate and the payback period for modifying 12 diesel engine vehicles to 12 NGV engine vehicles were presented and discussed in **Table 4-7**.

Table 4-7: The cost saving rate and the payback period of NGV engine installation

Type of equipment	NGV engine modification (dedicated retrofit)	Units
Equipment price	4,800,000	baht/12 vehicles
Average distances of 12 diesel vehicles	32,268.81	km/month
Combustion rate of diesel engine vehicles	6.37	km/L
Combustion rate of NGV engine vehicles	11.91	km/kg
Retail price of diesel	29.99	baht/L
Retail price of NGV	10.50	baht/kg
Cost rate of diesel	4.71	baht/km
Cost rate of NGV	0.88	baht/km
Cost saving rate	3.83	baht/km
Cost saving rate	123,485.11	bath/month
Payback period	38.87	month
Payback period	3.24	year

The equipment price for NGV engine modification and installation was 4,800,000 baht/12 vehicles (400,000 baht/vehicle) (PTT, 2013). When there was modification of 12 diesel engine vehicles to 12 NGV engine vehicles, the cost saving rate and the payback period for 12 NGV engine vehicles were 123,485.11 baht/month and 3.24 years, respectively.

4.4.2 Comparison between efficiency indicators of the old and new transportation systems

i. Comparison between energy efficiency

In term of energy efficiency, **Figure 4-7** showed that energy efficiency was 2.97E-01 and 3.03E-01 kg/MJ for the entire old and new systems, 2.14 and 2.49 kg/MJ for the old and new transportation systems, respectively. These results indicated that the new transportation can yield higher energy efficiency than the old transportation by 16.36%. When there was modification of 12 diesel engine vehicles (old transportation) to 12 NGV engine vehicles (new transportation), the new transportation could decrease 57,786.83 MJ/month or 14.17% of energy utilized in infectious waste collection and transportation compared with the old transportation. Comparison between energy efficiency of the entire old and new systems indicated that the new transportation could slightly increase energy efficiency of the entire new system by 2.01% because energy utilized in the new systems decreased only 1.97% compared with the old system.

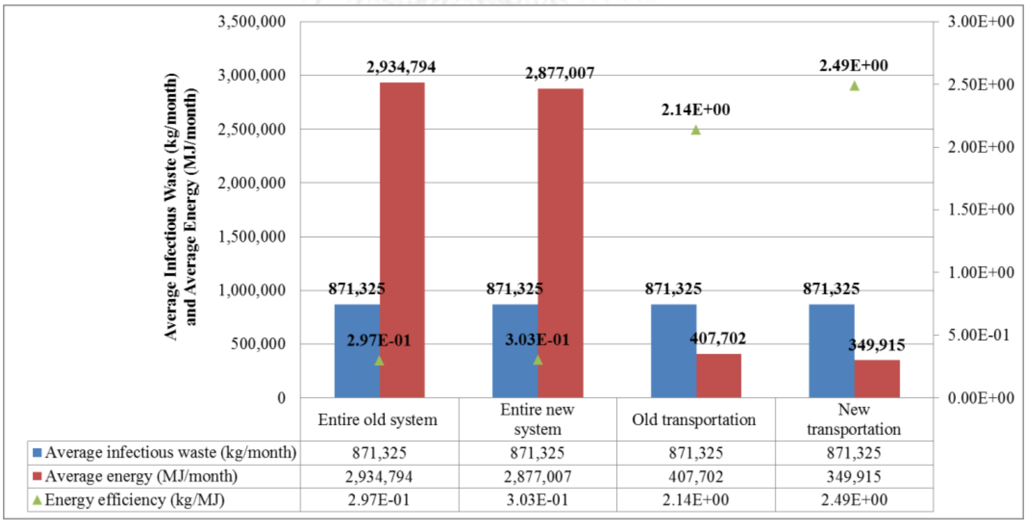


Figure 4-7: Energy efficiency indicators of the transportation in term of infectious waste

ii. Comparison between CO_2 emission efficiency

CO_2 emission efficiency was illustrated in **Figure 4-8**. The CO_2 emission efficiency was 1.28 and 1.29 kg waste/kg CO_2 for the entire old and new systems, 34.60 and 50.16 kg waste/kg CO_2 for the old and new transportation systems, respectively.

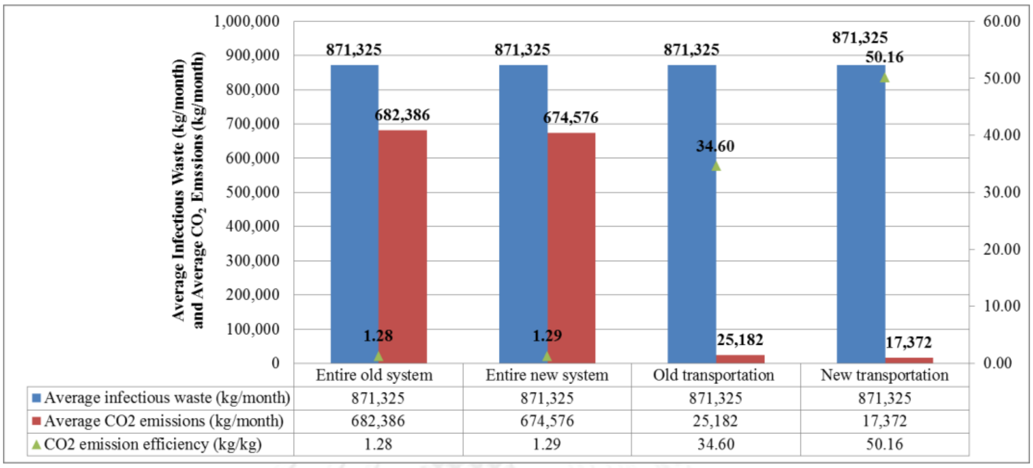


Figure 4-8: CO_2 emission efficiency indicators of the transportation in term of infectious waste

These results indicated that the new transportation gave higher CO_2 emission eco-efficiency than the old transportation by 44.97%.The entire new system gave higher CO_2 emission efficiency than the old system by 0.78%. Regarding average CO_2 emissions, the new transportation could decrease 7,810.05 kg/month or 31.01% of average CO_2 emissions compared with the old transportation system. Consideration between CO_2 emission efficiency of the entire old and new systems indicated that the new transportation could increase slightly CO_2 emission efficiency of the entire new system because average CO_2 emissions from the entire new system decreased only 1.14% compared with the entire old system.

iii. Comparison between efficiency of treatment costs

Efficiency of treatment costs was evaluated as the ratio of average infectious waste treatment value and average economic value (costs) in baht/month. **Table 4-8** showed that efficiency of treatment costs was 0.96 and 1.07 kg/baht for the entire old and new systems, 4.19 and 7.72 kg/baht for the old and new transportation systems, respectively.

Table 4-8: Efficiency indicator of treatment costs of the transportation

Types of stages	Entire old system	Entire new system	Old transportation	New transportation
Efficiency of treatment costs (kg/baht)	0.96	1.07	4.19	7.72

These results indicated that the new transportation has higher efficiency of treatment costs than the old transportation by 84.25%, and the entire new system has higher efficiency of treatment costs than the entire old system by 11.46%. When there was modification of 12 diesel engine vehicles (old transportation) to 12 NGV engine vehicles (new transportation), the new transportation could save 45.68% of average costs comparing with the old transportation.

Average costs of the new transportation consisted of 25.20% of average costs of NGV used in 12 NGV engine vehicles, 25.24% of averagely fixed costs for NGV engine modification and installation, and 49.56% of average costs of diesel and NGV used in 7 vehicles staying the same. In comparison between average costs of NGV used in 12 NGV engine vehicles and average costs of diesel used in 12 diesel engine vehicles, the new transportation could save 81.27% of average costs compared with the old transportation, but the new transportation had to pay 25.24% of averagely fixed costs for NGV engine modification and installation from total costs. Consideration between efficiency of treatment costs of the entire old and new systems indicated that the new transportation increased cost efficiency of the entire new system because average costs of the entire new system decreased 10.48% compared with the entire old system.

4.4.3 Comparison between eco-efficiency indicators of the old and new transportation systems

i. Comparison between energy eco-efficiency

Energy eco-efficiency was evaluated as the ratio of gross profit margin in baht/month and the sum of energy consumption from incinerators plus transportation plus electricity use in MJ/month. The results found that energy eco-efficiency was 2.35 and 2.39 baht/MJ for the entire old and new systems, respectively.

Table 4-9: Energy eco-efficiency indicators of the entire old and new systems

Types of stages	Entire old system	Entire new system
Gross income (baht/month)	6,883,468	6,883,468
Average energy (MJ/month)	2,934,794	2,877,007
Energy eco-efficiency (baht/MJ)	2.35	2.39

These results indicated that the entire new system had higher energy eco-efficiency than that of the entire old system by 2.01%. Regarding average energy consumption, the entire new system could decrease 57,786.84 MJ/month or 1.97%

of energy consumption compared with the entire old system while the disposal company still earned the same gross income.

ii. Comparison between CO_2 emission eco-efficiency

CO_2 emission eco-efficiency was evaluated as the ratio of gross profit margin in baht/month and the sum of CO_2 emissions from incinerators plus transportation plus electricity use plus the wastewater treatment plant 1 in kg/month. The results found that CO_2 emission eco-efficiency was 7.14 and 7.20 baht/kgCO_2 for the entire old and new systems, respectively.

Table 4-10: CO_2 emission eco-efficiency indicators of the entire old and new systems

Types of stages	Entire old system	Entire new system
Gross income (baht/month)	6,883,468	6,883,468
Average CO_2 emissions (kg/month)	682,386	674,576
CO_2 emission eco-efficiency (baht/kg)	10.09	10.20

These results indicated that the entire new system gave higher CO_2 emission eco-efficiency than that of the entire old system by 1.09%. Regarding average CO_2 emissions, the entire new system could decrease 7,810 kg/month or 1.14% of CO_2 emissions compared with the entire old system while the disposal company still earned the same gross income.

CHAPTER V

PUBLIC AND PRIVATE HOSPITALS’ SURVEY

In this Chapter V, the survey results from public and private hospitals for improving efficiency of infectious waste management in Bangkok were presented and discussed. The total survey responses were 65 hospitals or 45.45% from the total number of government and private hospitals (143 places) located in 50 districts of Bangkok. The survey response rates were 56.76% for government hospitals (from total 37 places) and 41.51% for private hospitals (from total 106 places). The survey results received from government and private hospitals were analyzed together. The results were divided into 2 parts as follows: (i) infectious waste management systems within public and private hospitals and (ii) satisfaction of public and private hospitals from services provided by the disposal company (the Krungthep Thanakom Co., Ltd).

5.1 Infectious waste management systems within public and private hospitals

This part presented and discussed the results of infectious waste management within public and private hospitals in Bangkok. The results in Section 5.1 were divided into nine subsections as follows: (a) types of containers for infectious waste collection, (b) infectious sharp accidents, (c) infectious disease accidents, (d) workers’ annual health checkup, (e) incentives to infectious waste management, (f) establishment of training and education programs, (g) problems of waste mixing, (h) problems of temporary storage areas and (i) allocation and separation of temporary storage areas.

a. Types of containers for infectious sharp collection

For infectious sharp collection, **Table 5-1** showed that 43.08%, 36.92%, 10.77% and 4.62% of hospitals used special rigid plastic containers, general rigid plastic containers, other types of containers and corrugated boxes, respectively. Moreover, 4.62% of hospitals used more than one type of containers as mentioned above for infectious sharp collection. Other types of containers were plastic bottles, cardboard boxes, and big rigid plastic gallons for collecting big or long infectious sharps.

Table 5-1: Types of containers for infectious sharp collection

Types of containers	Respondents	Percentage (%)
Special rigid plastic containers	28	43.08
General rigid plastic containers	24	36.92
Others	7	10.77
Corrugated boxes	3	4.62
General and special regid plastic containers	1	1.54
General regid plastic containers and others	1	1.54
Special rigid plastic containers and others	1	1.54
Total	65	100

These results indicated that most hospitals used special and general rigid plastic containers which are strong and resistant to laceration and perforation of infectious sharps. These intend to reduce and prevent workers' infectious sharp accidents in collecting and transferring infectious sharps and wastes for treatment and disposal. On the other hand, 4.62% of hospitals used corrugated boxes for infectious sharp collection which were easy to stabbing and perforation especially of infectious needle sticks. These could be risky and causing infectious sharp accidents and infectious diseases to workers.

b. Workers' accidents damaged from infectious sharps

About the working accidents from waste management in hospitals, **Table 5-2** showed that around 61.54% of hospitals had no infectious sharp accidents to workers who had the responsibility for collecting and transferring infectious sharps and wastes at sources to a temporary storage area within public and private hospitals. In contrast, about 36.92% and 1.54% of hospitals experienced less than 5 times per year and more than 5 times per year of workers' infectious sharp accidents, respectively.

Table 5-2: The number of workers' accidents from infectious sharps during the operation

The number of accidents damaged from infectious sharps	Respondents	Percentage (%)
No accidents	40	61.54
Less than 5 times/year	24	36.92
More than 5 times/year	1	1.54
Total	65	100

These results indicated that most hospitals had no infectious sharp accidents because workers wear prevention equipment and strictly follow rules and regulations of Ministry of Public Health for collecting and transferring infectious sharps and wastes. In addition, hospitals used containers for infectious sharp collection which are strong and resistant to stabbing and perforation of infectious sharps. On the other hand, 39.06% of hospitals still faced infectious sharp accidents because some hospitals used containers which are easy to stabbing and perforation of infectious shapes or had low costs and quality for infectious sharp collection.

c. Workers' accidents damaged from infectious diseases

From the survey, 100% of hospitals had no workers' accidents damaged from infectious diseases. These results indicated that all hospitals' workers wore prevention equipment and strictly followed rules and regulations of Ministry of Public Health for collecting and transferring infectious sharps and wastes in order to reduce and prevent infectious diseases. In case of workers' infectious sharp accidents, it indicated that all hospitals immediately provided health checkup programs and specific vaccines for infectious disease prevention.

d. Workers' annual health checkup

Table 5-3 showed that around 83.08% of hospitals had workers' annual health checkup for collecting and transferring infectious wastes, but about 16.92% of hospitals had no workers' annual health checkup. These results indicated that most hospitals pay attention to workers' health because workers' annual health checkup is necessary to be done to screen, treat and prevent general and infectious diseases. On the other hand, some hospitals neglected workers' annual health checkup, and this would lead to the spreading of infectious diseases from workers within public and private hospitals to outside people and their family.

Table 5-3: Workers' annual health checkup

Workers' annual health checkup	Respondents	Percentage (%)
Yes	54	83.08
No	11	16.92
Total	65	100

e. Workers' incentives to infectious waste management

Table 5-4 showed that 70.77% of hospitals did not provide compensation and other welfare to workers for increasing their motivation in infectious waste management within public and private hospitals. However, around 21.54%, 4.62% and 3.08% of hospitals provided other types of welfare, compensation, and both compensation and welfare, respectively to motivate their workers. Workers' compensation obtained from public and private hospitals ranged from 500 to 4,000 baht/month. Workers' other welfare was obtained from professional fees, active payment or diligent, overtime (OT with 60 baht/hour), free medical care and health checkup programs and specific vaccines for infectious disease prevention.

Table 5-4: Workers' incentives to infectious waste management

Incentives for workers	Respondents	Percentage (%)
No compensation and other welfare	46	70.77
Other welfare	14	21.54
Compensation	3	4.62
Compensation and other welfare	2	3.08
Total	65	100

These results indicated that 29.23% of hospitals specially paid attention to increasing workers' motivation in infectious waste management within their public and private hospitals by providing special compensation and other welfare.

f. Establishment of training programs about infectious waste management

Table 5-5 showed that 87.69% of hospitals had established training programs about infectious waste management to medical personnel and workers. The number of established training programs in most hospitals ranged from 1 to 4 times per year. Moreover, the number of established training programs in some hospitals reached 12 times per year. On the other hand, 12.31% of hospitals had no establishment of training programs.

Table 5-5: Establishment of training programs about infectious waste management

Establishment of training programs about infectious waste management	Respondents	Percentage (%)
Yes	57	87.69
No	8	12.31
Total	65	100

These results indicated that most hospitals paid attention to each step of infectious waste management at beginning of sources of infectious waste generation, collection and transfer, storage, treatment and disposal by establishing the training programs. These could increase the efficiency of infectious waste management within public and private hospitals and reduce and prevent accidents damaged from infectious sharps and wastes during the operation. On the other hand, some hospitals did not establish training programs for providing knowledge about appropriate infectious waste management. Therefore, workers would inappropriately collect, transfer and deal with infectious wastes, and these led to risks causing infectious sharp accidents and infectious diseases.

g. Problems about general wastes mixed with infectious wastes

Table 5-6 showed that about 81.54% of hospitals had no general wastes mixed with infectious wastes to the disposal company. However, around 18.46% of hospitals had general wastes mixed with infectious wastes. Types of general wastes mixed with infectious wastes in some hospitals were plastic bags and bottles, snack packaging, paper, tissue, cases for containing needles, syringes, suction and medical materials and food wastes discarded from patients' relatives.

Table 5-6: Problems about general wastes mixed with infectious wastes

General wastes mixed with infectious wastes	Respondents	Percentage (%)
No	53	81.54
Yes	12	18.46
Total	65	100

These results indicated that most hospitals clearly allocated and separated each type of bins for collecting each type of wastes to reduce and prevent general wastes mixed with infectious wastes. This helps public and private hospitals to reduce the amount of general wastes mixed with infectious wastes to the disposal company. In contrast, some hospitals still faced problems about general wastes mixed with infectious wastes. These increased the amount of infectious waste to the disposal company and costs for collection and transfer and treatment and disposal.

h. **Problems about a temporary storage area for infectious waste collection**

Table 5-7 showed that about 76.92% of hospitals had no problems about a temporary storage area for infectious waste collection, but around 23.08% of hospitals had more than one problem about a temporary storage area for infectious waste collection, for example a limitation of the storage areas and entry and exit routes of the storage areas difficult to transport . Other problems occurring in some hospitals focused on delayed services for infectious waste collection and transfer provided by the disposal company.

Table 5-7: Problems about a temporary storage area for infectious waste collection

Problems of a temporary storage area for infectious waste collection	Respondents	Percentage (%)
No problems	50	76.92
Limitation of the storage area	8	12.31
Limitation of the storage area and the excessive amount of infectious wastes with limited area capacity	2	3.08
Others	2	3.08
Limitation of the storage area, the excessive amount of infectious wastes with limited area capacity and entry and exit routes of the storage area difficult to transport	1	1.54
Limitation of the area and others	1	1.54
Entry and exit routesof the storage area difficult to transport	1	1.54
Total	65	100

These results indicated that most hospitals had no problems about temporary storage areas, but 23.08% of hospitals still faced these problems, such as limitation of temporary storage areas, the excessive amount of infectious waste or entry and exit routes of the storage areas difficult to transport. These problems led to infectious waste collection outside temporary storage areas causing spreading of infectious diseases.

i. Allocation and separation of a temporary storage area for collecting each type of wastes

Table 5-8 showed that 70.77% of hospitals had allocation and separation of temporary storage area for collecting recyclable, general, infectious wastes and other hazardous wastes, but 29.23% of hospitals had allocation and separation of temporary storage area for collecting some types of wastes as mentioned above. These results indicated that all hospitals paid attention to allocation and separation of temporary storage areas for collecting each type of wastes to reduce and prevent spreading of pathogens, parasites and bacteria to other wastes.

Table 5-8: Allocation and separation of a temporary storage area for collecting each type of wastes

Allocation and separation of a temporary storage area for collecting each type of wastes	Respondents	Percentage (%)
Recyclable, general, infectious wastes and other hazadous wastes	46	70.77
General and infectious wastes and other hazardous wastes	8	12.31
Recyclable, general and infectious wastes	6	9.23
General and infectious wastes	5	7.69
Total	65	100

5.2 **Satisfaction of hospitals from services provided by the Krungthep Thanakom Co., Ltd**

This part **presented** and discussed the results of satisfaction of public and private hospitals from services in collection, transportation, treatment and disposal of infectious waste provided by the disposal company. The results in Section 5.2 were divided into seven subsections as follows: (a) protective equipment wearing, (b) compliance of rules and regulations during the operation, (c) schedule for infectious waste collection and transfer, (d) frequency in infectious waste collection and transfer, (e) establishment of the seminar, (f) the cost rate for infectious waste collection and transfer and (g) an overview of services provided.

i. Workers' prevention equipment wear during the operation

Figure 5-1 showed that 13.85%, 55.38% and 26.15% of hospitals were highly satisfied, satisfied and moderately satisfied, respectively with workers' prevention equipment wear during collecting and transferring infectious wastes onto special vehicles. However, only 3.08% and 1.54% of hospitals were unsatisfied and highly unsatisfied, respectively with workers' prevention equipment wear.

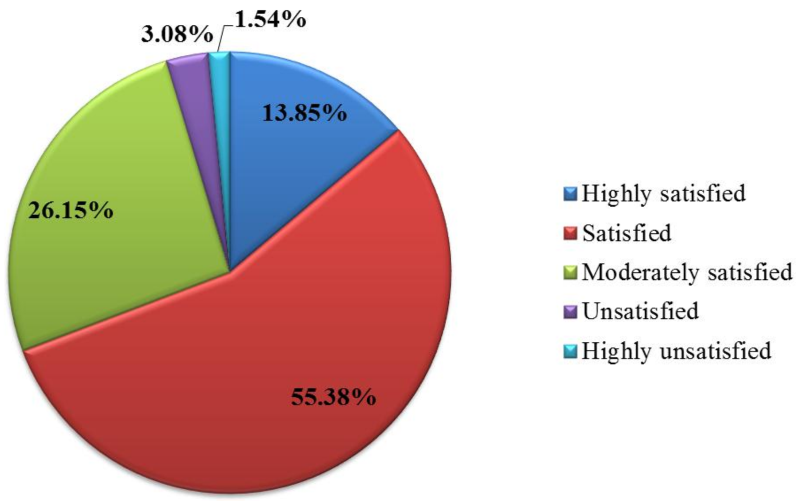


Figure 5-1: Satisfaction of public and private hospitals for workers' prevention equipment wear during the operation

These results indicated that the disposal company's most workers strictly wore prevention equipment during collecting and transferring infectious waste onto special vehicles, but a small number of workers still were careless and negligent of wearing prevention equipment during the operation causing infectious sharp accidents and diseases.

ii. Workers' operation strictly following rules and regulations of Ministry of Public Health during infectious waste collection and transfer onto special vehicles

Figure 5-2 showed that 21.54%, 53.85% and 21.54% of hospitals were highly satisfied, satisfied and moderately satisfied, respectively with workers' operation strictly following rules and regulations of Ministry of Public Health during infectious waste collection and transfer onto special vehicles. However, 1.54% and 1.54% of hospitals were unsatisfied and highly unsatisfied, respectively with workers' operation strictly following rules and regulations of Ministry of Public Health.

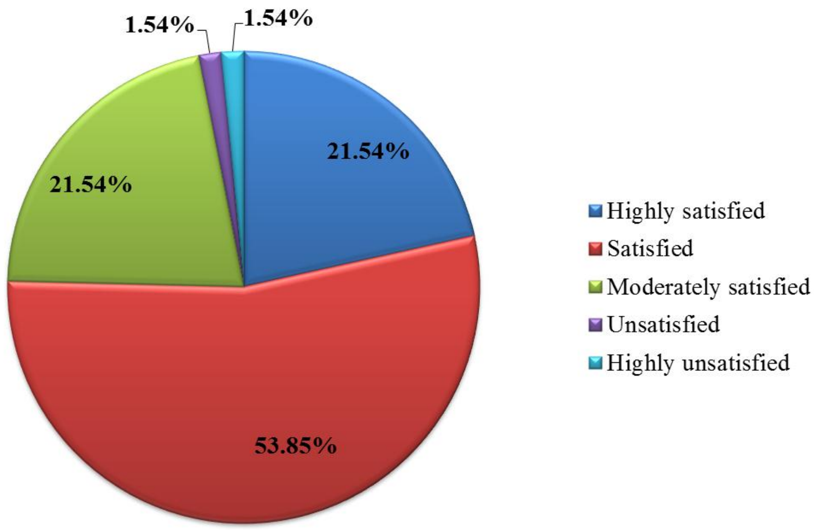


Figure 5-2: Satisfaction of public and private hospitals for workers' operation strictly following rules and regulations of Ministry of Public Health during infectious waste collection and transfer onto special vehicles

These results indicated that the disposal company's most workers strictly followed rules and regulations in collecting and transferring infectious waste onto special vehicles, and they did not throw and stomp infectious waste during the operation. On the other hand, a small number of workers still neglected to follow rules and regulations during the operation which caused red plastic bags containing infectious waste broken and led to infectious sharp accidents and spreading of infectious diseases.

iii. Date and time for infectious waste collection and transfer in each public and private hospital determined by the disposal company

Figure 5-3 showed that 26.15%, 46.15% and 23.08% of hospitals were highly satisfied, satisfied and moderately satisfied, respectively with date and time for infectious waste collection and transfer from their hospitals to the disposal company, but 1.54% and 3.08% of hospitals were unsatisfied and highly unsatisfied, respectively with date and time for infectious waste collection and transfer.

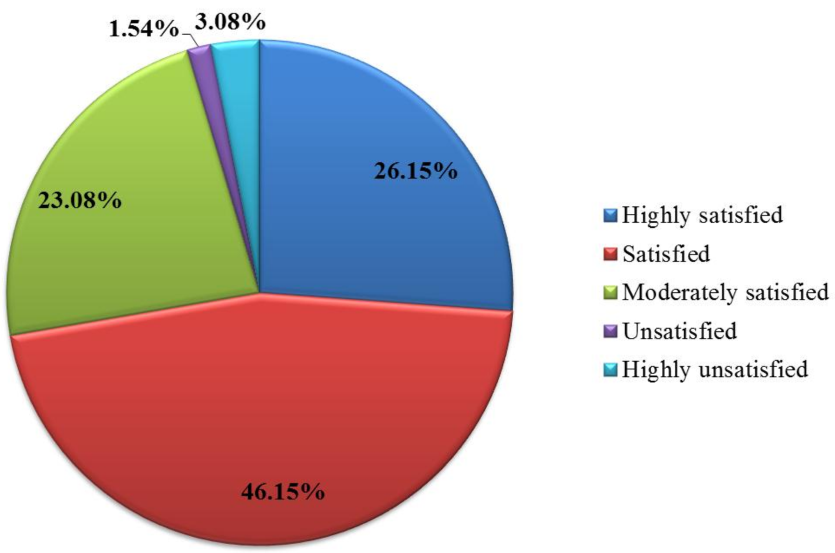


Figure 5-3: Satisfaction of public and private hospitals for date and time in infectious waste collection and transfer in each public and private hospital determined by the disposal company

These results indicated that the disposal company determined date and time in infectious waste collection and transfer which were suitable for the amount of infectious waste generated from each public and private hospital. On the other hand, the date and time still were obstacles to a small number of hospitals which were not suitable for the amount of infectious waste generated causing a lot of remaining infectious waste at a temporary storage area of public and private hospitals.

iv. Frequency in infectious waste collection and transfer by the disposal company

Figure 5-4 showed that 26.15%, 41.54% and 26.15% of hospitals were highly satisfied, satisfied and moderately satisfied, respectively with frequency in infectious waste collection and transfer by the disposal company, but 6.16% of hospitals were unsatisfied with frequency in infectious waste collection and transfer.

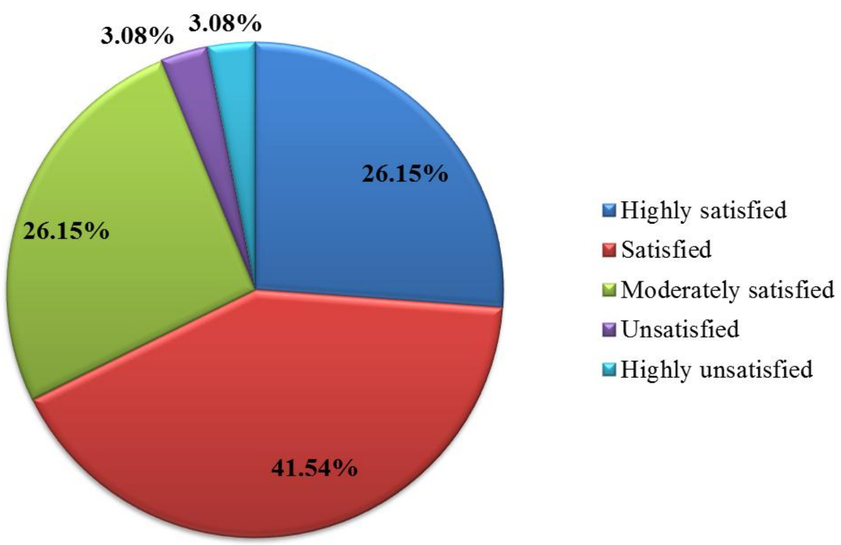


Figure 5-4: Satisfaction of public and private hospitals for frequency in infectious waste collection and transfer at sources to the disposal company

These results indicated that the disposal company paid attention to infectious waste collection and transfer in order to reduce problems about remaining infectious waste at a temporary storage area of hospitals. However, a small number of hospitals still faced problems about remaining infectious waste at temporary storage area because infectious waste generated was not often collected and transferred by the disposal company.

v. Establishment of the seminar for providing knowledge about infectious waste management to public and private hospitals once a year

Figure 5-5 showed that 20.00%, 50.77% and 24.62% of hospitals were highly satisfied, satisfied and moderately satisfied, respectively with establishing the seminar about infectious waste management provided by the disposal company, but 4.62% of hospitals were unsatisfied with establishing the seminar about infectious waste management.

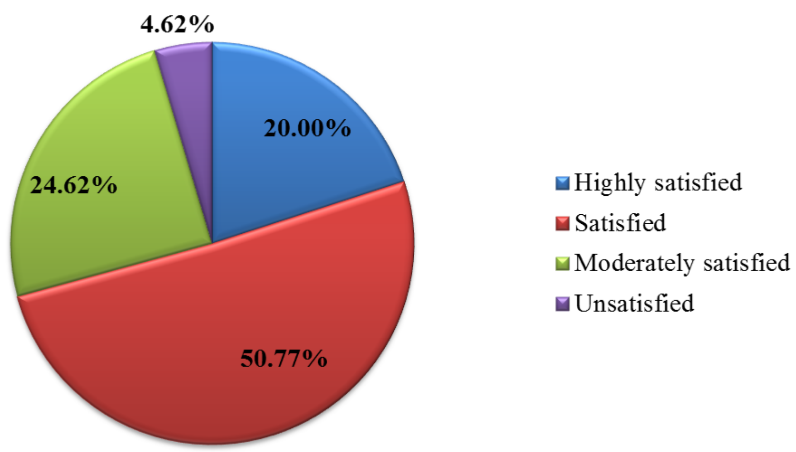


Figure 5-5: Satisfaction of public and private hospitals for establishment of the seminar for providing knowledge about infectious waste management to public and private hospitals once a year

These results indicated that the seminar about infectious waste management established once a year by the disposal company was enough and useful to public and private hospitals to bring knowledge about appropriate management to apply in their hospitals.

vi. The cost rate for infectious waste collection and transfer with 5 baht/kg charged from public and private hospitals

Figure 5-6 showed that 13.85%, 60.00% and 23.08% of hospitals were highly satisfied, satisfied and moderately satisfied, respectively with the cost rate of 5 baht/kg for infectious waste collection and transfer, but 3.08% of hospitals were unsatisfied with this cost rate.

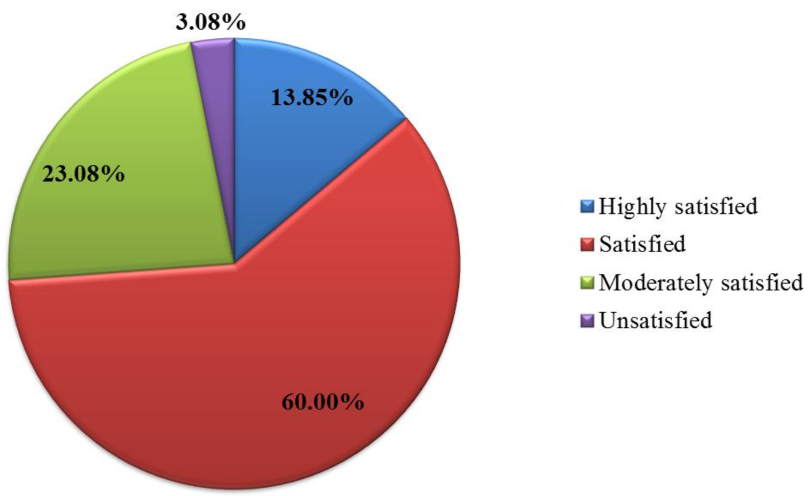


Figure 5-6: Satisfaction of public and private hospitals for the cost rate in infectious waste collection and transfer with 5 baht/kg charged from public and private hospitals

These results indicated that the cost rate of 5 baht/kg in infectious waste collection and transfer was reasonable that hospitals could pay.

vii. An overview for providing services in infectious waste management of the disposal company

Figure 5-7 showed that 18.46%, 67.69% and 13.85% of hospitals were highly satisfied, satisfied and moderately satisfied, respectively with an overview of services in infectious waste management provide by the disposal company.

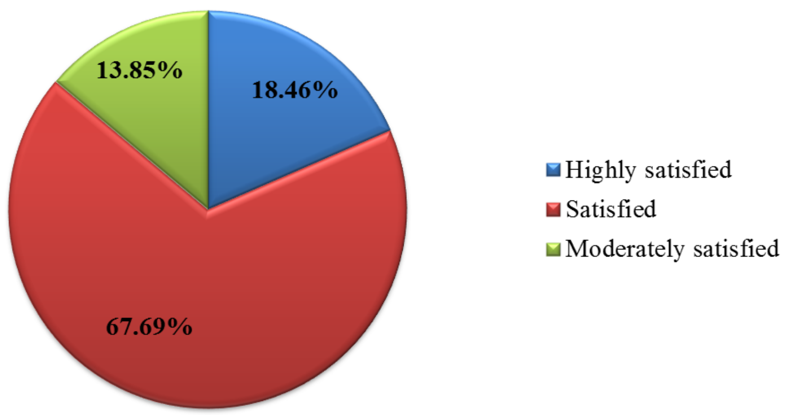


Figure 5-7: Satisfaction of public and private hospitals for an overview in providing services in infectious waste management of the disposal company

These results indicated that the disposal company had the high efficiency for providing services in collection, transportation, treatment and disposal of infectious waste generated from public and private hospitals.

CHAPTER VI

RECOMMENDATIONS

In Chapter VI, the recommendations on infectious waste management in Bangkok focused on improvement of management systems for sources of infectious waste generation, the transportation and incinerators of the disposal company. Therefore, the recommendations for improving the efficiency of infectious waste management in Bangkok were divided into two main parts as follows: (i) recommendations for improving the efficiency of the incinerators and transportation and (ii) recommendations of good management practices for hospitals and the disposal company.

6.1 Recommendations for improving the efficiency of the incinerators and transportation

Based on the MFA and eco-efficiency results, there are recommendations of management strategies for improving the efficiency of the infectious waste incinerators and collection and transportation routes as follows:

General operating

- The primary chamber of incinerators should be fully heated up to reach at 560 °C by observing a temperature gauge before infectious waste is added to increase complete combustion.
- The disposal company should have technicians and operators to control and maintain the incinerators for 24 hours. They should periodically check parameters (e.g., temperature in the primary and secondary chambers,

excess air and air flow rate) affecting infectious waste burning processes to control and maintain them as standard values to provide complete combustion in the incinerators.

Waste loading

- Workers should feed the proper amount of infectious waste in each batch (40 kg/time) with continuous frequency (every 2.30 to 3.0 minutes) to the incinerators to provide good air mixing with infectious waste and maintain temperature in each chamber with complete combustion. The weight in each batch and frequency in infectious waste feed are created according to plant design and some information from visiting the disposal facility.

Burning processes

- Because the infectious waste incinerators have been operated for 18 years, technicians and operators should check leakage of pipes, tanks and joints for water and fuel transfer and storage to the incinerators including insulators, burners and refractory lining if these problems are found, they should immediately maintain.
- The disposal company should conduct the feasibility study to find out whether there are any waste gases with enough potential to generate electricity. If there is a potential, the Krungtheptanakom can install a small electricity generator by using thermal energy from infectious waste burning processes in moving turbines for electricity production, and it can help the disposal company save costs in a long term.

- Technicians and operators should check and control temperature (1,000-1,200) in the secondary chamber to provide complete combustion of exhaust gases emitted from infectious waste incineration in the primary chamber to reduce their quantities to atmosphere.

Logistics

- Currently, the disposal company's routes for infectious waste collection and transportation still face some problems (e.g., traffic jam collection efficiency) which result in insufficient efficiency. Therefore, the disposal company should investigate other problems affecting efficiency of infectious waste collection and transportation and identify possibility to change or increase routes for infectious waste collection and transportation and time in each route to increase efficiency of waste management system based on a distance, the different amount of infectious waste generated.

6.2 Recommendations of good management practices for hospitals and the disposal company

Based on the survey results, there are three main management strategies for improving the efficiency and services of infectious waste management in Bangkok in short and long terms as follows: (i) enhancing training and education programs, (ii) promoting efficiency of waste separation at sources and (iii) increasing efficiency of waste collection and logistics.

6.2.1 Enhancing training and education programs

- Hospitals and the disposal company should have training and education programs about all steps of appropriate infectious waste management, protective equipment wear during the operation, types of infectious waste, risks and accidents caused from inappropriate management to their all personnel.
- The training and education programs should be continuously or once a month provided to staff, workers, nurses, nursing students, doctors and medical personnel to raise their awareness of appropriate infectious waste management.
- The information of these training and education programs should be revealed and announced to patients and their companions in patterns of brochures, boards and documents which are easy to read and understand overall details resulting in raising their awareness of management practices (e.g., they should discard wastes according to each type of bins in hospitals to minimize problems of waste mixing and the amount of infectious waste to the disposal company)
- Hospitals and the disposal company should establish clinic centers for providing knowledge and information about appropriate infectious waste management to public people, students, graduates, government and private agencies which interest to study to improve the efficiency of management and develop management strategies.

- **Advantages**

- The training and education programs can be immediately conducted, and they are a basic guideline for providing knowledge and information about appropriate infectious waste management for all personnel of hospitals and the disposal company.
- The training and education programs can help them (e.g., staff, workers, nurses, nursing students, doctors and medical personnel) have enough knowledge in appropriate infectious waste management, and they can help them raise awareness and carefulness of risks and accidents caused from infectious waste and sharps.
- The training and education programs can be conducted to improve the efficiency of all personnel who responds to infectious waste management in both short and long terms.

- **Disadvantages**

- The training and education programs may want specialists or experts in each side of infectious waste management who want quite high compensation.
- The training and education programs may not cover each personnel's different knowledge and ability levels.

6.2.2 Promoting efficiency of waste separation at sources

- Staff, workers, nurses, nursing students, doctors and medical personnel should separate and collect each type of infectious waste to appropriate containers (e.g., infectious sharps should collect in special or general rigid plastic containers which are strong and resistant to laceration and perforation of infectious sharps to reduce and prevent infectious sharp accidents).
- Hospitals' all personnel should separate the type of infectious waste as liquids and secretions which can be discarded to hospitals' wastewater treatment plant to reduce the amount of infectious waste to the disposal company and treatment costs.
- Hospitals should have each type of bins (e.g., recyclable (cans, bottles and paper), general, infectious and organic wastes) placed adequately in hospitals' areas to reduce and prevent waste mixing and the amount of infectious waste to the disposal company, and the bins should be visibly labeled with symbols and names of each type of wastes.
- Hospitals should allocate and separate explicitly temporary storage areas for each type of wastes to reduce and prevent a problem of waste maxing. Especially, temporary storage areas for infectious waste should be strictly controlled and cleaned every time after the operation to reduce and prevent the growth of bacteria, parasites, pathogens and other infectious carriers.

- **Advantages**

- Waste separation in hospitals can reduce waste mixing, the amount of infectious waste to the disposal company and treatment costs.
- Appropriate waste separation can reduce and prevent accidents caused from infectious waste and sharps.
- Waste separation can help companies or agencies about waste treatment and disposal increase the efficiency of waste management because wastes are separated into different types which are easy to recycling, reuse, treatment or disposal.

- **Disadvantages**

- Waste separation must depend on each personnel's awareness who responds to infectious waste management in hospitals.
- Infectious waste as liquids or secretions may increase a burden to the wastewater treatment system, and they may cause outbreaks of bacteria, parasites, pathogens and other infectious carriers to communities if the wastewater treatment system of hospitals is ineffectively controlled and managed.
- Allocation and separation of temporary storage areas in hospitals may be limited with other functional areas, and construction of temporary storage areas in hospitals has quite high costs.

6.2.3 Increasing efficiency of waste collection and logistics

- Workers who have the responsibility for infectious waste collection and transportation in hospitals and the disposal company should strictly follow rules and regulation of appropriate infectious waste management, including wearing protective equipment during the operation (e.g., facemasks, boots, rubber gloves and plastic aprons).
- Workers who have the responsibility for infectious waste collection and transportation in hospitals and the disposal company should not throw and stomp red plastic bags containing infectious waste during collection and transportation.
- Handcarts, vehicles and containers for infectious waste collection and transportation in hospitals and the disposal company should be cleaned every time after the operation, and they should not be worked together with collection and transportation of other wastes.
- The disposal company should collect and transport infectious waste at sources according to the schedule with enough frequency depending on the amount of infectious waste generated by each hospital.
- In case of an emergency, if the disposal company cannot collect and transport infectious waste at sources according the schedule, it should immediately contact hospitals' staff and make again an appointment with hospitals' staff for collection and transportation within six hours.

- In case of the excessive amount of infectious waste, the disposal company should arrange special vehicles apart from the same number of vehicles or increase collection and transportation routes to cope with this problems.
- The disposal company's all special vehicles for infectious waste collection and transportation should be installed the global positioning system (GPS) to control them to be pre-established routes, including their speed level.

- **Advantages**

- For wearing protective equipment and following rules and regulation, they can reduce and prevent workers' accidents caused from infectious waste and sharps during the operation.
- Regarding the cleaning of handcarts, special vehicles, containers and temporary storage areas after the operation, it can disinfect, reduce and prevent the growth and outbreaks of bacteria, parasites, pathogens and other infectious carriers to humans.
- Regarding the increase of special vehicles and collection and transportation routes, it is very necessary to have to cope with arising problems, immediately.

- For installation of GPS on the special vehicles, it can help the disposal company monitor and control drivers' behavior to follow rules and regulations.

- **Disadvantages**

- For wearing protective equipment and following rules and regulations, they may depend on workers' different awareness of appropriate infectious waste management.
- For the increase of special vehicles and collection and transportation routes and installation of GPS on the special vehicles, they may result in increase of costs of the disposal company.

CHAPTER VII

CONCLUSIONS

In this chapter VII, all of the results of this study are summarized. The research applied MFA, CF and eco-efficiency to investigate and evaluate the current situation, environmental impacts and the efficiency of infectious waste management in Bangkok at sources of infectious waste generation to the final treatment process. Moreover, the research recommends management strategies to better improve the efficiency of infectious waste management in Bangkok. The key findings from this research are summarized as follows:

7.1 Mass flow analysis development

Mass flow analysis of infectious waste management in Bangkok is developed to better understand an overview of the origins and flow paths of infectious waste (in terms of quantity and changed forms) and the current status of management. The main findings are summarized as follows:

- The totally average number of public health facilities and hospital beds is 2,409 places and 28,141 beds, respectively.

- The infectious waste generation rate from public health facilities ranges from 21.23 to 11,062.03 kg/month/place with a weighted average of 5,541.58 kg/month/place.

- Two main contributors to the MFA diagram are government and private hospitals which generate higher amount of infectious waste than other public health facilities in Bangkok.

- The totally average number of trips of 18 special vehicles for collecting and transferring 871,325 kg/month of infectious waste from sources to the disposal company is 687 trip/month.

- Twenty pre-established routes for collecting and transferring infectious waste generated from public health facilities to the disposal company are very necessary to reduce and prevent risks of spreading of infectious diseases, pathogens and bacteria from infectious waste containing vehicles, and they can help the disposal company determine the exact distance and time in infectious waste collection and transfer.

- The current infectious waste incinerator units can handle 29.04 ton/day of infectious waste generated, but the amount of infectious waste in Bangkok has been steadily increasing. Therefore, BMA should install more infectious waste incinerators to cope with this problem.

- From the MFA results, air pollutants are the main impact on the environment.

- The wastewater treatment plant 1 (as activated sludge system) can remove 61.02% of total wastewater components.

- 10.33% of bottom ashes from infectious waste incineration were not analyzed for the concentration of heavy metals before buried at a secure landfill.

- The total costs for handling 871,325 kg/month of infectious waste are 6,883,468 baht/month (approximately 7,900 baht/ton) which is quite expensive. This may be a cause of illegal dumping of infectious waste often occurred in Thailand.

7.2 Measurement of CO_2 emissions

This study applied the CF concepts to evaluate CO_2 emissions from each activity and the entire system of infectious waste management in Bangkok. The main findings from evaluating CO_2 emissions are summarized as follows:

- From the operational boundaries, the total CO_2 emissions were from two main scopes. The largest portion was from collection and transportation, two incinerators and wastewater treatment plant 1 (scope 1) (98.35%). The CO_2 emissions from the purchased electricity (scope 2) were 1.65%.

- From the analysis of GHG sources, 100% of CO_2 emissions were from type S (stationary combustion) with 96.10%, type M (mobile combustion) with 3.69%, and type F (fugitive emissions) with 0.21% of total CO_2, respectively.

- Total CO_2 emissions (682,385.81 kg/ month) from the entire system of infectious waste management in Bangkok are the main contributor to causing climate change and global warming. Therefore, these may help BMA's policy makers decide to create and propose mitigation and management strategies for solving these problems.

7.3 Evaluation of efficiency

This study applied the eco-efficiency concepts to evaluate the efficiency of infectious waste management in Bangkok and compare the efficiency with other management systems. The results are described below:

7.3.1 Efficiency analysis of infectious waste management

Efficiency indicators of energy consumption, CO_2 emissions and treatment costs of the entire system, two incinerators and transportation are evaluated to specify the hotspot for improvement resulting in the increase of the efficiency of the entire system. The main findings from evaluating efficiency indicators are summarized as follows:

- From the analysis of three efficiency indicators, two incinerators have higher energy consumption, CO_2 emissions and treatment costs for infectious waste treatment and management than energy consumption, CO_2 emissions and treatment costs of transportation. It is significant to observe that two incinerators are the hotspot that should be improved to increase the efficiency of the entire system.

7.3.2 The new transportation scenario analysis

Modification of 12 diesel engine vehicles for infectious waste collection and transportation to 12 NGV engine vehicles is proposed and analyzed for better improving infectious waste management along with evaluating three efficiency indicators of the new transportation compared to the old transportation. The main findings from analyzing and evaluating efficiency indicators of the new transportation are summarized as follows:

- The entire new system can reduce energy consumption, CO_2 emissions and treatment costs for infectious waste management.
- In order to achieve the goals and benefits of the efficiency and the new transportation scenario, the concepts must be presented to the disposal company's authority managers, and they must consider the cost saving rate, the payback period and less environmental impacts of the new transportation as a decision making tool to develop and increase the efficiency of infectious waste management.

7.4 Survey results and recommendations

The survey was applied in this study to analyze and evaluate current situations of infectious waste management within hospitals and services provided by the disposal company including recommendations for better improving the efficiency of transportation and incinerators. The main findings from the survey are summarized as follows:

7.4.1 Infectious waste management within hospitals

- Some hospitals do not pay attention to training and education programs about appropriate infectious waste management to their all personnel, and there is no annual health checkup for workers who respond to infectious waste management.

- Some hospitals still face many problems, such as waste mixing, infectious sharp accidents, waste segregation and limitation of temporary storage areas. Some hospitals still use inappropriate containers for infectious sharp collection causing infectious sharp accidents.

7.4.2 Services provided by the disposal company

- The disposal company's workers still are careless and negligent in wearing protective equipment and following rules and regulations during collecting and transferring infectious waste onto special vehicles.

- Schedule and frequency in infectious waste collection and transfer determined by the disposal company still cause the remaining amount of infectious waste within some hospitals' temporary storage areas.

7.4.3 Recommendations for improvement

- Awareness of waste segregation is very necessary to be done by hospitals' all personnel to reduce the amount of infectious waste before it is collected and transferred to the disposal company.

- Hospitals and the disposal company should create awareness of wearing protective equipment and following rules and regulations to their workers during the operation to reduce and prevent infectious sharp accident and diseases.

- Training and education programs about appropriate infectious waste management are basic guidelines for all personnel of both hospitals and the disposal company to save them during the operation.
- Temporary storage areas within both hospitals and the disposal company should be strictly controlled and cleaned every time after finishing the operation.

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Appendix A

Secondary data and factors

Table A-1: Average amount of diesel used in vehicles in L/month

Number	Car registration	Types of vehicles	Card number	Mar-13 Diesel (L/month)	Apr-13 Diesel (L/month)	May-13 Diesel (L/month)
1	95-3571	IWCV	3870	466.82	466.82	400.14
2	95-3572	IWCV	3888	666.89	666.89	866.96
3	95-6723	IWCV	3896	208.40	400.14	466.82
4	95-6724	IWCV	3904	266.76	266.76	400.13
5	97-6108	IWCV	3912	1,000.33	994.01	995.33
6	ณค-6627	IWCV	3920	640.21	533.51	0.00
7	ณค-6628	IWCV	3938	0.00	0.00	50.02
8	ณค-6629	IWCV	0708	266.76	373.46	256.75
9	ณค-6630	IWCV	3953	586.86	400.13	566.86
10	ตม-2667	IWCV	3961	266.76	373.46	516.84
11	ตม-2668	IWCV	3979	373.46	373.46	566.86
12	ตม-2669	IWCV	3987	160.05	106.04	254.95
13	ฒญ-4252	IWCV	7716	50.02	50.02	50.02
14	ฒญ-4304	IWCV	7708	50.02	50.02	50.02
15	ศน-7092	Private vehicle	3995	94.36	100.03	100.03
Total (L/month)				5,097.70	5,154.74	5,541.72
Average (L/month)				5,264.72		

Table A-2: Average amount of NGV used in vehicles in kg/month

Number	Car registration	Types of vehicles	Card number	Mar-13 NGV (kg/month)	Apr-13 NGV (kg/month)	May-13 NGV (kg/month)
1	99-3504	IWCV	1891	600.44	900.11	1,197.51
2	99-3505	IWCV	1909	1,225.33	914.73	780.88
3	ฒญ 4252	IWCV	1501	842.72	689.64	871.54
4	ฒญ 4304	IWCV	1519	419.81	522.52	633.24
5	50-1031	IWCV	2054	1,217.31	833.36	411.45
6	50-0882	IWCV	2062	722.20	711.43	798.51
Total (kg/month)				5,027.81	4,571.78	4,693.13
Avergae (kg/month)				4,764.24		

Table A-3: Average amount of water supply and electricity use in the disposal company

Water supply			Electricity		
Number	**Date**	**Unit**	**Number**	**Date**	**Unit**
1	Oct 2012	1,106	1	Oct 2012	18,480
2	Nov 2012	1,092	2	Nov 2012	19,840
3	Dec 2012	902	3	Dec 2012	_
4	Jan 2013	1,290	4	Jan 2013	18,720
5	Feb 2013	1,274	5	Feb 2013	19,360
6	Mar 2013	1,335	6	Mar 2013	19,760
7	Apr 2013	1,321	7	Apr 2013	19,440
8	May 2013	1,207	8	May 2013	19,600
Average (m^3/month)		1,190.88	Average (kWh/month)		19,314.29

Table A-4: Emission factors, 100 years GWP, fuel combustion rates and lower heating values used for calculation

	Nane	Units	Emission factors				References
			CO_2 [kg CO_2/unit]	CH_4 [kg CH_4/unit]	N_2O [kg N_2O/unit]	Total [kg CO_2eq/unit]	
Stationary combustion							
	LPG	kg	3.11E+00	4.93E-05	4.93E-06	3.1133	LPG 1 litre = 0.54 kg (DEDE)
Mobile combustion							
	Diesel	litre	2.70E+00	1.42E-04	1.42E-04	2.7446	IPCC Vol.2 table 3.2.1, 3.2.2, PTT
	NGV	kg	2.13E+00	3.49E-03	1.14E-04	2.2472	IPCC Vol.2 table 3.2.1, 3.2.2, DEDE
Electricity use							
	Thailand Grid Mix Electricity	kWh				0.5813	Thailand Grid Mix Electricity LCI Database 2552 (2009)
Global warming potential							
	GHG	100-years GWP		Existing in atmosphere (years)			
	CO_2	1		200-450			IPCC Vol.2 table 2.14
	CH_4	25		12			
	N_2O	298		114			
Fuel combustion rate							
	Vehicles	Fuels	Units	Fuel combustion rates			
	Average pickup trucks	Diesel	km/L	6.369			American Petroleum Institute, 2004
	NGV pickup trucks	CNG	km/kg	11.905			
Energy							
	Fuels		Units	Net Calorific Value / LHV			
	Diesel		MJ/L	35.94 ± 0.45			University of Birmingham, 2011
	LPG		MJ/kg	46.28 ± 0.74			
	NGV		MJ/kg	45.86 ± 3.95			

Appendix B

Air pollution emission and wastewater standards

Table B-1: Air pollution emission standards for the infectious waste incinerator

Types of air pollutants	Standard values	Determination methods
Sulfur dioxide (SO_2) (ppm)	< 30	USEPA Methods 6 and 8
Nitrogen dioxide (No_xas NO_2) (ppm)	< 180	USEPA Method 7
Hydrogen chloride (HCl) (ppm)	< 25	USEPA Method 26
Hydrogen fluoride (HF) (ppm)	< 20	USEPA Methods 26 and 26A
Polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/Fs as International Toxic Equivalent; I-TEQ) (ng/m^3)	< 0.5	USEPA Method 23
Total Suspended Particulate (mg/m^3)	< 120	USEPA Method 5
Opacity (%)	< 10	USEPA Method 9
Mercury (Hg) (mg/m^3)	< 0.05	USEPA Method 29
Cadmium (Cd) (mg/m^3)	< 0.05	USEPA Method 29
Lead (Pb) (mg/m^3)	< 0.5	USEPA Method 12

Note: Calculating the concentrations of air pollutants at 25° C, at atmospheric pressure with 760 mm HG or 1 atm., at a dry condition (Dry basis) and volume of 50% of excess air in the combustion or 7% of oxygen (Reference conditions).

Table B-2: Wastewater standards from an industrial factory

Parameters in wastewater	Standard values
pH	5.5 - 9.0
Chemical oxygen demand (COD) (mg/L)	< 120
Biochemical oxygen demand (BOD) (mg/L)	< 20
Total dissolved solids (TDS) (mg/L)	< 3,000
Total suspended solids (TSS) (mg/L)	< 50
Sulfide (S) (mg/L)	< 1.0
Total Kjeldahl nitrogen (TKN) (mg/L)	<100
Oil $ Grease (mg/L)	< 5.0
Free chlorine (mg/L)	< 1.0

Appendix C

The questionnaire form

แบบอบถามเพื่อการพัฒนาประสิทธิภาพระบบการจัดการขยะมูลฝอยติดเชื้อในกรุงเทพมหานคร

โปรดใส่เครื่องหมาย ✔ ในช่อง ☐ ที่ท่านเลือกหรือเติมข้อความให้ตรงกับความเป็นจริงของท่านมากที่สุด

ตอนที่1: สอบถามการจัดการขยะมูลฝอยติดเชื้อในสถานพยาบาลและสถานบริการสาธารณสุขในกรุงเทพมหานคร

1. สถานพยาบาลหรือสถานบริการสาธารณสุขของท่านมีการใช้ภาชนะแบบใดในการคัดแยกขยะมีคมติดเชื้อ

☐ กล่องกระดาษ  ☐ ภาชนะพลาสติกแข็งทั่วไป  ☐ ภาชนะพลาสติกแข็งสั่งทำพิเศษ 

☐ อื่นๆ...

2. พนักงานเก็บขนขยะมูลฝอยติดเชื้อในสภานพยาบาลหรือสถานบริการสาธารณสุขของท่านเคยประสบอุบัติเหตุจากการที่มแทงของขยะมีคมติดเชื้อเคยหรือไม่

☐ เคย ☐ จำนวน < 5 ครั้งต่อปี ☐ ไม่เคย

☐ จำนวน > 5 ครั้งต่อปี

3. พนักงานเก็บขนขยะมูลฝอยติดเชื้อในสถานพยาบาลหรือสถานบริการสาธารณสุขของท่านเคยประสบกับโรคติดเชื้อที่เกิดจากขยะมูลฝอยติดเชื้อเคยหรือไม่

☐ เคย กรุณาให้รายละเอียด... ☐ ไม่เคย

……………………………………………………………………….

4. สถานพยาบาลหรือสถานบริการสาธารณสุขของท่านมีการตรวจสุขภาพของพนักงานเก็บขนขยะมูลฝอยติดเชื้อมีหรือไม่

☐ มี จำนวนกี่ครั้ง................ ..ต่อปี ☐ ไม่มี

5. สถานพยาบาลหรือสถานบริการสาธารณสุขของท่านมีสิ่งใดที่เพิ่มแรงจูงใจในการทำงานให้กับพนักงานเก็บขนขยะมูลฝอยติดเชื้อมีหรือไม่

☐ มี ☐ ค่าตอบแทนจำนวนเงินกี่บาท..............................ต่อเดือน ☐ ไม่มี

☐ สวัสดิการอื่นๆ...

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6. สถานพยาบาลหรือสถานบริการสาธารณสุขของท่านมีการจัดฝึกอบรมเกี่ยวกับกับการจัดการขยะมูลฝอยติดเชื้อให้กับบุคลากรทางการแพทย์และพนักงานเก็บขนมีหรือไม่

□ มี จำนวนครั้ง....................ต่อปี □ ไม่มี

7. ขยะมูลฝอยติดเชื้อในสถานพยาบาลหรือสถานบริการสาธารณสุขของท่านมีการปะปนขยะมูลฝอยทั่วไปมีหรือไม่

□ มี ประเภทใดของขยะมูลฝอยทั่วไปที่ปะปน

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□ ไม่มี

8. สถานพยาบาลหรือสถานบริการสาธารณสุขของท่านมีปัญหาเกี่ยวกับพื้นที่ชั่วคราวสำหรับเก็บขยะมูลฝอยติดเชื้อเพื่อรอการขนย้ายไปสู่โรงงานเตาเผาของบริษัทกรุงเทพธนาคมมีหรือไม่

□ มี □ ความจำกัดของพื้นที่ □ ไม่มี

□ ปริมาณขยะมูลฝอยติดเชื้อมากเกินความจุ

□ เส้นทางเข้าออกของพื้นที่ยากต่อการขนส่ง

□ อื่นๆ

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9. สถานพยาบาลหรือสถานบริการสาธารณสุขของท่านมีการจัดสรรและแบ่งแยกพื้นที่ชั่วคราวสำหรับเก็บขยะมูลฝอยติดเชื้อออกจากขยะประเภทอื่นหรือไม่

□ มี แบ่งเป็น □ ขยะรีไซเคิล □ ไม่มี

□ ขยะมูลฝอยทั่วไป

□ ขยะมูลฝอยติดเชื้อ

□ ขยะอันตรายอื่นๆ เช่น สารเคมี คีโม

10. ท่านมีข้อคิดเห็นหรือข้อเสนอแนะเพิ่มเติม ที่คิดว่าจะเป็นการส่งเสริมและเพิ่มประสิทธิภาพในการจัดการขยะมูลฝอยติดเชื้อในสถานพยาบาลหรือสถานบริการสาธารณสุขของท่านอย่างไร

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ตอนที่ 2: สอบถามความพึงพอใจของผู้ประกอบการสถานพยาบาลและสถานบริการสาธารณสุขต่อการให้บริการในการจัดการขยะมูลฝอยติดเชื้อโดยบริษัทกรุงเทพธนาคม

(ระดับความพึงพอใจ: 5=มากที่สุด 4=มาก 3=ปานกลาง 2=น้อย 1=น้อยที่สุด)

การจัดการขยะมูลฝอยติดเชื้อโดยบริษัทกรุงเทพธนาคม	**ระดับความพึงพอใจ**				
	5	**4**	**3**	**2**	**1**
1. พนักงานเก็บขนขยะมูลฝอยติดเชื้อมีการใส่อุปกรณ์ป้องกันในระหว่างปฏิบัติงาน					
2. ในการเก็บและขนย้ายขยะมูลฝอยติดเชื้อจากสถานพยาบาลและสถานบริการสาธารณสุขขึ้นรถเก็บขน พนักงานเก็บขนขยะมูลฝอยติดเชื้อปฏิบัติหน้าที่อย่างเคร่งครัดและตามข้อปฏิบัติของกระทรวงสาธารณสุข					
3. ตารางเวลาในการเก็บขนขยะมูลฝอยติดเชื้อตามที่กำหนดไว้แต่ละสถานพยาบาลและสถานบริการสาธารณสุขกับบริษัทกรุงเทพธนาคม					
4. ความถี่ในการเก็บขนขยะมูลฝอยติดเชื้อ					
5. การจัดสัมมนาในการให้ความรู้เกี่ยวกับการจัดการขยะมูลฝอยติดเชื้อแก่สถานพยาบาลและสถานบริการสาธารณสุขปีละ ครั้ง 1					
6. ค่าใช้จ่ายในการเก็บขนขยะมูลฝอยติดเชื้อจากสถานพยาบาลและสถานบริการสาธารณสุขใน อัตราบาทต่อกิโลกรัม 5					
7. ภาพรวมของการให้บริการในการจัดการขยะมูลฝอยติดเชื้อของบริษัทกรุงเทพธนาคม					

ขอบคุณครับที่กรุณาให้ความร่วมมือในการกรอกแบบสอบถาม
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