EVALUATIONOF REFUSE DERIVED FUEL (RDF) AS ALTERNATIVEENERGYSOURCEFOR THE PALMOIL INDUSTRYANDITSPOTENTIAL ENVIRONMENTAL IMPACT

BY

SIRIPORN BOONPA

A DISSERTATION SUBMITTED IN PARTIALFULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY (ENGINEERING AND TECHNOLOGY)
SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
THAMMASAT UNIVERSITY
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A Dissertation Presented

By

SIRIPORN BOONPA

Submitted to

Sirindhorn International Institute of Technology

Thammasat University

In partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY IN TECHNOLOGY

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JULY 2016

Acknowledgements

Though only my name appears on the cover of this dissertation, a great many people have contributed to its production. I owe my gratitude to all those people who have made this dissertation possible and because of whom my graduate experience has been one that I will cherish forever.

My deepest gratitude to my advisor, Associate Professor Dr. Alice Sharp, I have been amazingly fortunate to have an advisor who gave me the freedom to explore on my own and at the same time the guidance to recover when my steps faltered. Dr. Alice taught me how to question thoughts and express ideas. Her patience and support helped me overcome many crisis situations and finish this dissertation .I hope that one day I would become as good an advisor to my students as Dr. Alice has been to me.

My co-advisor, Associate Professor Dr. Sandhya Babel, has been always there to listen and give advice. I am deeply grateful to her for the long discussions that helped me sort out the technical details of my work.

Associate Professor Dr. Chart Chiemchaisri, Dr. Noppara Plucktaveesak, and Assistant Professor Dr. Paiboon Sreearunothai are the best committees. Their insightful comments and constructive criticisms at different stages of my research were thought-provoking and they helped me focus my ideas. I am grateful to them for holding me to a high research standard and enforcing strict validations for each research result, and thus teaching me how to do research.

I am also thankful to external examiner, Professor Dr. Anke Bockreisfor carefully reading and commenting on countless revisions of this manuscript.

In this way, I express my gratitude to Sirindhorn International Institute of Technology for providing all the necessary facilities to conduct the research.

I would also like to express my thanks to Joint Graduate School of Energy and Environment (JGSEE) of KMUTT for their scholarship which has enabled me to carry out this research.

Many friends have helped me stay sane through these difficult years. Their support and care helped me overcome setbacks and stay focused on my graduate study. I greatly value their friendship and I deeply appreciate their belief in me.

Most importantly, none of this would have been possible without the love and patience of my family. My family has been a constant source of love, concern, support and strength all these years. I would like to express my heart-felt gratitude to my family.

Finally, I appreciate the financial support from TU Research Scholarships and Bangchak Graduate Scholarships that funded parts of the research discussed in this dissertation.

Abstract

EVALUATION OF REFUSE DERIVED FUEL (RDF) AS ALTERNATIVE ENERGY SOURCE FOR THE PALM OIL INDUSTRY AND ITS POTENTIAL ENVIRONMENTAL IMPACT

by

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Increasing amounts of municipal solid waste (MSW) have become an issue for urban and rural municipalities. The aims of the research were to evaluate heating properties and combustion characteristics of the MSW, and to determine its potential environmental impacts if used as an alternative fuel in the palm oil industry.

The research summarizes the results of a comparative analysis for use of Refuse Derived Fuel (RDF) as opposed to the use of Conventional fuel (CF) specifically for the Palm Oil industry in Southern Thailand andthe possible environmental impacts. RDF, in this study, was prepared by using MSW from the Lamae Municipality in Chumphon, Thailand where palm oil cultivation and milling is engaged, and has one of the largest palm oil industries in Thailand. The RDF was prepared from two main waste components, paper and low density polyethylene plastic (LDPE) in five various ratios. The RDF and CF fuel from the palm oil industry, such as wood and biomass were analyzed for their heating properties and potential environmental impacts in terms of their global warming potential, acidification, and human toxicity.

More than 15 million tons of solid waste is generated annually, and this requires an enormous budget allocation for solid waste management (SWM). In order to increase the efficiency in SWM, waste-to-energy (WtE) technologies are provided as a solution toward a successful policy. Currently, there are 5 WtE technologies being employed in Thailand. The 5 types of technology are incineration, RDF, anaerobic digestion, pyrolysis and gasification, and landfill gas recovery.

In this research, solid waste from the selected site of the (Lamae municipality) in Thailand contain a high heating value solid waste fraction, namely plastic and paper. Plastic (soft) waste that made from low density polyethylene (LDPE) is the largest portion of MSW, which contributes to 47%of the total solid waste generated. The second largest component is paper, which contributes to 24%of the total solid waste generated. This has potential for energy production and utilization as RDF.

RDF in this study was prepared by using MSW from the Lamae Municipality in Chumphon, Thailand. MSW from the Lamae municipality was chosen to study in this research due for two reasons. First reason; Lamae district in Chumporn province engages in palm oil cultivation and milling, and has one of the largest palm oil industries in Thailand. The second reason, the solid waste composition is suitable for using it as fuel in industry because it is high heating value. For this research, the RDF was prepared from two main solid waste components, paper and LDPE in various ratios (100% of paper: 0% of LDPE, 75% of paper: 25% of LDPE, 50% of paper: 50% of LDPE, 25% of paper: 75% of LDPE and 0% of paper: 100% of LDPE). The heating properties, combustion characteristics, potential gas emissions during the combustion, and potential environmental impact of the RDF and the CF from the palm oil industry such as wood and biomass were determined.

was not limited to alternative reuse energy source, but it also investigated the potential environmental impacts on the palm oil industry by using life cycle assessment (LCA) method and the Intergovernmental Panel on Climate Change (IPCC).A life cycle approach was used to calculate and compare the environmental impacts from burning the RDF and CF. The environmental impacts were studied in

terms of their global warming potential (kg CO_2-eq), acidification (kg SO_2-eq) and human toxicity (kg toluene-eq)per 1 kg of production (crude palm oil).

The results demonstrated that the heating value and the environmental impacts varied with the different ratios. This research verified that RDF production and use of palm oil in the palm oil industry is an environmentally and economically viable solution for Lamae Municipality in Chumphon, Thailand. The result of this research area provides a data source for an industrial process model which will become more significant for national energy policies in Thailand.

Keywords: Municipal solid waste (MSW), Refuse derived fuel (RDF), Conventional fuel (CF), waste-to-energy (WtE), Low density polyethylene plastic (LDPE), Life cycle assessment (LCA), Intergovernmental Panel on Climate Change (IPCC)

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Chapter 1
Introduction

1.1 Statement of problem

Environmental concerns on municipal solid waste management (MSWM) have become a global challenge because of the ever increasing population, which results in increasing amounts of MSW. In developing countries including The Kingdom Thailand, this factor is further exacerbated by inadequate financial resources, and inadequate management and technical skills within municipalities and government authorities[1].

The Kingdom of Thailand, one of the fastest growing industrial countries in South East Asia, and is faced by the increasingly serious problems of solid waste disposal and energy security and environmental issues. Solid waste disposal is a tremendous problem in Thailand. The amount of MSW generated in Thailand in 2013 was 73,342 tons/day or 26.77 million tons/year with less than 25% of annual solid waste being properly managed [2]. Most of the solid waste that is disposed is handled through an inadequate management system which not only releases pollutants contaminating both air and water; additionally, it releases harmful greenhouse gases into the atmosphere.

Energy is another major problem. Thailand currently imports almost 70% of its power requirements [3].The government has planned to increase the energy security of the country [4].

To tackle these problems, the goal of this research is to determine the viability of RDF as a renewable energy resource from solid waste, since waste to energy (WtE) offers a solution to Thailand's solid waste disposal, energy security and environmental issues.

RDF is currently being considered as a solution for MSW disposal and fuel recovery. RDF can replace coal in the industrial sector and has been successfully used in industrial boilers. Using MSW as a fuel source decreases solid waste to be dumped into landfill, thus freeing sites for proper land-use planning. It also directly contributes to a decrease in CF demand. However, the heating value of fuel produced from the MSW is currently inconsistent because it is derived from solid waste which varies in composition and heating value. Therefore, an additional study on the appropriate composition of solid waste materials to be used as RDF is highly recommended.

Currently in use are six technologies to convert solid waste to energy in Thailand. They consist of: incineration refuses derived fuel (RDF), biogas production by anaerobic digestion, pyrolysis, gasification, and landfill gas recovery. Each technology can be tailored to suit the different types of waste and local conditions, This is determined by various factors which include; the quantity, composition of the waste, separation practices, number of staff, investment cost, operational cost, proper land use planning requirements and potential local environmental impacts.

MSW is a heterogeneous feedstock containing materials of varying shapes, sizes, and composition. If the MSW is used its 'as received' state and input into the WtE processes, it can lead to variable (and even unstable) operating conditions, resulting in quality fluctuations of the end products. In addition, the more advanced thermochemical treatment technologies requires an input feed with a sufficiently high calorific value in order to obtain high process efficiencies[5]. For these reasons, RDF which is a processed form of MSW is a preferred solution as input for WtE systems.

RDF, due to its lack of use as an alternative fuel, from solid waste, currently does not have market support. Thailand's Palm oil industry however; was selected for this research because of the synergy that is created between the food industry and the energy (biodiesel) industry. It currently is being considered, by the Ministry of Energy, as a solution for MSW disposal and fuel recovery. RDF can replace coal in the industrial sector and has been successfully used in industrial boilers. Using MSW as a renewable alternative fuel source decreases solid waste discharged into landfills, thus freeing sites for proper land-use planning. It also directly contributes to a decrease in CF demand. However, the heating value of fuel produced from the MSW is currently inconsistent because it is derived from solid waste which varies in composition and heating value. Therefore, an additional study on the appropriate composition of waste materials to be used as RDF is highly recommended.

Thailand has an opportunity to separate itself from the other developing countries. If the country adopts a policy on the use of RDF from MSW as renewable alternative fuel for industry, namely the palm oil industry, we will not only be able to reduce the amount of solid waste disposal, and CF consumption but also resolve the devastating environmental effects of the MSW problem. Therefore, this research explores the potential of using the RDF as alternative energy source for the palm oil industry, in terms of the RDF properties with regards to its, heating value, and its potential reduction of environmental impacts.

1.2 Objectives

1. Research the characteristics of MSW as well as the other properties of solid waste for a selected city.
2. Prepare and characterize the properties of RDF in terms of its heating value and its potential environmental impacts.
3. Compare the heating value and potential environmental impacts of the RDF versus the CF for the palm oil industry.
4. Evaluate the potential of using RDF as alternative energy source specifically for the palm oil industry in Southern Thailand.

1.3 Scope of study

1. The selected research site location was based on its proximity to the palm oil industry in Lamae district Chumphon Province, southern Thailand.
2. Measure the quantity and characterize the properties of MSW with regards to:

- Composition
- Density
- Heating value
- Moisture content
- Volatile matters
- Ash
- Environmental impact

3. Select two proper compositions of solid waste for the RDF samples preparation based on its quantity and heating value.

4. Prepare five ratios of RDF samples from the two proper compositions of solid waste, namely soft plastic and paper waste:

- RDF I; 100% of paper: 0% of solid waste plastic (LDPE)
- RDF II; 75% of paper: 25% of solid waste plastic (LDPE)
- RDF III; 50% of paper: 50% of solid waste plastic (LDPE)
- RDF IV; 25% of paper: 75% of solid waste plastic (LDPE)
- RDF V; 0% of paper: 100% of solid waste plastic (LDPE)

5. Characterize the properties of the RDF samples and the CF (rubber wood) in term of heating value.

6. Characterize the combustion performance of the RDF and the CF by using thermo-gravimetric analysis (TGA)

7. Determine the GHG emissions during the combustion of the RDF by the portable flue gas analyzer testo350:

- Carbon monoxide (CO)
- Carbon dioxide (CO_2)
- Nitrogen oxides (NOx)
- Sulfur dioxides (SOx)

8. Research the potential environmental impacts of using RDF as fuel compared to CF for the palm oil industry by using LCA process method. The potential environmental impacts shall include:

- The global warming potential (kg $CO_{2\text{-eq}}$)
- Acidification (kg $SO_{2\text{-eq}}$)
- Human toxicity (kg $\text{toluene}_{\text{-eq}}$)

9. Propose RDF pollution prevention measures the palm oil industry.

10. Evaluate the potential of using RDF as viable alternative energy source for the palm oil industry.

Chapter 2
Literature Review

2.1 Situation of solid waste generation in Thailand

According to the Pollution Control Department (PCD), the MSW in Thailand is classified into four categories [6]; degradable solid waste, recyclable waste, hazardous waste, and general waste. The major MSW types of solid waste are food, paper, plastic, clothes, wood, rubber and leather, glass, metal, stone, and others such as sand, dust, and ash. Thailand has a common MSW generation rate typical for a developing country, with a range of 0.91-1.89 kg/capita/day [7]and a national average of 1.15 kg/capita/day [8]. The quantity of solid waste generated in Thailand, shown in Fig. 2.1 depends greatly on household income, structure, pattern of living, behavior of consumption, attitude of living, regulation, geographical location, and season [9]. The amount of MSW generated in Thailand in 2013 was 73,342 tons/day or 26.77 million tons/year [10]. From this, 15.45% of the waste was generated in Bangkok [11]. The solid waste generation rate in Thailand is presented in Fig. 2.1. About a third of waste is recovered via recycling and managed disposal, while the remaining is discharged into landfills. To explain further: The Landfill is the final disposal site for waste. Landfill classification varies by different regions, nations, sites, population, and amount of wastes generated. According to Johannessen and Boyer [12], landfills are classified into six major types: 1) semi-controlled dump, 2) controlled dump, 3) engineered landfill, 4) sanitary landfill, 5) sanitary landfill with top seal, and 6) controlled contaminant release landfill.

Approximately one third of waste is recovered by recycling and management via integrated solid waste management systems, while the remaining is discharged into landfills. According to Chart [13], surveys on the disposal sites revealed the presence of 95 landfills and 330 open dumps in Thailand.

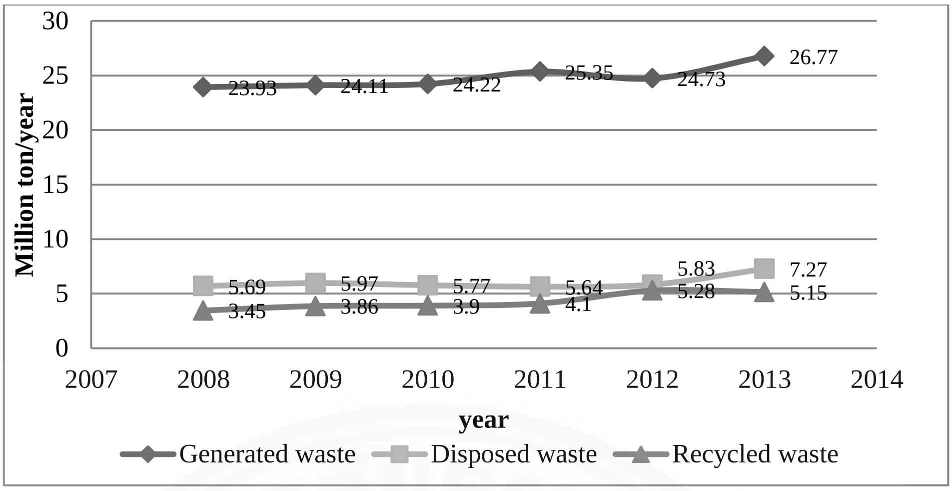


Fig.2.1 Solid waste generation rate in Thailand

2.2 Energy and solid waste management policies in Thailand

Thailand's economic growth, fast industrial expansion, rapid growth in population, and energy consumption has become a much more serious issue in recent years. Thailand has relied heavily on energy imports. According to the 2011 data estimates over 60 % of primary commercial energy demands were obtained through importation. Of that 60% of energy imports, oil imports took the highest proportion at 80 % of the total domestic oil consumption. A disturbing trend since the country is incapable of increasing its domestic petroleum production to meet the domestic demand. Renewable energy recovered from waste substances will reduce the dependency on importation of oil. In addition, it also will reduce the consumption of oil imports by providing fuel for power generation, which previously depended on natural gas at over 70 %. RDF would join the other target alternative renewable energy resources along with natural gas for power generation, solar, wind energy by type of wind turbine farm, micro hydro, biomass, biogas from solid waste/garbage. The government of Thailand has set renewable energy as a national priority on its agenda.

2.2.1 National energy policies in Thailand

The government has planned to increase the energy security of the country. The Government has proposed a new plan: Thailand Integrated Energy Blueprint (TIEB), which is composed of five parts which are: (1) Thailand Power Development Plan (PDP), (2) Energy Efficiency Development Plan (EEDP), (3) Alternative Energy Development Plan (AEDP), (4) oil plan, (5) gas plan. However, the WtE is proposed in AEDP (2012 - 2021). AEDP as shown in Fig. 2.2 has been approved by the Department of Alternative Energy Development and Efficiency, Ministry of Energy on 30 November 2011. Thailand's Ministry of Energy estimates that the potential of power generation in Thailand from biomass, biogas, and MSW is 4,390 MW. Other sources with high potential are solar and wind (3,200 MW). There is also a potential to generate another 1,608 MW of power from hydro-power. WtE is ranked fourth in the national energy policy and development plan [14, 15]. According to the national energy policies in Thailand, the energy from solid waste in 2021 has a target set at solid waste 160 MW.

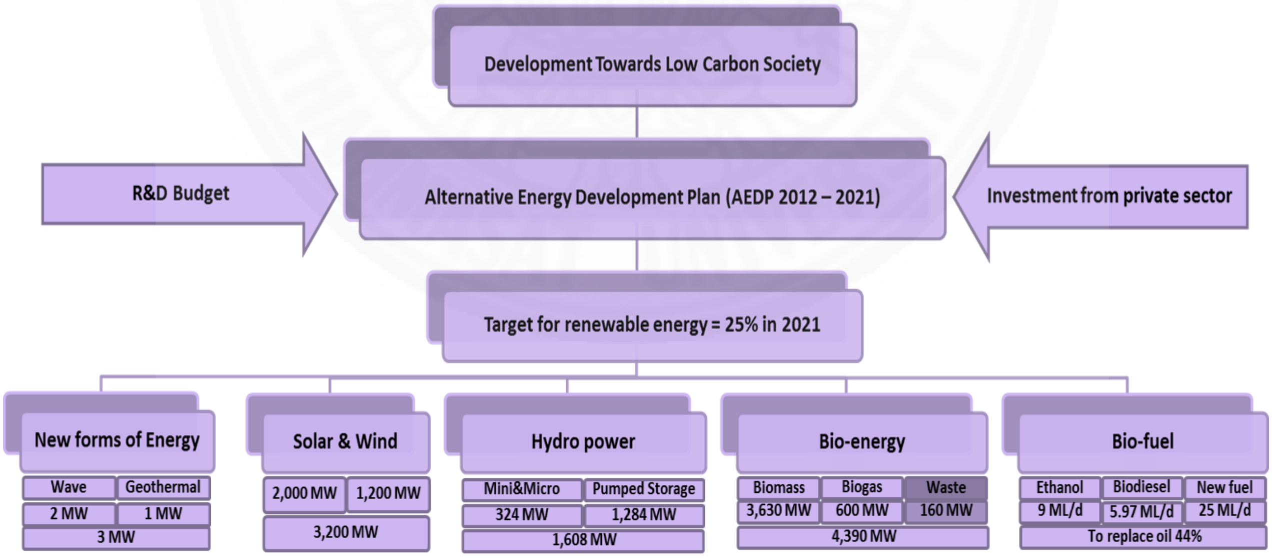


Fig. 2.2 Alternative Energy Development Plan (AEDP 2012 – 2021) for Thailand

2.2.2 Policies on MSWM in Thailand

The Pollution Control Department (PCD), the national authority that is responsible for the MSW management policy and planning, has four policy frameworks on MSW strategies listed as [16]:

1. Applying reduce, recycle, reuse (the 3Rs) for achieving waste reduction & utilization;
2. Promoting an integrated waste management system to reduce the landfill areas and generate renewable energy;
3. Encouraging the cooperation of adjacent local governments for the establishment of waste management facilities;
4. Endorsing public and private sectors to participate in waste management projects.

The policy of MSWM includes four main strategies resulting in zero waste that is dependent upon the overall effectiveness and efficiency of urban management support and the personal responsibility of each citizen.

2.3 Solid waste management and waste-to-energy technology

2.3.1 Solid waste management hierarchy

In general the integrated MSWM strategies are based on the six-tier solid waste management hierarchy (prevention, minimization, reuse, recycling, energy recovery, and disposal) solid waste [17]. Current MSWM in Thailand is classified by the solid waste management hierarchy in Fig. 2.3a. At present most MSW in Thailand is disposed of in landfills while solid waste prevention, the most favoured option, is not widely practiced. The preferred solid waste management scheme in Thailand (Fig. 2.3b), has shown that when solid wastes are prevented, minimized, and reused, the quantity of solid waste to be treated is reduced. Thus, this is the favoured paradigm in MSWM.

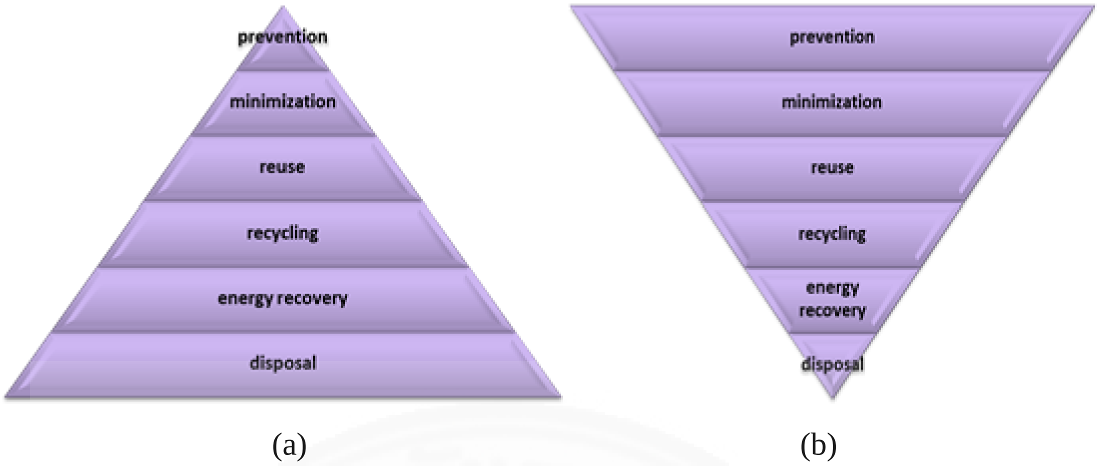


Fig. 2.3 Paradigm of solid waste management (a) current situation and (b) preferred hierarchy in Thailand

Once the valuable materials are recovered; the leftover solid waste can be managed further via WtE technology in order to generate renewable energy as well as further reduce the quantity of solid wastes to be disposed of.

2.3.2 Integrated solid waste management (ISWM)

ISWM aims to improve environmental conditions by controlling pollution (including air, soil, groundwater, surface water, and cross media pollution), protecting environmental health, and ensuring the sustainability of ecosystems in the urban and rural regions. The ISWM system includes three main steps resulting in zero waste [18]. Before all processes, the solid waste must be collected and sorted. The first step is to recover valuable materials from the solid waste by following the reuse and recycling practice [7]. The second step is the biological treatment of organic materials. For example, organic wastes can be composted to produce fertilizers (aerobic process); the anaerobic digestion (anaerobic process) can be used to transform organic waste into biogas that can be used to produce energy. By products of the anaerobic digestion can be dried to produce fertilizers. The third step is thermal treatment, focusing on ways to reduce the volume of solid wastes, such as burning of mixed MSW, or separated solid waste such as plastic and paper. This process also can convert the heat into electricity, by doing so, the space for landfills can be greatly reduced in addition, the issue of landfill gas (LFG) shall be reduced [9]. The ISWM schematic diagram for Thailand is represented in Fig. 2.4.

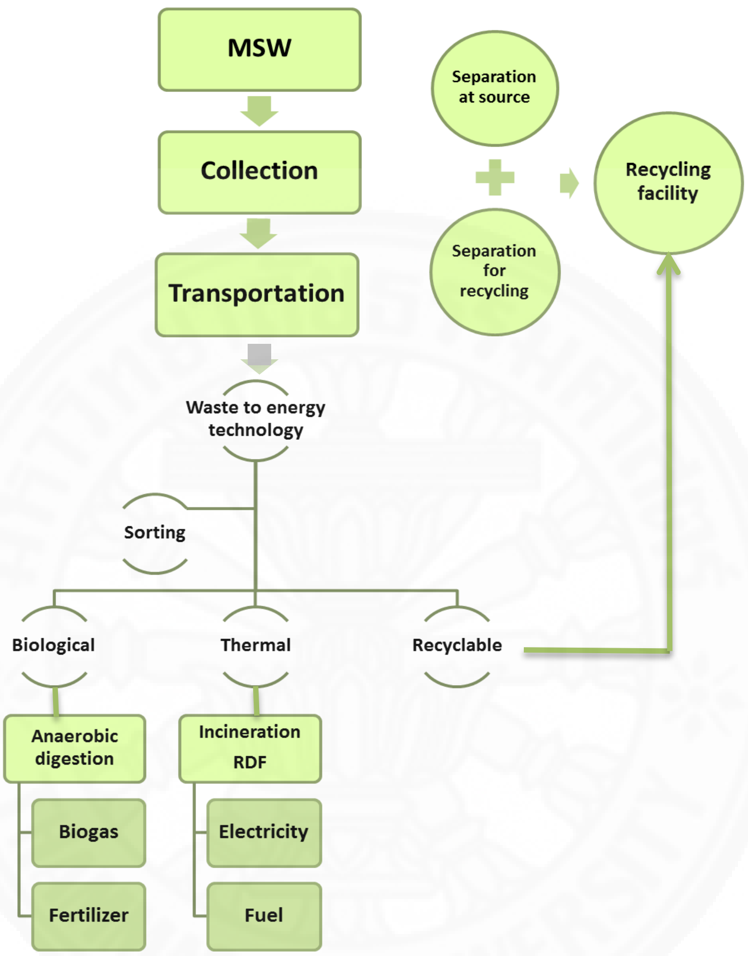


Fig. 2.4 Schematic representation of integrated MSWM in Thailand

2.3.3 Composition of municipal solid waste (MSW)

The composition of the solid waste varies with cities and countries depending on the standard of living, life style, social and religious traditions, and the consumption patterns of the people. The total amount of solid waste generated in Thailand is estimated to be about 41.5 tons/day [11]. The composition of the MSW generated in Thailand is represented in Fig. 2.5. Data in Fig. 2.5 shows that the major component of solid waste in Thailand is organic materials 61% of generated solid waste .It's imperative therefore to implement the appropriate organic waste treatment policy [19-21], for example: converting organic waste to energy by anaerobic digestion, via the appropriate technology.

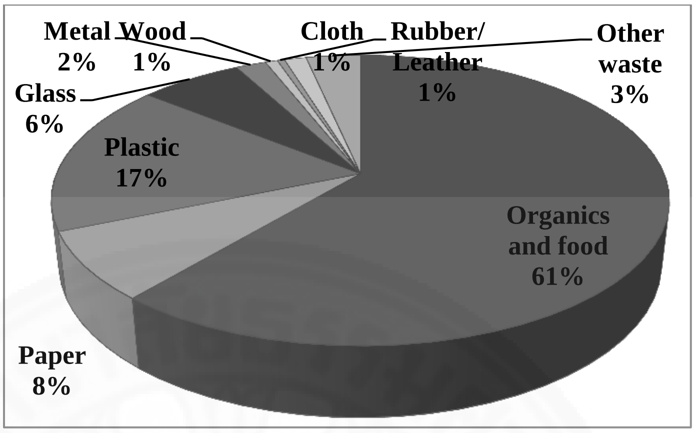
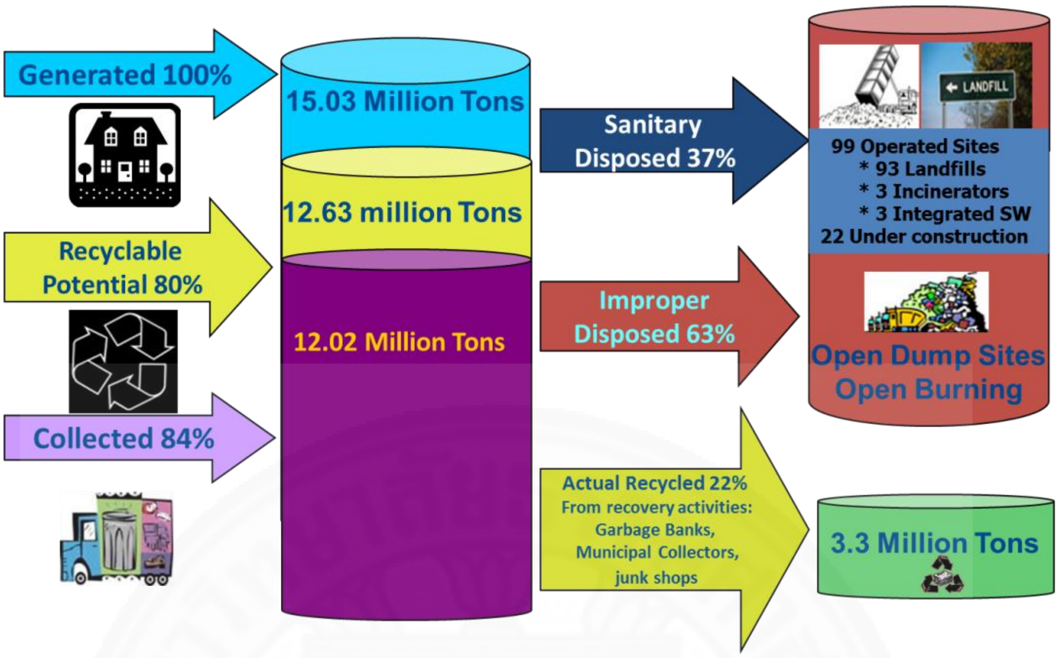


Fig. 2.5 Composition of MSW in Thailand

2.3.4 Final disposal technology of MSW

Open dumping is the most common method of MSW disposal in Thailand [22], as shown in Fig. 2.6. This is due to unavailable solid waste collection services in many small municipalities and local administrative organizations. The MSW in Thailand are operated by 64% of open dumping and open burning, 35% by landfill, and 1% by incineration.

Open dumping and open burning: Open dumping and open burning have been the status quo for managing MSW for many years. These sites receive a huge quantity of MSW per day. In addition, open dumping leaches into the aquifer and pollutes soil and groundwater [23]. The Thai government is concerned with regards to developing sanitary landfill sites in several municipality areas [10]. Open dumping sites still remain a choice for many areas due to their low cost and effective performance in getting rid of a huge amount of solid waste. However, open dumping must not be allowed any further because it is unsightly, unhygienic, and potentially disastrous impacts to our environment.



(Source: Surveys of solid waste and hazardous Substances Management Bureau, Pollution Control Department)

Fig. 2.6 Final disposal of MSW in Thailand

Landfill: Sanitary landfills are usually located far from sources, resulting in increased transfer costs and additional investments for infrastructure. Direct land filling of such solid waste creates a nuisance due to the generation of highly concentrated leachate, methane gas emission, and extreme waste settlement in landfills. Rapid solid waste decomposition eventually affects landfill stability. Even though there are 93 sanitary landfill sites in Thailand [24], more sites are still required in order to decrease the amount of open dumping and open burning of solid waste.

Incineration: Incineration is another method for MSW management in Thailand. This method is used for huge municipal and tourist municipal areas because sanitary landfills are not enough for the MSW. Currently there are4 incinerators [25] for municipality solid wastes: PJT Technology Co., Ltd. [26] performers the incineration at Phuket province which can burn 700 tons of solid waste per day (700 tons/day), AMATA Industrial Estate, Chonburi province (60 tons/day), Saraburi province (16 tons/day), and Samut Prakan province(100 tons/day). Even though incineration can rapidly reduce the amount of solid waste, it also increases air pollution, especially in municipal areas just as rapidly.

2.3.5 Solid waste to energy technology

This section provides an overview of the six technologies, as identified in the statement of the problem, used for the conversion of solid waste to energy such as heat, steam, gases, and oils. Furthermore this section also compares different types of solid waste-to-energy technologies as shown in Table 2.1.

Incineration with energy recovery: Incineration, also referred to as 'combustion', is a specialized process that involves the burning of combustible materials in any state to form gases and residue [27-30]. The basic elements of an incinerator include a feed system, combustion chamber, exhaust gas system, and a residue disposal system. Modern incinerators use continuous feed systems and moving grates within a primary combustion chamber lined with heat resistant materials. The solid waste must be mixed, dried, and then heated, all for specific amounts of time and at controlled temperatures. Different types of incinerators are in common use [31], such as mass-fired combustors, RDF combustors, and industrial incinerators [32].

Refuse derived fuel (RDF): RDF is a fuel produced through the management of MSW. RDF can also be named solid recovered fuel or specified recovered fuel (SRF) [33]. RDF can be classified into seven types by size, as defined in section 2.4.2. The residual wastes, after separation collection of recoverable materials, are treated through mechanical reprocessing and fractionation [34]. The RDF obtained from this process is traded and co-burnt in installations for power generation or in a manufacturing process where heat is required [35], such as co-combustion in coal fired boilers, co-incineration in cement kilns [36, 37], and co-gasification with coal or biomass. The project has been carried out with the cooperation of the Municipality of Phitsanulok and the German Agency for Technical Cooperation; Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ). A pilot facility was envisaged to treat 50 % of incoming solid waste in the landfill [38]. Presently, there is a RDF production plant in Thailand, using Mechanical Biological Treatment (MBT) in Phitsanulok municipality. This project has been carried out by GTZ in cooperation with Pollution Control Department (PCD). After MBT, the wastes were separated into 3 groups as follows [39];

1) size< 10 mm. contributes 13.6% and is suitable for making soil conditioner

2) 10<size<40 mm. contributes 7.3% and is applicable for using as bio-filter

3) size>40 mm. contributes 79.1% and is suitable for making RDF

The success of this solid waste management solution in Thailand is due to its low cost and limited equipment requirements.

Biogas production by anaerobic digestion: The organic fraction of the solid waste is mashed and placed in a contained digester to decay without oxygen [40]. Primarily carbon dioxide and methane are produced as biogas [41, 42], but also small amounts of hydrogen sulfide, ammonia, and other compounds are produced by this process as well. The solid material drawn from the anaerobic digester is called digestate. It is rich in nutrients (such as ammonia, phosphorus, potassium, and more than a dozen trace elements) and is an excellent soil conditioner. In Thailand, the purpose of anaerobic digesters is to utilize the produced biogas as a source of fuel for generators [43] and the sludge byproduct as a fertilizer [44].

Pyrolysis: Pyrolysis is the chemical decomposition process created by heat in the absence of oxygen converting carbonaceous material into fuel gas that can be used as a substitute for natural gas. The pyrolysis process, like incineration, is continuous or batch fed, producing char, pyrolysis oils, and gases [45]. The process is conducted at high temperature, most commonly in what is called a fluidized bed. Cellulose molecules within the municipal solid waste dissociate instead of burn, due to the absence of oxygen. The fragments of the dissociated molecule form methane, carbon dioxide, hydrogen, carbon monoxide, and water [46]. Currently pyrolysis is used for community solid wastes in Thailand: Warin Chamrap, Ubon Ratchathani Province (6 tons/day of plastic solid waste generated 4,500 L/day of fuel oil).

Gasification: Gasification is a modification of pyrolysis in that a limited quantity of oxygen is introduced, and the resulting oxidation produces enough heat to make the process self-sustaining [47]. Gasification occurs at very high temperatures (greater than 700ºC) and involves the partial combustion of a carbonaceous fuel (combustible, putrescible, and plastic fractions of the solid waste), which produces combustible fuel gas rich in carbon monoxide, hydrogen, and some saturated hydrocarbons (mostly methane) [48].

Landfill gas recovery: Generation of methane gas from a sanitary landfill is similar to anaerobic digestion, but without operational control of the process. The solid waste is simply left as it is, with no efforts made to increase gas production; gas is simply captured as it is generated. Landfill gas typically consists of 50-60% methane, 40-50% carbon dioxide, and trace levels of other gases. Typical landfill gas has an energy equivalent to about half of that of natural gas [49].

Table 2.1Comparison of different types of waste-to-energy technology

Attributes	Incineration	RDF	Anaerobic digestion	Pyrolysis	Gasification	Landfill gas
Methods	Thermochemical	Thermochemical	Biochemical	Thermochemical	Thermochemical	Biochemical
Suitable solid waste characteristics	Sorted combustible solid waste	Sorted combustible solid waste	Sorted organic waste: suitable for either wet or dry waste depending on type of AD system	Sorted heterogeneous MSW	Sorted organic (combustible, putrescible, and plastic fractions of the solid waste)	Unsorted solid waste
Description	Solid waste is broken down to produce heat.	Solid waste is broken down to produce a high calorific fraction.	Organic biodegradable waste broken down without oxygen (anaerobic) to produce methane gas, carbon dioxide, water, and digestate (which is composted). Can be wet or dry.	Solid waste is broken down by heat in the absence of oxygen to produce fuel gas.	Solid waste is broken down by heat with a limited quantity of oxygen to produce fuel gas.	Solid waste placed in a landfill breaks down over time due to biological, physical, and chemical processes, such as bioreactor landfills; Offers a more sustainable approach to landfill disposal of solid wastes.
Energy form	Heat	Solid fuel	Bio gas	Char, pyrolysis oil, and gases	Syngas	LFG

Table 2.1 Comparison of different types of waste-to-energy technology *(continue)*

Attributes	Incineration	RDF	Anaerobic digestion	Pyrolysis	Gasification	Landfill gas
General performance	Thermal treatment can divert 70 percent [50] of solid waste from landfill	Can divert most combustible of solid waste from landfill	Can divert all or most organic and biodegradable products (food, yard solid waste, some paper)	Can divert most mixed (heterogeneous) solid waste streams from landfill	Can divert most combustible organic waste from landfill	A wide range of performance is available. Individual facilities are custom designed and constructed to meet desired solid waste management objectives
Community skills	Thermal treatment is a high-tech system that requires skilled technical operators. Depending upon the specific technology, it is suitable for communities ranging from small villages to large urban areas.	RDF systems treat solid waste and require skilled technical operators. Depending upon the specific technology, it is suitable for large urban area.	Anaerobic digestion is a high-tech system that requires skilled technical operators. It is most suited to reasonably large urban areas to justify the operational cost of the system.	Pyrolysis of solid waste is a high-tech system that requires skilled technical operators. Depending upon the specific technology, it is suitable for large urban area.	Gasification of solid waste is a high-tech system that requires skilled technical operators. Depending upon the specific technology, it is suitable for large urban area.	Landfill disposal of solid waste is a necessary element of an integrated approach to solid waste management for all Thai communities

Table 2.1 Comparison of different types of waste-to-energy technology *(continue)*

Attributes	Incineration	RDF	Anaerobic digestion	Pyrolysis	Gasification	Landfill gas
Costs	Costs will vary depending upon the specific thermal technology used and the operating capacity required [51]	Costs will vary depending upon the technology used and the operating capacity required [52]	Costs decrease for economies of scale at 100,000 tons/year [53]]	Costs will vary depending upon the technology used and the operating capacity required	Costs will vary depending upon the technology used and the operating capacity required	Costs vary significantly depending upon solid waste input rates and solid waste characteristics, site-specific conditions, regulatory requirements, size of facilities and economies of scale, design and construction requirements, and local/regional competition from other landfills
Factors that influence acquisition	The availability of local energy markets is a critical factor in the decision	The availability of local energy markets is a critical factor in the decision	The availability of local energy markets is a critical factor in the decision	The availability of local energy markets is a critical factor in the decision	The availability of local energy markets is a critical factor in the decision	Low costs relative to other options. Limitations on availability of other alternatives
Possible environmental impact	Air pollution, particulate matter, solid residue, and wastewater	Soot or dust and air pollution generated from fuel burning	Odor and disease generated from solid waste fermentation	Gas or vapor from combustion, carbon black, solid residue from burning, and wastewater	Gas or vapor from combustion, carbon black, solid residue from burning, and wastewater	Methane gas is a risk for explosion
Energy implication	Thermal energy and conversion to electrical energy	Thermal energy and conversion to electrical energy	Energy for conventional engines and boilers	Energy for conventional engines and boilers	Energy for making products; Methanol, Ammonia, Diesel fuel	Energy for conventional engines and boilers

2.4 Refuse derived fuel (RDF)

2.4.1 Why RDF and the definition of RDF

Due to the changing environmental legislation and the need for alternative fuels, new designs for mechanical and biological treatment of solid waste facilities are being developed all over the world. RDF is an alternative fuel produced by shredding, sorting and dehydrating the light fraction of MSW. These fuels can replace fossil fuels in many applications, such as power for cement kiln plants.

The RDF and Solid Recovered (SRF) are the fuel produced through the management of municipal solid waste (MSW).

Refuse derived fuel (RDF) is produced from domestic waste which includes biodegradable material as well as plastics, and has a lower calorific value than SRF. RDF is used in combined heat and power facilities.

Solid recovered fuel (SRF) is a high quality alternative to fossil fuel produced from commercial waste including paper, card, wood, textiles and plastic. It can be produced to a range of specifications to meet customer requirements.

The domestic solid wastes (residual solid wastes after separate collection of recoverable materials) are treated through mechanical reprocessing and fractionation. The RDF obtained from this process is traded treated and co-burnt in installations for power generation or in a manufacturing process where heat is required (e.g. cement production). RDF can be used for energy recovery and it is generally used for the thermal conversion processes, such as co-combustion in coal fired boilers, co-incineration in cement kilns, and co-gasification with coal or biomass. The use of RDF has the following advantages:

- Permit to manage municipal solid waste and it is a valid alternative to dumping and landfill.

- Use of RDF in industrial processes offers more flexibility than the simple incineration of solid waste. Its use permits reduction of the emission of CO_2 since the plants can partially replace the use of fossil fuel.

- According to the national environment policies, the use of RDF permits to obtain a tradable commodity as white and green certificates. These certificates respectively prove that a specified amount of energy saving has been achieved and that certain electricity is generated using renewable energy sources.

2.4.2 Classification of RDF

RDF can be classified into seven categories by following the ASTM standards E856-83 (2006) as follows;

- RDF-1: Solid wastes used as a fuel in its discarded form.
- RDF-2: Solid wastes processed to coarse particle size with or without ferrous metal separation such that 95% by weight passes through a 6 in square mesh screen, namely Coarse RDF.
- RDF-3: Solid wastes processed to separate glass, metal and inorganic materials, shredded such that 95% by weight passes 2 in square mesh screen, namely Fluff RDF.
- RDF-4: Combustible solid wastes processed into powder form, 95% weight passes through a 10 mesh screen (0.035 in square), namely Powder RDF.
- RDF-5: Combustible solid wastes densified (compressed) into the form of pellets, slugs, cubettes or briquettes, namely densified RDF.
- RDF-6: Combustible solid wastes processed into liquid fuels, namely RDF slurry.
- RDF-7: Combustible solid wastes processed into gaseous fuels, namely RDF syngas.

2.4.3 Production process of RDF

All RDF processes typically begin with shredding MSW to a finer size; then separate the fuel fraction from the residue. In plants where no additional preparation is included, the operation is called a "shred-and-burn" RDF facility. Frequently, the separated fuel fraction is further processed to recover metals and sometimes glass. The normal sequence of RDF preparation is shredding, air classifying/screening, magnetic separation, and sometimes eddy current separation for nonferrous metal recovery. Many variations of the process have been developed, each of which has certain advantages. Fig. 2.7 shows a schematic flow for a typical process to make RDF. A typical plant of this type represented in the schematic diagram could process 500 to more than 2,000 tons per day of MSW [54].

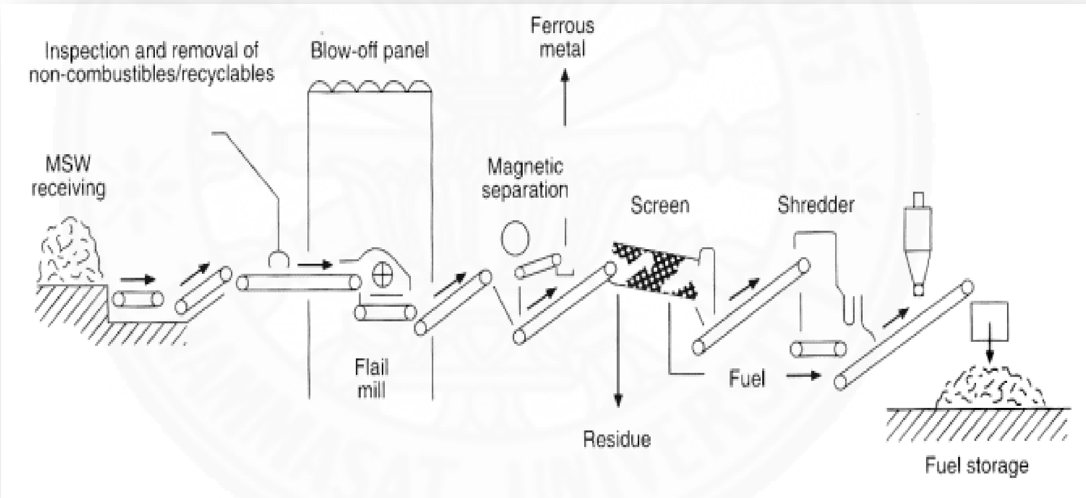


Fig. 2.7 Schematic flow sheet for a typical process to make RDF[55]

2.4.4 Application of RDF

Currently, RDF is being used in energy-intensive industries, such as cement, power generation, either co-combustion or mono-combustion [34]. In cement kilns, combustion takes place under very high flame temperatures about 1450ºC and has relatively long residence times. These conditions are favorable for the burning of

RDF. Based on the technical and environmental considerations, the analysis of burning RDF in a cement kiln shows that no special firing technology has to be installed except the RDF handling system. However, there is an upper limit to the total fuel consumption. Not more than 30 percent for firing RDF. This limitation is required in order to properly manage the emission levels of air pollutants such as acid gases, dioxins, furans, *etc* [31]. The power plant uses RDF in the pusher grate boiler to generate the steam, which will be fed to the matching steam turbine with generator to produce electricity. The generated electricity will be supplied to the grid system.

2.5 The Palm oil industry (specifically located in Lamae district Chumphon Province, Southern Thailand)

A palm oil mill produces crude palm oil and kernels as primary products and biomass as secondary product. A typical mill has many operational process steps as shown in Fig. 2.8. The process comprises of; sterilization, stripping, digestion and pressing, clarification, purification, drying and storage. Sterilization process consumes high amounts of energy because it uses of high-temperature and wet-heat treatment of loose fruit by pressurized steam.

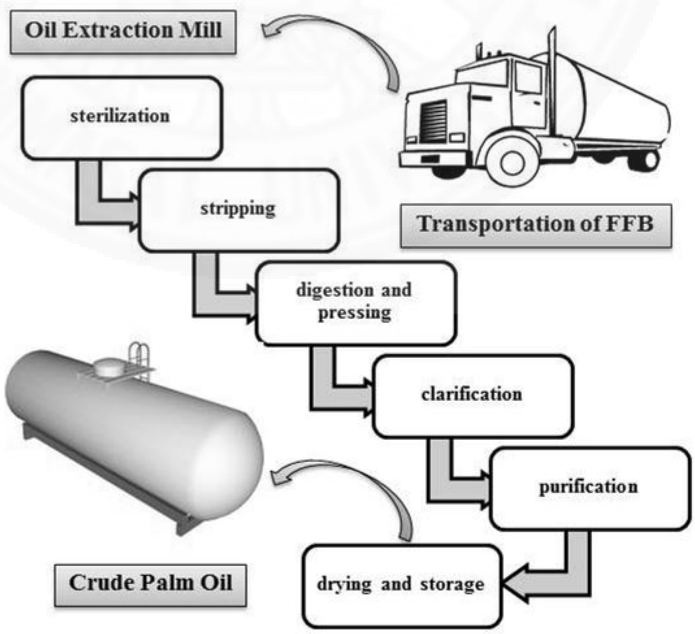


Fig. 2.8 Diagram of crude palm oil processing

2.5.1 Palm oil production processes

Featuring all stages required to produce palm oil to international standards, are generally handling from 3 to 60 tons of fresh fruit bunches (FFB)/hour are generally handled. The large installations have mechanical handling systems (bucket and screw conveyors, pumps and pipelines) and operate continuously, depending on the availability of FFB. Boilers, fuelled by wood, fiber and shell, produce superheated steam, used to generate electricity through turbine generators. The lower pressure steam from the turbine is used for heating purposes throughout the factory. Most processing operations are automatically controlled. Routine sampling and analysis by process control laboratories ensure smooth, efficient operation. Although such large installations are capital intensive, extraction rates of 23 - 24 % palm oil per bunch can be achieved. The following is a brief description of the palm oil extraction process, and how palm fruits undergo the process of being turned into oil. Palm oil is edible oil that is derived from the flesh of palm fruit. In the unprocessed form it has a bright red color and is solid in its consistency. The palm oil tree produces fresh fruit bunches all year round The majority of the oil is formed in the last two weeks of this process and a correct judgment of the ripeness is essential to assure high quality of production. The bunch is removed from the plant by hand with the aid of harvesting tools. The main extraction steps are sterilization, threshing, digestion, pressing, clarification, purification, and packaging.

2.5.1.1 Sterilization

The fresh fruit bunches are cooked with live steam for 90 – 120 minutes. Sterilization objectives are: Lipase enzyme inactivation, making fruits easily release from bunches, making fruits softer, making nut/pulp separation easier, and coagulation of the proteins.

2.5.1.2 Threshing

After bunches are cooked they are fed to the thresher which is a drum with holes on the side where bunches are centrifuged to separate from the fruits. The bunch waste is incinerated. The ash, is a rich source of potassium, and is used in compost.

2.5.1.3 Digestion

Digestion is the process of releasing the palm oil in the fruit through the breaking down of oil-bearing cells. Fruits are lifted by a cup elevator to the top of the digester vessel. This vessel contains a live steam heating system and agitator shafts. The main aim during digestion is to break oily cells, in order to make oil extraction easier. This process takes 30 minutes at 90-100 ºC.

2.5.1.4 Pressing

Pressing is accomplished just after the material leaves the digestion vessels and it produces slurry made of approximately 53% oil, 40% water and 7% solids and also a cake that consists of fibers and nuts. Method of pressing could be dry or wet. Dry method is oriented on squeezing the oil out of the mixture, moisture, fiber and nuts are added by applying mechanical pressure on the digested mash. Wet method uses hot water to leach out the oil.

2.5.1.5 Clarification, Purification, and Packaging

The next steps are Clarification, Purification, and Packaging. Clarification consists of separating the oil from impurities (water and fine solids) made in settling tanks and three phase decanters. Recovered oil is then purified in the plate centrifuges and dried under vacuum. Finally, in the packaging step the Extra Virgin Palm Oil is filtered to remove any remaining particulate matter and packaged in drums.

2.5.2 Situation of the palm oil industry in Thailand

Palm oil has become the world's leading vegetable oil in terms of consumption and production with 61.43 million tons produced worldwide in 2015. The biggest producer, with 33 million tons share in production in 2015, was Indonesia, followed by Malaysia (19.5 million tons) and Thailand (2.2 million tons) [56]. Global production of palm oil and thus the plantation of oil palm have been increasing tremendously in the last decade. Palm oil is versatile in its uses in the food industry, chemical industry, and increasingly as a feedstock for biofuels, which is another reason for the rising popularity of palm oil. Other factors include the increasing demand for vegetable oils in general and the comparably low prices of palm oil.

2.5.2.1 National trends of oil palm development in Thailand

Currently there are, fourteen bio-diesel plants, twelve palm oil refineries and more than sixty palm oil crushing mills are in operation in Thailand **[57]**. In 2015 production of palm oil reached 22 million tons of which 0.15 million tons was exported. Fig.2.9 shows the annual production of palm oil in Thailand for the last forty years.

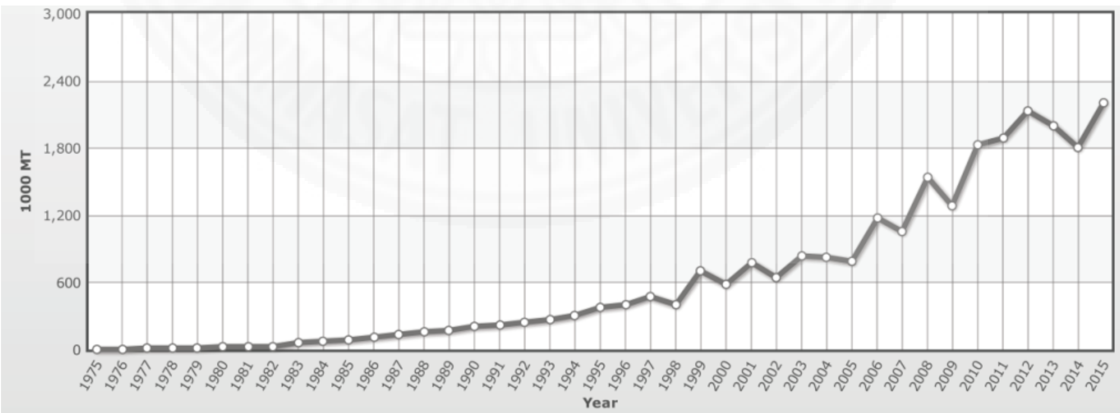


Fig. 2.9 Thailand's palm oil production by year

The area planted with oil palm in Thailand has been increasing constantly, with an average 4,000 hectare in 1977 to 710,000 hectare in 2015. This is very much in line with the average annual growth rate as shown in Fig. 2.10.

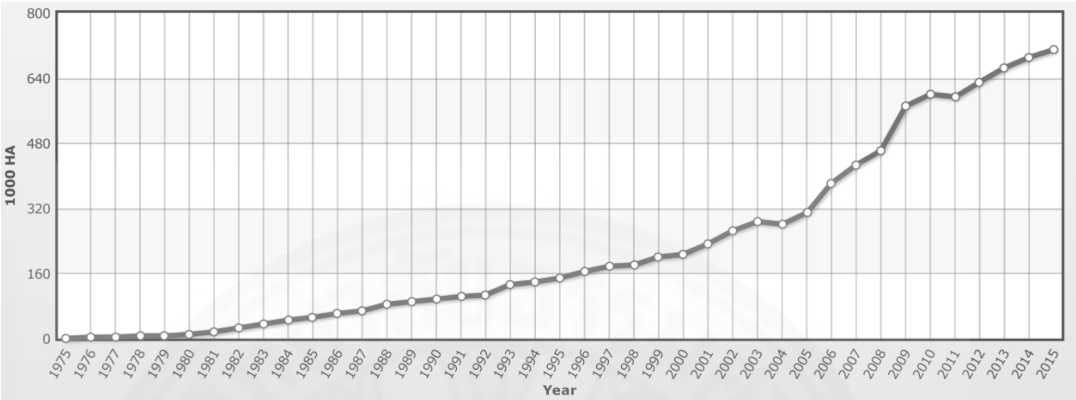


Fig. 2.10 Thailand’s palm oil area harvested by year

Approximately 90% of the total area planted with oil palm in Thailand is concentrated in the southern provinces of Thailand. The eastern and north eastern provinces are prominent areas of expansion, mainly in Chon Buri and Trat on the east coast. The three main fresh fruit bunch (FFB) producing provinces of Krabi, Surat Thani and Chumphon accounted for 72.1% of the total planted area in 2008. Table 2.2 gives an overview of the most important provinces for palm oil plantation as well as the average annual yields per hectare [58].

Table 2.2 Planted area, harvested area and FFB yield per ha in Thailand

Province	Planted area (ha)	Harvested area (ha)	Yield/hectare (tons)
Trad	10,735	6,540	20.3
Chonburi	13,096	11,844	19.5
Prachuabkirikhan	26,912	12,741	18.6
Chumporn	117,179	102,820	21.1
Ranong	11,724	7,687	18.3
Suratthani	146,441	120,440	20.2
Phangnga	16,345	13,078	17.8
Krabi	154,529	129,075	21.3
Trang	17,444	14,493	17.9
Nakhornsrithamarat	23,866	14,455	18.4
Satun	16,726	14,093	16.0
Others	25,277	12,438	
Total	580,275	459,704	

2.5.3 Situation of energy use in palm oil production

At present, electricity has been used as energy in the palm oil industry as showed in Fig.2.11.

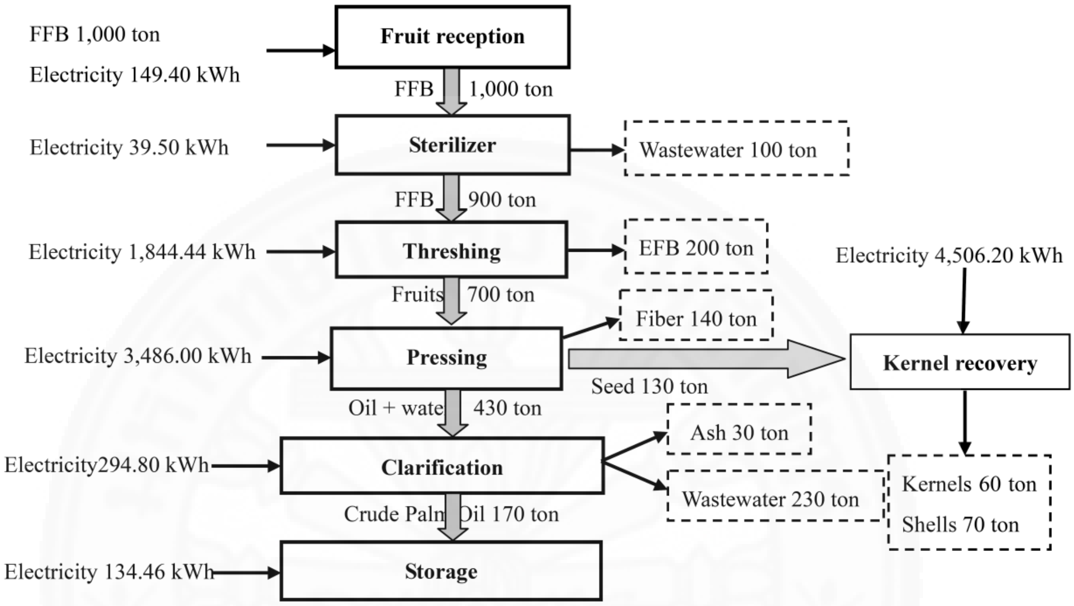


Fig. 2.11 The electricity requirements for in the palm oil mill [59]

The production process in a palm oil mill is shown in Fig. 2.11. The analysis reflect that 10,454.80 kWh electricity generated to supply the processing power for producing 1,000 tons of FFB per day, which is estimated to be about 10.45 kWh/ton of FFB. However, palm oil production generates enormous amounts of process residues, such as fibers (140 tons/day), shells (70 tons/day), and empty fruit bunch (EFB) (200 tons/day). The fibers are used as fuel in a boiler to produce high-pressure steam which is expanded through a steam turbine to produce electricity. Low-pressure steam is reuse in the manufacturing process for sterilization, digestion, purification, and also for temperature control.

Biomass from rubber tree is also used as fuel in the palm oil mill is shown in Table 2.3. Roots, stumps and leaves of rubber tree branches are common biomass used in the process. In Thailand, the amount of roots, stumps and leaves of rubber tree branches available each year equal to 808,025.00 tons/year. This amount is equivalent to 126.04 ktoe of crude oil and 294,929,125.00 kWh of electricity. The amount of swarf rubber wood available each year equal to 1,939,260.00 tons/year. This amount is equivalent to 302.49ktoe of crude oil and 707,829,900.00kWh of electricity. The amount of slab rubber wood available each year equal to 1,939,260.00 tons/year. This amount is equivalent to 302.49 ktoe of crude oil and 707,829,900.00 kWh of electricity. The amount of rubber wood chips and sawdust available each year equal to 484,815.00tons/year. This amount is equivalent to 75.62 ktoe of crude oil and 176,957,475.00 kWh of electricity [60].

Table 2.3Type of biomass used as fuel in the palm oil mill [60]

Biomass	**Available**	**Production**	
	Amount	Crude oil potentials-$_{eq}$	Electrical energy$_{-eq}$
	(tons/year)	(ktoe/year)	(kWh/year)
Roots, stumps and leaves rubber tree branches	808,025.00	126.04	294,929,125.00
Swarf rubber wood	1,939,260.00	302.49	707,829,900.00
Slab rubber wood	1,939,260.00	302.49	707,829,900.00
Rubber Wood Chips and Sawdust	484,815.00	75.62	176,957,475.00

However, these amounts are grossly insufficient to replace electricity in the palm oil mill with biomass due to lack of cultivating rubber trees, as a result of a petulance that hit Southern Thailand about 5 years ago. Therefore, one way to solve this issue is converting solid waste to energy through RDF from MSW.

2.6 Potential environmental impacts from RDF combustion

2.6.1 Carbon dioxide (CO_2)

Carbon dioxide (CO_2), the most significant GHG directly affected by anthropogenic activity, is the byproduct of the oxidation of carbon in organic matter, either through combustion of carbon-based fuels or the decay of biomass. Natural CO_2 sources include volcanic eruptions, respiration of organic matter in natural ecosystems, natural fires, and exchange of dissolved CO_2 with the oceans. The main anthropogenic sources are (a) fuel combustion [61-65]and (b) deforestation and land use changes (such as converting agricultural land or forests to urban development)[66-70], which release stored organic matter and reduce the ability of natural ecosystems to store carbon.

2.6.2 Nitrogen oxides (NO_x)

Nitrous oxide (N_2O) is produced by fertilizer use, animal waste management, fossil fuel combustion, and industrial activities. Oxides of Nitrogen (NO, NO_2, and NO_X) are the byproducts of endothermic reactions within combustion engines and cause significant environmental pollution. The main source of NO_X is from the engine of automobiles. These pollutants are harmful to humans in their respective form and are partially responsible for the depreciation of the ozone layer. (O_3) as well adds to the development of acid rain. NO_X is most prevalent in our societies as a contributor to asthmatic conditions as well as the photochemical smog found throughout many industrialized cities.

2.6.3 Chlorine (Cl_2)

Chlorine is a key parameter for the describing the influence of Refuse Derived Fuel (RDF) quality on combustion processes. In MSW a wide range of sources of both organic and inorganic chlorine can be identified. For RDF that produced from household waste, it will be improving the fuel quality by separating polyvinyl chloride (PVC) particles from the RDF. It will significantly reduce the average chlorine concentration.

2.6.4 Sulfur oxide (SO_x)

Sulfur dioxide (SO_2) is not a “greenhouse gas” but its presence in the atmosphere may influence climate change. SO_2 can react with a variety of photochemically produced oxidants to form sulfate aerosols. The concentration of these particles is increasing due to the burning of fossil fuels which contain sulfur. Over limited regions of the northern hemisphere, the effect of these particles is comparable in size, although opposite in effect, to that of human generated greenhouse gases up to the present time. Although SO_2 is not a direct greenhouse gas, it is an aerosol precursor and as such, has a cooling effect on the climate.

2.7 Life Cycle Assessment (LCA)

Life cycle assessment (LCA) as defined in ISO 14040, the principles and framework for including [71]: definition of the goal and scope of the LCA, the life cycle inventory analysis (LCI) phase, the life cycle impact assessment (LCIA) phase, the life cycle interpretation phase, reporting and critical review of the LCA, limitations of the LCA, the relationship between the LCA phases, and conditions for use of value choices and optional elements. It is applied for considering the potential environmental impacts throughout a products life cycle. From raw material, production, usage, end of life, treatment, recycling and final disposal of the product (cradle to grave) as shown in Fig 2.12.

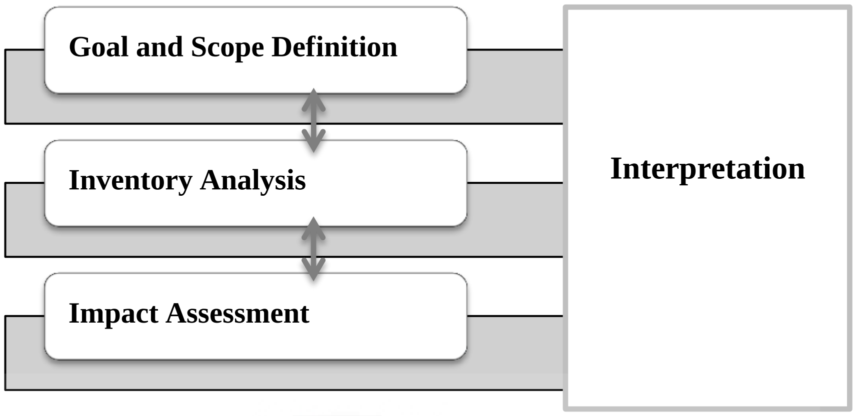


Fig. 2.12 Life cycle assessment stages

- Goal and scope definition: Defining suitable goal and scope for the LCA research. It includes the definition of a reference unit. The goal and scope should address the overall approach used to establish the system boundaries. The system boundary determines which unit processes are included in the LCA and must reflect the goal of the research. This provides a clear, full and definitive description of the product or service being investigated, and also enables subsequent results to be interpreted correctly. In this research, the functional unit is 1 kg of crude palm oil.

- Inventory analysis: Compiling an inventory of relevant inputs and outputs of a products system. The inventory involves data collection and modeling of the RDF production, as well as description and verification of data. This encompasses all data related to environmental (e.g., CO_2) and technical developments. Examples of input and output quantities include: inputs of materials, energy, chemicals and other, outputs of air emissions, water emissions or waste. Usually, life cycle assessment inventories and modeling are carried out using dedicated software packages. Depending on the software package used, it is possible to model life cycle social impacts in parallel with environmental life cycle. The data must be related to the functional unit defined in the goal and scope definition. Data will be presented in tables and some interpretations be made already at this stage. The results of the inventory is an LCI which provides information about all inputs and outputs in the form of an elementary flow from the environment and from all the unit processes involved in the research.

- Impact assessment: Evaluating the potential environmental impacts associated with the selected inputs and outputs. The first step is the data characterization where impact potentials are calculated based on the LCI results. The next step is the normalization of data on which provides a basis for comparing different types of environmental impact categories (all impacts get the same unit). In weighting step, a weighting factor to each impact category is assigned depending on the relative importance. This step is necessary to create a single indicator, i.e., the carbon dioxide equivalent (kg $CO_{2\text{-eq}}$).

- Interpretation: Interpreting the results. Climate change is represented based on the International Panel on Climate Change (IPCC)'s guidelines for national greenhouse gas inventories weightings of the global warming potential of various substances. Substances known to contribute to global warming are weighted based on an identified global warming potential expressed in kg $CO_{2\text{-eq}}$. In this research, the impact categories (namely climate change) were applied using SimaPro software based on the IPCC Method and the Ecoinvent Database.

Although LCA was originally developed for analyzing the environmental performance of products, since the end the 90s, this methodology has also been used for the analysis of solid waste management [72]. Right from the start, LCA was used to compare different alternatives for treatment of one specific solid waste flow [73-78], but also to compare more complex systems such as the integrated solid waste management systems, including all solid waste fractions [79-87]. The benefit of using LCA is that it helps to expand the perspective of the analysis and to have a complete view of the entire system, gathering all processes and environmental impacts associated there in. This approach can avoid the unintentional shifting of environmental loads between different steps of the solid waste management systems, geographical areas, environmental compartments (air, land and water) or impact categories (e.g. global warming, acidification, etc.) [88-99].

Chapter 3
Methodology

3.1 Study framework

MSW in this research from Lamae Municipality in Chumphon, Refers to heir density, physical compositions, moisture content, dry matter, volatile solid, ash/non-volatile solid, heating value, and potential environmental impacts were analyzed. The data from these properties were used for the predation and study of the different ratios for RDF. The appropriate ratio of RDF was used as alternative energy source for the palm oil industry. The diagram research framework is shown in Fig. 3.1.

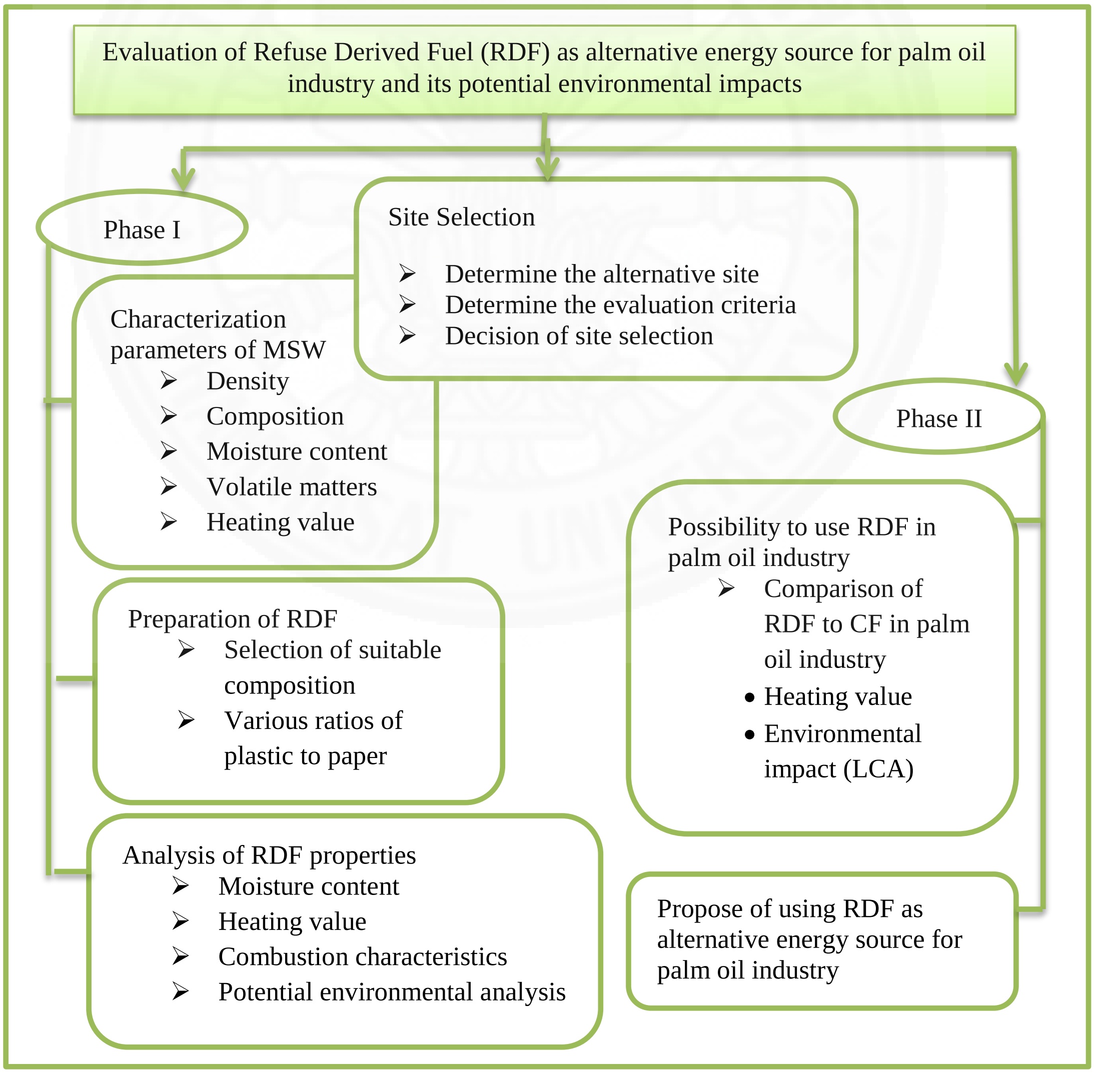


Fig. 3.1 Diagram of study framework

3.2 Site selection

Site selection is an important criterion in evaluation of RDF as alternative energy source for the palm oil industry. Selection of the appropriate solid waste source and the appropriate industrial area simultaneously creates a challenging evaluation process in that requires consideration of alternative solutions and evaluation criteria. The screening of the research site is determined by following 4 criteria as showed in Fig. 3.2. The research area is located in southern Thailand because it is the palm oil plantation areas. Accordingly the results of potential solid waste for WtE and crude palm oil mills in southern Thailand are shown in Table 3.1.Chumporn province was selected for the research due to its many crude palm oil mills in the province (19 mills).Chumporn province also the data showed a high amount of potential solid waste for WtE (256 ton/day). Furthermore it is has no plans for a WtE plant. Lamae district is mentioned as an appropriate area because of it is small land and lack of solid waste treatment technology as showed in Fig. 3.3, while the solid waste generation rate increases every year because of increasing population.

Table 3.1Potential solid waste for WtE and crude palm oil mills in southern Thailand

Province	Amount of potential solid waste for WtE (ton/day) [100]	Palm oil mill (mills) [101]	Under planning of WtE Plant (Center) [100]
Nakhornsrithamarat	773	1	1
Suratthani	629	21	1
Trang	310	4	2
Krabi	295	11	1
Chumporn	256	19	-
Phangnga	161	2	2
Satun	146	5	2
Ranong	126	3	-

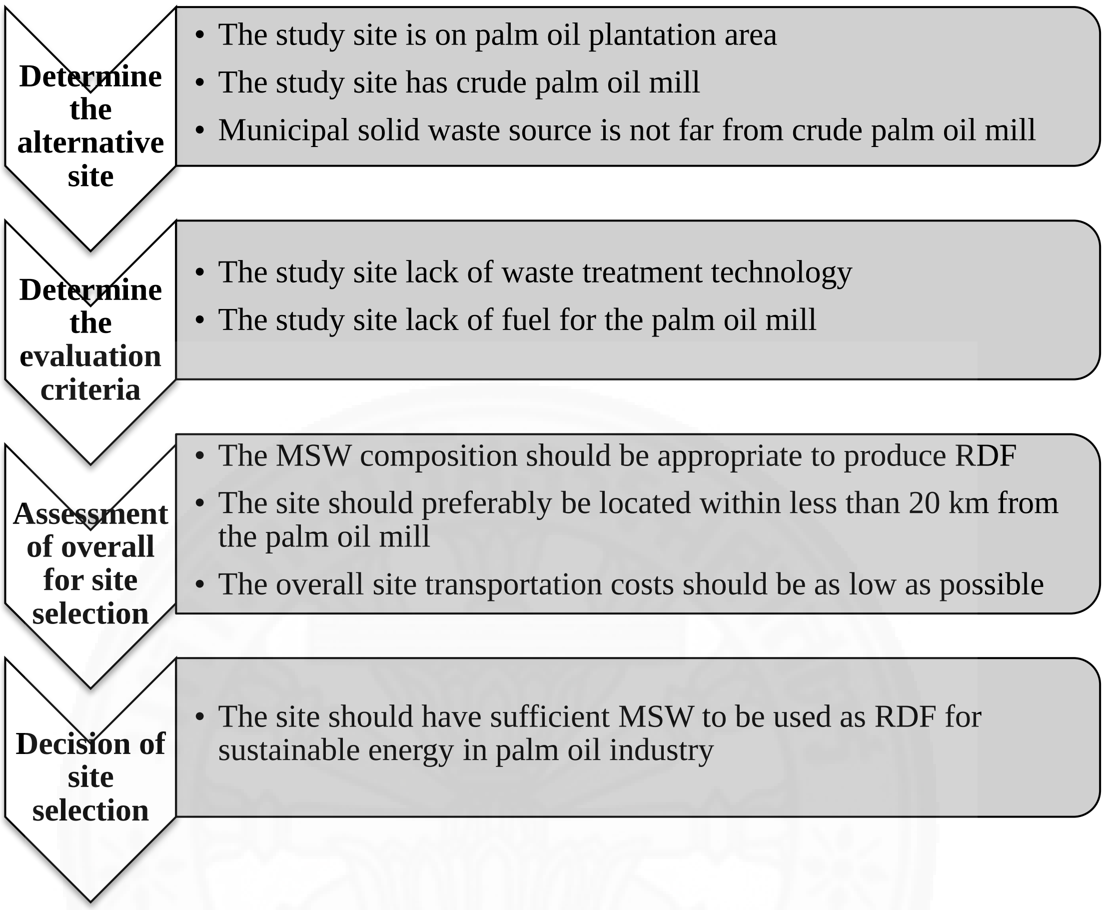


Fig. 3.2 Criteria for identifying the site selection

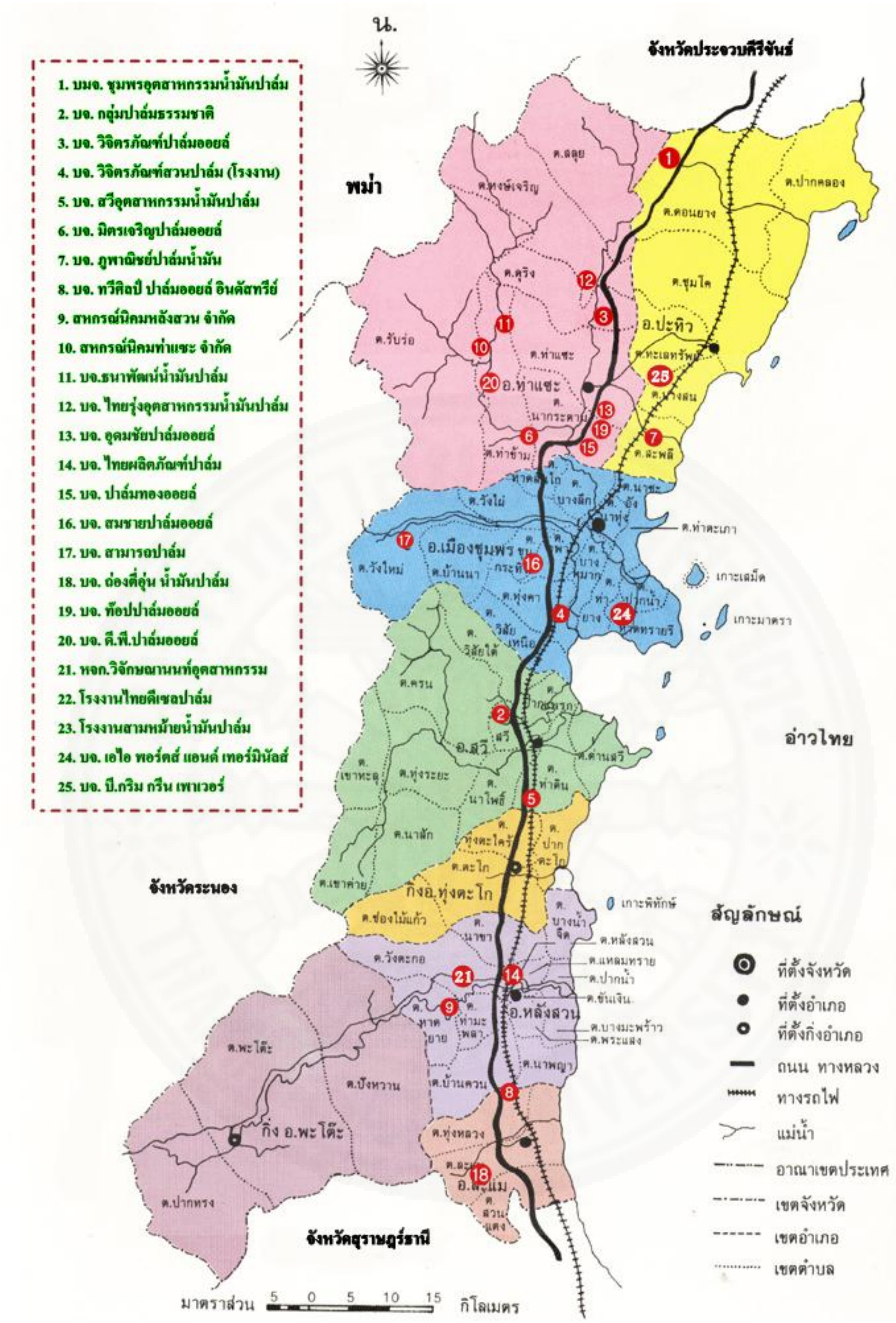


Fig. 3.3 Palm oil mill in Chumphon Province[102]

According to the above mentioned Lamae municipality in Chumphon, Thailand was selected as the appropriate study site for the evaluation of RDF as alternative energy source for palm oil industry fort his research.

3.3 Characteristics and analysis of MSW

For the studying of density, physical compositions, moisture content, dry matter, volatile solid, ash/non-volatile solid, and heating value were analyzed by following standard methods as shown in Table 3.2. Each parameter was run in triplicate. According to ASTM D5231 - 92(2008) standard method, weights of 200 to 300 lb (91 to 136 kg) for sorting samples of unprocessed solid waste are determined for weekly period of (5-7 days).

Table 3.2 Analytical parameters

Item	Parameter	Analytical parameters	Reference
1	Density	ASTM D5057 - 10	[103]
2	Physical compositions	ASTM D5231 - 92(2008)	[104]
3	Moisture content and dry matter	ASTM E790-87(1996)	[105]
4	Volatile solid and ash/non-volatile solid	ASTM E897-88(2004)	[106]
5	Heating value	ASTM E711-87(2004)	[107]
6	Combustion characteristics	ASTM D7348-13	[108]
7	Potential environmental analysis	Testo350	[108]

3.2.1 Density

Density of MSW at the landfill site starting at the total weight of the load was measured by filling the solid waste into a 10 L bucket and weighing. The average weight of load coming and the density of solid waste were calculated and these weights were used to determine the total estimate load coming to the site in 1 day which repeats 7 days in a week.

3.2.2 Sorting

The MSW was sorted into selected categories manually for the major components, such as paper, metal, glass, textile, plastic (hard), plastic (soft), and organic material which repeats 7 days in a week as show in Fig. 3.4.The weights of components were measured using a balance which measures up to 35 kg.

Fig. 3.4 Solid waste characterization baskets

3.2.3 Moisture content and dry matter

The analysis of MSW, moisture contents of solid waste, was analyzed according to the standard procedures. For this purpose seven solid waste components namely: paper, metal, glass, textile, plastic (hard), plastic (soft), and organic material were measured. The initial weight of the selected amounts from each component was recorded before drying in an electric oven, whose temperature was maintained at 107±3°C as show in Fig. 3.5. The samples were kept in the oven for 24 h and after ensuring that the drying has been completed, the weights of the samples were recorded to calculate the moisture content on wet basis and converted to dry matter.

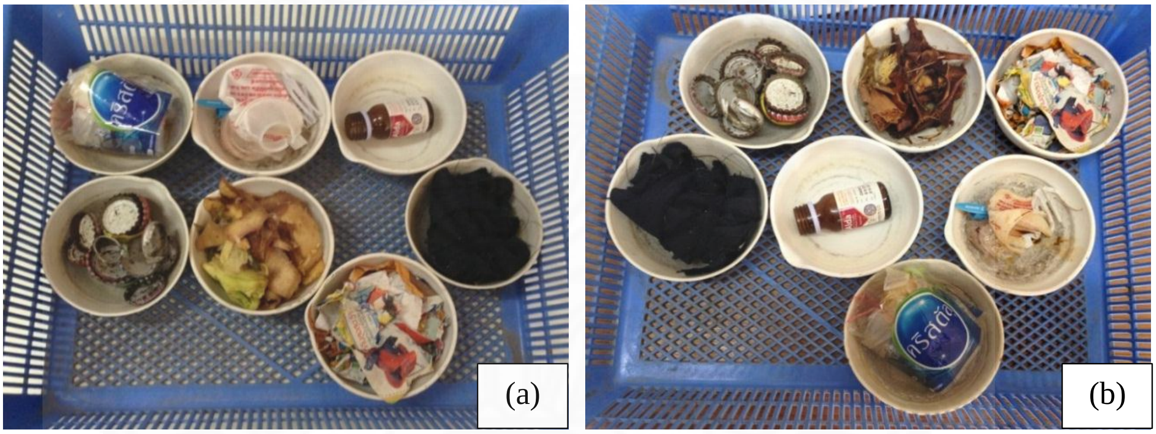


Fig. 3.5 MSW before (a) and after (b) analyzing the moisture content and dry matter

3.2.4 Volatile solid and ash/non-volatile solid

The ASTM standards E897-88 (2004) is the standard testing method for volatile matter. In the analysis samples weigh to the nearest 0.1 mg about 1 g of thoroughly mixed air dried analysis samples in a weighed crucible and insert directly into the furnace chamber, which is maintained at a temperature of 650±20°C as show in Fig 3.6. After heating for 2 h remove the crucible from the furnace and allow it to cool and then weigh as soon as it gets cold. Calculate the percentage loss of weight minus the percentage of moisture in accordance with test method E790.The results represent the volatile matter. The flow chart of volatile matter and ash process is shown in Fig. 3.7. Calculate the percentage of volatile matter, V_{ad}, as follows in equation (3.1). Calculate the ash percent in the analysis sample as follows in equation (3.2)

Fig.3.6 Furnacefor analyzing the volatile solid and ash/non-volatile solid of MSW

$$V_{ad} = \left[\frac{A-B}{A} x100\right] - M_{ad} \qquad (3.1)$$

where A = weight of the used sample, g,

B = weight of sample after heating, g, and

M_{ad} = moisture (as-determined), %.

$$Ash\ as\ determined, \% = \left[\frac{A-B}{C}\right] x100 \qquad (3.2)$$

Where A = weight of container and ash residue, g

B = weight of empty container, g

C = weight of ash analysis sample, g (includes residual moisture)

Weigh to the nearest 0.1 mg about 1 g of sample in a weighed crucible

↓

Close with a cover, place into the furnace chamber

↓

Heat at 650±20°C for 2 h

↓

Cool on a metal cooling block and then weigh the sample after heating

↓

Calculate the volatile matter and ash in the analysis sample

Fig. 3.7 The flow chart of volatile matter and ash process

3.2.5 Heating value

A small quantity of material from the dried samples were set aside for the analysis of calorific value and the calorific values of selected solid waste components were measured in a bomb calorimeter according to E711-87 (2004) standard method, the nearest 0.1 mg about 1 g of sample was determined as show in Fig. 3.8. Characterization and analysis of solid waste flow chart is shown in Fig. 3.9.

Fig. 3.8 Sample pellet for measuring the heating value by Bomb calorimeter

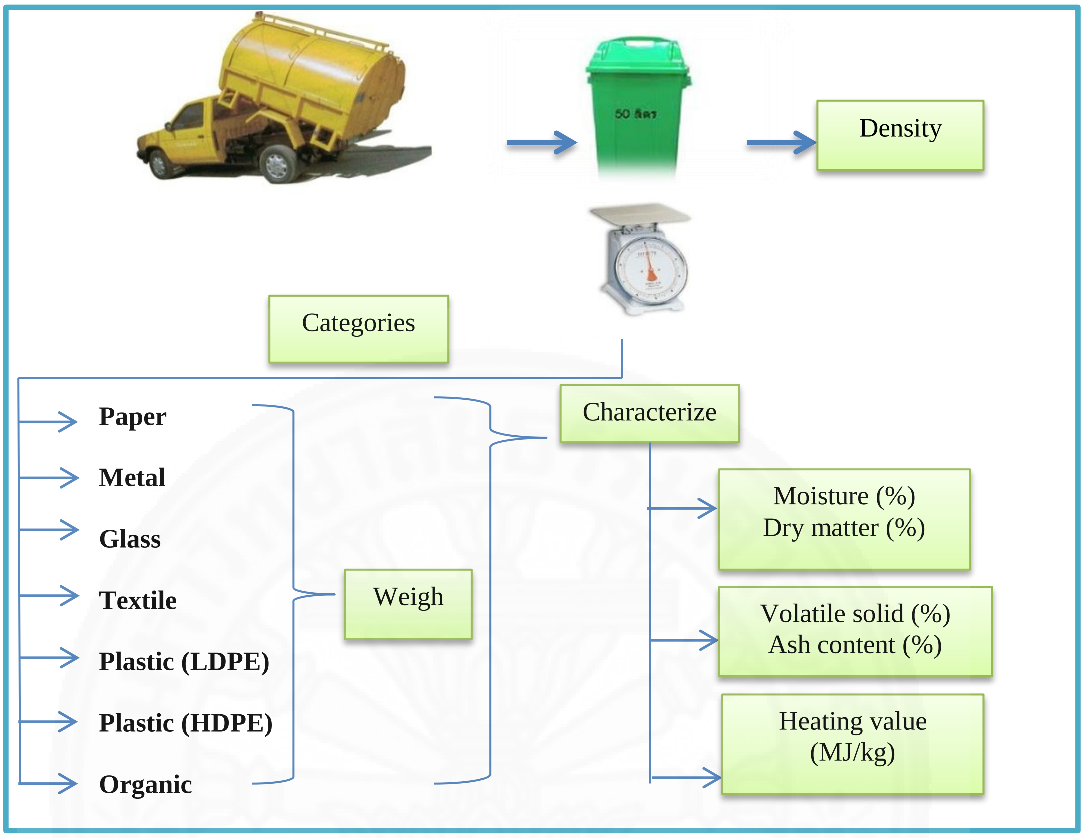


Fig. 3.9 Flow chart of characterization and analysis of solid waste

3.3 Characterization of the properties of RDF

The most important criteria in selecting alternative fuels for use in the palm oil industry were percentage of moisture content, heating value and air emission after combustion. This data was evaluated to determine the use of RDF as alternative energy source for the palm oil industry.

3.3.1 RDF preparation and physical properties analysis

According to the physical properties of each MSW component, the 2 suitable components of MSW (namely paper and plastic) (LDPE) were chosen to prepare the RDF samples with the different ratios.

3.3.2 Preparing RDF sample for analysis

In the following experiments samples of RDF were prepared by using MSW at various ratios of LDPE to paper. The production of the RDF first used LDPE waste as a base, and combined with paper waste as various ratios (100:0, 75:25, 50:50, 25:75, 0:100 % by weight). Second, the raw materials were mixed in the granulator and mixer. After that the well-mixed material was pelleted through a hydraulic machine. The pellet RDF sample was 5 mm in thickness, and 13 mm in diameter as shown in Fig. 3.10. According to the composition of MSW at Lamae Municipality, the soft plastic waste (LDPE) was the largest portion of MSW, which contributes to 47% of total solid waste generated. The second largest component was paper waste (24%). The composition of HDPE was the small portion of MSW and contributed to 5% of total solid waste generated. Therefore, paper and plastic (LDPE) were chosen to prepare the RDF samples with the different ratios. HDPE and LDPE are different grades of polyethylene and the key difference between them is the alignment of the polymer molecules. As a result, they may have substantially different physical properties and different applications. HDPE: Shampoo bottles, food storage containers, laundry and house cleaning bottles, shipping containers, milk, water, and juice jugs, detergent bottles, grocery bags, recycling bins, water pipes. LDPE: Bags for dry cleaning and newspapers, shrink wrap, films, squeezable bottles (honey/mustard), bread bags, garbage bags. The sorting of plastics is a very essential step in different waste management technique. Manual sorting is suitable when plastic component are present in large amount but it is a labor intensive process. In automated sorting technique NIR (near infrared) offers great advantage among all wave sorting technique but not suited for dark colored plastic and can be used on transparent bodies. In air sorting lighter particles are separated from heavier ones based on specific gravity. In electrostatic sorting method materials are separated based on electrostatic charge. In float-sink separation technique the plastics are in a fluid that has density in between the materials making it possible for less dense material to float and heavier to sink whereas sorting by selective dissolution is based on batch dissolution of mixed plastics using solvents. In order to assess the property of RDF in comparison with CF, pellets of CF were prepared with 4 different ratios as shown in Table 3.3.

Table 3.3 The composition of RDF and CF samples

Sample name		% of composition by weight				
		Paper	Plastic (LDPE)	Wood	Palm oil fruit bunch	Palm shell
RDF	100Pa:0Pl	100	0	-	-	-
	75Pa:25Pl	75	25	-	-	-
	50Pa:50Pl	50	50	-	-	-
	25Pa:75Pl	25	75	-	-	-
	0Pa:100Pl	0	100	-	-	-
CF	100W:0B	-	-	100	0	-
	50W:50B	-	-	50	50	-
	0W:100B	-	-	0	100	-
	Palm shell	-	-	-	-	100

(a) (b) (c)

Fig. 3.10 The RDF and CF pellets were 5 mm in thickness, and 13 mm in diameter. (a) RDF, (b) rubber wood, and (c) palm oil bunch

3.3.3 Moisture content and dry matter of RDF

Moisture content and dry matter of RDF was examined by ASTM standards E790-87 (2004). The flow chart of moisture content process is shown in Fig. 3.11.

Heat the empty containers and covers at 107±3°C for 1 h

↓

Cool over a desiccant for about 15-20 min, and weigh

↓

Weigh approximately 1 g of the sample

↓

Put the sample quickly into the container, cover, and weigh

↓

Remove the cover and place in a desiccator

↓

Place the uncovered container into an oven

↓

Heat at 107±3°C for 1 h

↓

Remove, cover the container quickly, and cool in a desiccator over desiccant

↓

Weigh the sample and container as soon as cooled to room temperature

↓

Calculate the percent residual moisture in the analysis sample

Fig. 3.11 The flow chart of moisture content process

3.3.4 Heating value

Heating value was determined by using a bomb calorimeter with ASTM standards E711-87 (2004).The flow chart of calorific value or heating value process is shown in Fig. 3.12.

Weigh approximately 1 g of sample

↓

Put sample into the crucible

↓

Add 0.1 mL of water to the bomb by a pipette

↓

Connect a firing wire to the ignition terminals

↓

Allow the firing wire to maintain contact with the sample

↓

Charge the bomb with oxygen to a consistent pressure between 20 and 30 atm

↓

Record the initial temperature and the final temperature

↓

Calculate the calorific value of sample

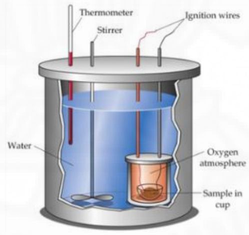


Fig. 3.12 The flow chart of calorific value or heating value process

3.3.5 Combustion performance by using thermo-gravimetric analysis (TGA)

The combustion characteristics of RDF samples with different ratios of paper and plastic (LDPE) via thermo-gravimetric analysis (TGA) were investigated. Five RDF ratios of paper and plastic blends were prepared and oxidized under dynamic conditions from temperature 25 to 1100 °C with heating rates at 10°C/min.

3.3.6 The gas emission during the combustion of RDF

The purpose of this study was to determine the use of RDF as alternative fuel and evaluate the performance of RDF, assessing environmental impact that arises during the combustion process. Additionally characterize the combustion gas emission and analyze potential environmental impact by replacing wood with RDF in the palm oil industry. For this purpose, combustion gas emissions measured during the combustion stage (CO, CO_2, NO_x and SO_x) was measured by using the testo350 Portable Emission Analyzer [109].

3.4 Potential analysis of RDF as alternative energy source; case study for the palm oil industry

The purpose of this study was to use RDF as a supplementary fuel and determine the performance of RDF by assessing RDF's effect on combustion and then characterize the combustion gas emission and analyze potential environmental impacts by replacing wood with RDF in the palm oil industry.

3.4.1 Environmental impact

Environmental impact categories were chosen and analyzed by following the combustible gas for RDF and CF. Combustion gas emission measured during combustion (CO, CO_2, NO_x and SO_x) were used to analyze potential environmental impacts from burning of the RDF and CF. Potential environmental impacts in terms of the global warming potential, acidification, and human toxicity were calculated by life cycle assessment (LCA) method. The selection of impact categories depends on gas emissions from combustion. These gas emissions do not contribute to other impact categories [110].

This study assesses the fuel characteristics of refuse from municipal solid waste (MSW) from Lamae Municipality in Chumphon, Thailand and compares it to CF such as wood and biomass. The study was not limited to alternative energy source, but also investigated potential environmental impact of the palm oil industry fuel.

3.4.2 Greenhouse gas emission

The International Panel on Climate Change (IPCC) was applied to calculate greenhouse gas (GHG) emissions. GHG emissions of MSW from the Lamae Municipality in Chumphon, Thailand were compared by two situations. First situation; all of solid waste generation was sent to landfill. The second situation, the amount of solid waste was without paper and LDPE compositions. Paper and LDPE compositions were used as RDF in the palm oil industry. For this study, three main substances of GHG emissions (CH_4, CO_2, NO_2) were considered.

Chapter 4
Results and Discussion

4.1 Characterization and analysis of MSW

This section describes the results of the MSW characterization study carried out. Initially, the MSW characteristics, such as density, sorting, moisture content, dry matter, and volatile solid, ash/non I volatile solid and heating value are described. The average waste generated at Lamae Municipality in Chumphon was 15 ton/day as explain in 4.1(Characterization and analysis of MSW).

4.1.1 Density of MSW

Solid waste density was an important measurement used to define the number and the capacity of solid waste storage and collection facilities required. Based on solid waste density, and the capacity of trucks, the amount of solid waste collected can be measured in tons (weight). The high density measured reflects the less effectiveness of compaction vehicles for solid waste transportation. However, solid waste density provides rough information of the characteristics of solid waste produced. This parameter was affected by many factors, such as seasonal variation and the way that solid waste is put into containers. The density of MSW was generally about 0.378 ton/m^3 with a standard deviation (SD) value of ±0.012. Compared to the density of MSW in Thailand was 0.36ton/m^3 [111], slightly higher than that of Thailand's solid waste data. The reason could be that samples collected in this study were taken from solid waste collector trucks, while Thailand's solid waste data were taken at transfer stations.

4.1.2 Composition of MSW

The composition of MSW at Lamae Municipality in Chumphon, Thailand is shown in Table 4.1. The soft plastic waste (LDPE) was the largest portion of MSW, which contributes to 47% of total solid waste generated. The second and third largest components were paper waste (24%) and organic waste (15%). According to the previous data, the composition of MSW in Thailand showed that the organic waste was the largest portion of MSW, which contributes to 61.1% of total solid waste generated. According to the data analysis , main components of solid waste between Lamae Municipality and MSW in Thailand are different due to most of solid waste generated in Lamae comes from local markets and department stores that discharged a lot of carry bag that made from LDPE and packaging that made from paper. Although some of organic was presence in Lamae MSW the amount of organic waste was used as compost in the garden. Therefore, solid waste from this area is suitable for converting to an alternative energy source because of appropriate composition and high heating value.

4.1.3 Moisture content and dry matter

The moisture content was generally about 70.93, 20.65, 6.84, 5.85, 5.72, 2.55, and 1.61% in organic, paper, LDPE, metal, hard plastic (HDPE), textile, and glass respectively as shown in Table 4.1.The moisture content of each solid waste composition value varied due to the difference between LDPE waste and paper waste. The above data was used to indicate the benefit of RDF product in managing solid waste. The analysis reflects Low moisture content is better for producing RDF.

4.1.4 Volatile solid and ash/non-volatile solid

Volatile solids in most samples were found to vary from 87 to 99% of the total solids while the glass and metal waste contributed the volatile solid only 0.8 and 11% respectively as shown in Table 4.1. According to the Germany fuel standard, volatile matter is approximately 50-80% by weight [36]. Based on these results, HDPE, LDPE, textile, paper, and organic wastes can be used as raw material for production of RDF as energy source.

4.1.5 Heating value

Heating values or gross calorific values of oven dried components of the MSW were obtained from tests carried out according to the methods described in methodology section and the results are displayed in Table 4.1. The metal waste and glass waste were ignored in this investigation because of their low value. The highest heating value was observed for plastic (LDPE), while paper waste recorded lower heating levels.

Table 4.1Characteristics of MSW in Lamae

Parameters	paper	metal	glass	textile	plastic (HDPE)	plastic (LDPE)	organic
Compositions (% of solid waste generated)	24	3	2	4	5	47	15
Moisture content (% by weight)	20.65	5.85	1.61	2.55	5.72	6.84	70.93
Dry matter(% by weight)	79.35	94.15	98.39	97.45	94.28	93.16	29.07
Volatile solid(% by weight)	98.90	11.62	0.83	92.47	99.56	99.96	87.64
Ash/non-volatile solid(% by weight)	10.10	88.38	99.17	7.53	0.44	0.04	12.36
Heating value(cal/g)	3,343.21	-	-	3,774.62	5,261.23	8,809.03	4,531.79

Table 4.1 According to the results, the plastic (LDPE) waste was the largest portion of MSW, which contributes to 47% of the total solid waste generated with 6.84% moisture content. The second largest components were paper (24%) with a 20.65% value of moisture content. Volatile solids in both compositions were found higher than 98%.The highest heating value was observed for LDPE plastic (8,809.03 cal/g), while paper recorded 3,343.21 cal/g. Therefore, the 2 suitable components of MSW namely paper and plastic (LDPE) were chosen to prepare the RDF samples with the different ratios.

4.2 Characterization of the properties of RDF

According to the characterization and analysis of MSW, those results were used to produce RDF in the capacity of solid waste composition. In order to estimate the properties of the RDF the characteristics of RDF were studied and described in terms of; moisture content, dry matter, heating value, combustion performance, and potential environmental impacts.

4.2.1 Physical analysis

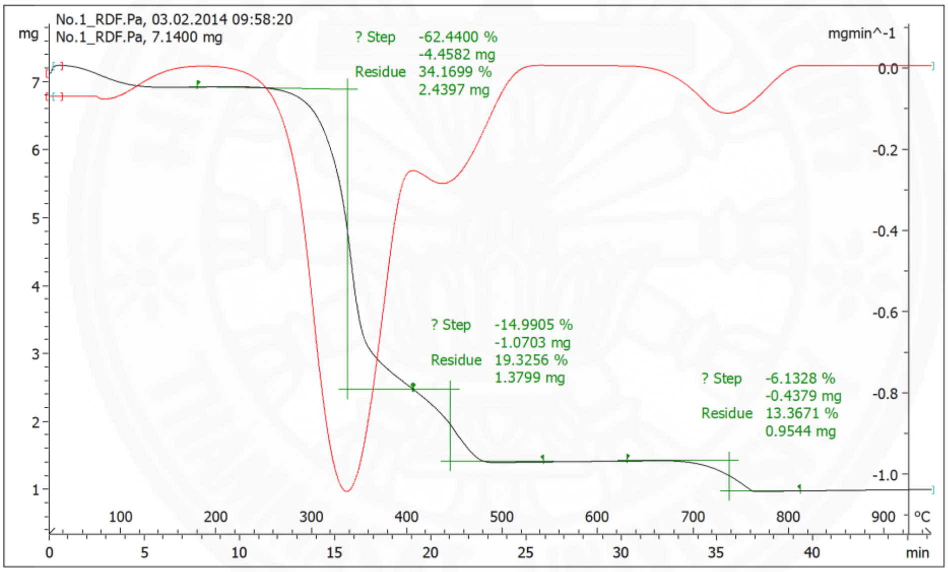
The moisture content and heating values of the RDF and CF are shown in Table 4.2. The heating value of RDF0:100 is lower than the heating value of LDPE because RDF0:100 is prepared by mixing of different fractions of LDPE products such as shopping bag, plastic film, and packaging. While the heating value of LDPE given in table 4.1 is evaluated from single fraction of LDPE product such as LDPE bottle. Results showed that the heating value of another samples was decreased when LDPE component was decreased. The heating values were specifically 5419, 4787, 3964, and 3320 cal/g in RDF25:75, RDF50:50, RDF75:25, and RDF100:0, respectively. Therefore, the quantity of heating value depended on LDPE. Meanwhile, it can be seen that the heating values of biomass were 3831- 4327 cal/g. Recently, Rubber wood has been used as fuel in the palm oil industry that presents heating value 4327 cal/g. The 3 ratios of RDF namely;RDF50:50, RDF25:75, and RDF0:100, that can replace CF in the palm oil industry because the heating value of those RDFs are higher than CF. Nevertheless, further study is needed to determine if the high heating value of the RDF replaced by CF will generate greater environmental impacts. . The results were analyzed in comparison with additional parameters.

Table 4.2 Characteristics of the properties of RDF and CF

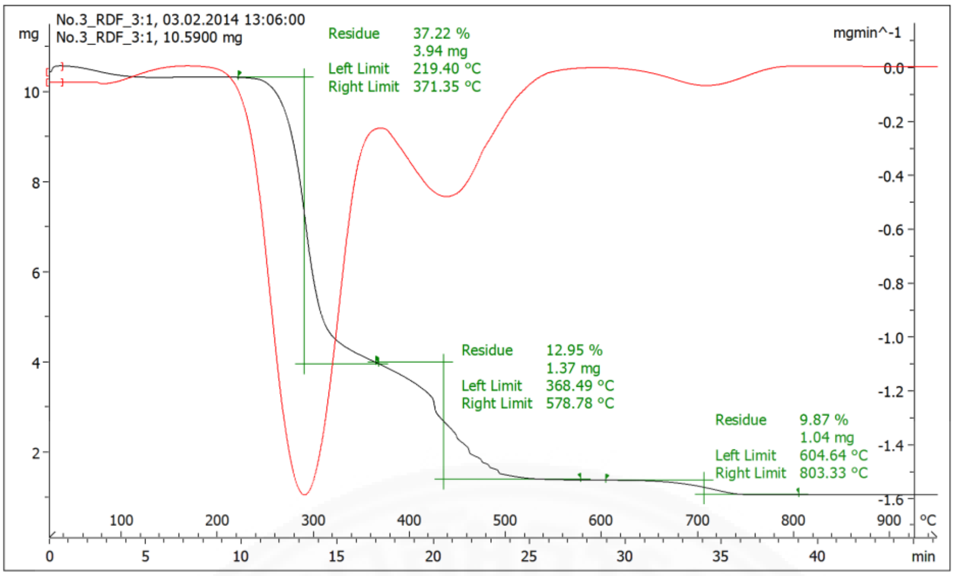
Samples		**Parameters**		
		Moisture content (% by weight)	Dry matter (% by weight)	Heating value (cal/g)
RDF	100Pa:0Pl	3.61	96.39	3320.30±52.01
	75Pa:25Pl	2.60	97.40	3964.36±19.95
	50Pa:50Pl	1.63	98.37	4787.58±48.70
	25Pa:75Pl	1.34	98.66	5419.14±22.54
	0Pa:100Pl	0.30	99.70	6046.28±28.43
CF	100W:0B	9.24	90.76	4327.50±92.76
	50W:50B	9.86	90.14	3978.17±49.09
	0W:100B	10.88	89.12	3831.15±13.58
	Palm shell	8.86	91.14	4313.87±57.39

4.2.2 Combustion characteristics of RDF

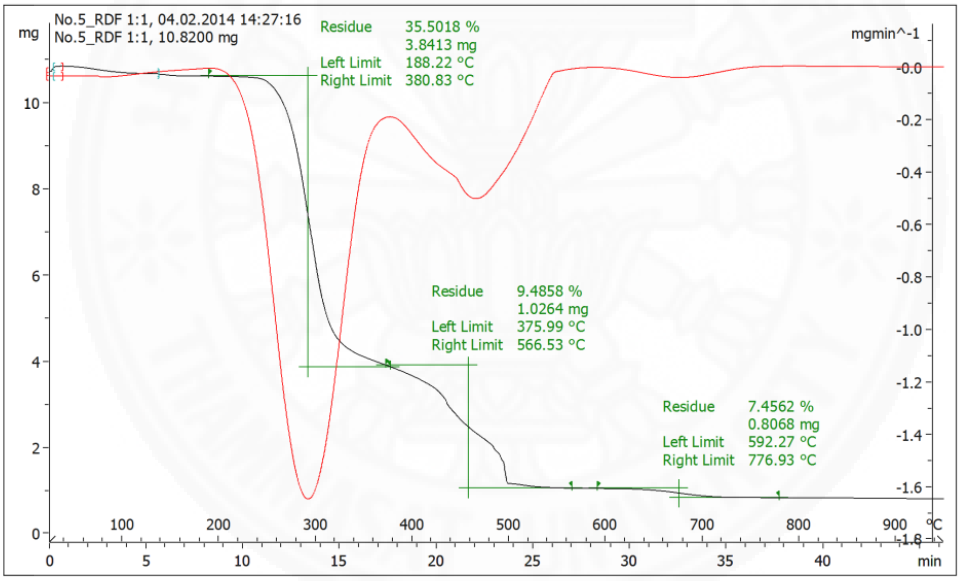
This section focused on primarily on 3 different ratios of the RDF namely; RDF50:50, RDF25:75 and RDF0:100. Additionally the different ratios of the RDF were part of the study as well. The study provided a trend analysis of combustion behavior with varying percentages of LDPE. RDF samples of different ratios of paper and plastic (LDPE) were compared. Table 4.3 and Fig. 4.8 (a)–(e) illustrate the thermal behavior by thermogravimetry (TG) and the derivative thermogravimetry (DTG) profiles of RDF samples in the presence of air. In all materials, initial weight loss with an increase in temperature takes place due to moisture loss and volatilization. Normally temperature of the boiler in the palm oil mill is established at 250 to 600^{o} C [112]. Therefore a temperature range was studied from 25 to 900^{o} C. It covered the temperature range of the boiler in the palm oil mill. RDF profiles exhibited for three weight loss were observed. A weight loss was observed from 0 to 300^{o}C heating due to the loss of moisture, 400 to 500^{o} C heating due to the loss of volatilization, and beyond 700^{o}C heating due to the presence of inorganic fillers. However, almost no ash was found for RDF0:100 as only 3.18% residue remained. Ash content of 19.33%, 12.95%, 9.49%, and 7.13% were obtained for RDF100:0, RDF75:25, RDF50:50, and RDF25:75, respectively.



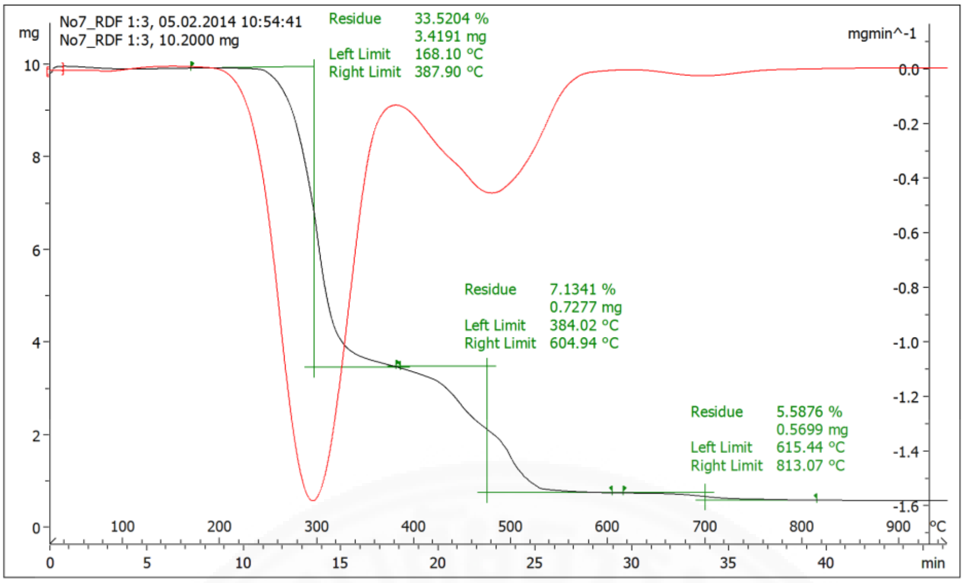
(a)


No.3_RDF_3:1, 03.02.2014 13:06:00
No.3_RDF_3:1, 10.5900 mg
Residue 37.22 %
3.94 mg
Left Limit 219.40 °C
Right Limit 371.35 °C
Residue 12.95 %
1.37 mg
Left Limit 368.49 °C
Right Limit 578.78 °C
Residue 9.87 %
1.04 mg
Left Limit 604.64 °C
Right Limit 803.33 °C
mg
mgmin^-1
°C
min

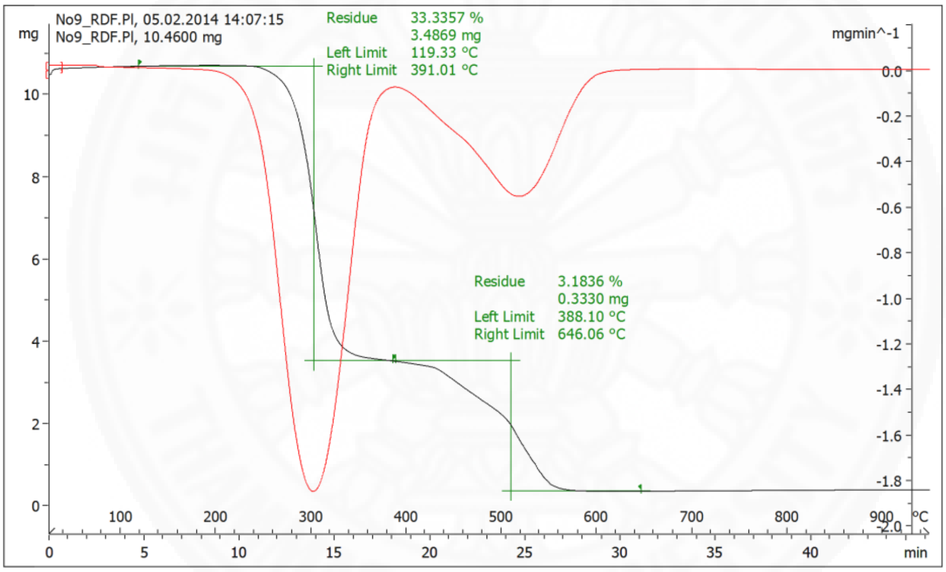
(b)


No.5_RDF 1:1, 04.02.2014 14:27:16
No.5_RDF 1:1, 10.8200 mg
Residue 35.5018 %
3.8413 mg
Left Limit 188.22 °C
Right Limit 380.83 °C
Residue 9.4858 %
1.0264 mg
Left Limit 375.99 °C
Right Limit 566.53 °C
Residue 7.4562 %
0.8068 mg
Left Limit 592.27 °C
Right Limit 776.93 °C
mg
mgmin^-1
°C
min

(c)



(d)



(e)

Fig. 4.1 Combustion characteristics of RDF samples

Remark: 100Pa:0Pl (a), 75Pa:25Pl (b), 50Pa:50Pl (c), 25Pa:75Pl (d), and 0Pa:100Pl (e)

TG methodology increases the data accuracy for the short term, using the main parameters as required for the industrial operation, such as: weight loss from moisture, volatile matter and the residue of weight from ash in the sample at the same time. The thermal decomposition samples using the TGA method is shown in Table 4.3. From the analysis of the results conclude that the combustion of the RDF occurred more completely when the percentage of LDPE was increased and also reflects a decrease in remaining ash. Many researchers have studied the combustion of biomass. They found that ash content of biomass after combustion was amount 3-7% by weight. Two different ratios of the RDF from this study, namely 25Pa:75Pl and 0Pa:100Pl released ash content at the same rate of biomass [113]. Therefore, we conclude the samples can avoid the concern of the ash content replacing biomass by RDF in the palm oil industry.

Table 4.3 Thermal behavior by TG and DTG of RDF samples

Sample name	**% residue of weight in different temperature period**		
	250-350^{o}C	400-500^{o}C	650-750^{o}C
100Pa:0Pl	34.17	19.33	13.37
75Pa:25Pl	37.22	12.95	9.87
50Pa:50Pl	35.50	9.49	7.46
25Pa:75Pl	33.52	7.13	5.59
0Pa:100Pl	33.34	3.18	N/A

Remark: 200-350^{o}C the loss of moisture, 400-500^o C the loss of volatile matter, and 650-750^{o}C the presence of inorganic fillers (in paper case it is $CaCO_3$)[114-116]

4.2.3 Potential environmental impacts during the combustion of RDF

The study considered the probable environmental impacts through the use RDF as a supplementary fuel. Data collected was used to determine the performance of the RDF by assessing the RDF's effect on combustion. It then characterized by the combustion of gas emissions. Finally an analysis was conducted on the data collected provide the potential environmental impact of replacing wood with the RDF in the palm oil industry. For this purpose, gas emissions were measured during the combustion phase (CO, CO_2, NO_x and SO_x).The amounts of gas emitted were shown in Table 4.4. It was found that emission measurements of the

RDF samples are similar to the value of wood in the palm oil industry. However; combustion gas emission results of the RDF samples were lower than the stack emission standard limits[117] such as CO < 6%, NO_x< 250 ppm and SO_x< 30 ppm.

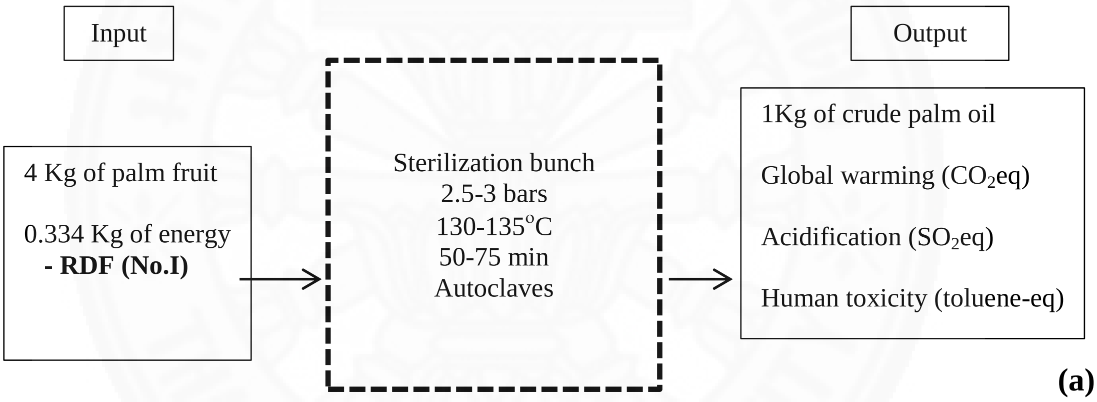
Table 4.4 Combustion gas emission results of RDF samples

Parameter	CO (%)	CO_2 (%)	NO_x(ppm)	SO_x(ppm)
100Pa:0Pl	0.35	10.6	0.8	<0.1
75Pa:25Pl	0.31	10.4	0.7	<0.1
50Pa:50Pl	0.28	9.3	0.5	<0.1
25Pa:75Pl	0.25	8.2	0.7	<0.1
0Pa:100Pl	0.20	7.7	0.6	<0.1
100W:0B	0.32	10.3	1.2	<0.1
50W:50B	0.36	10.5	0.8	<0.1
0W:100B	0.34	10.7	0.9	<0.1
Stack emission standard	< 6	N/A	< 250	< 30

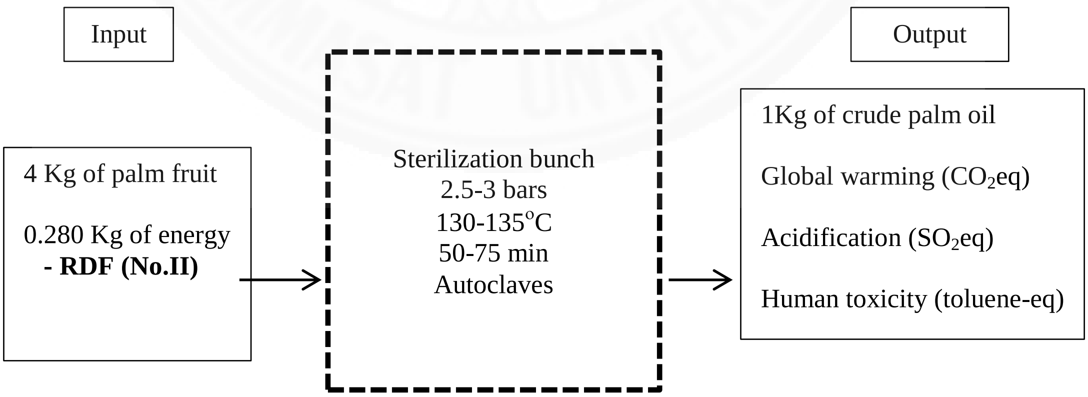
4.3 Analysis potential of the RDF as alternative energy source; case study for the palm oil industry

4.3.1 Environmental impact

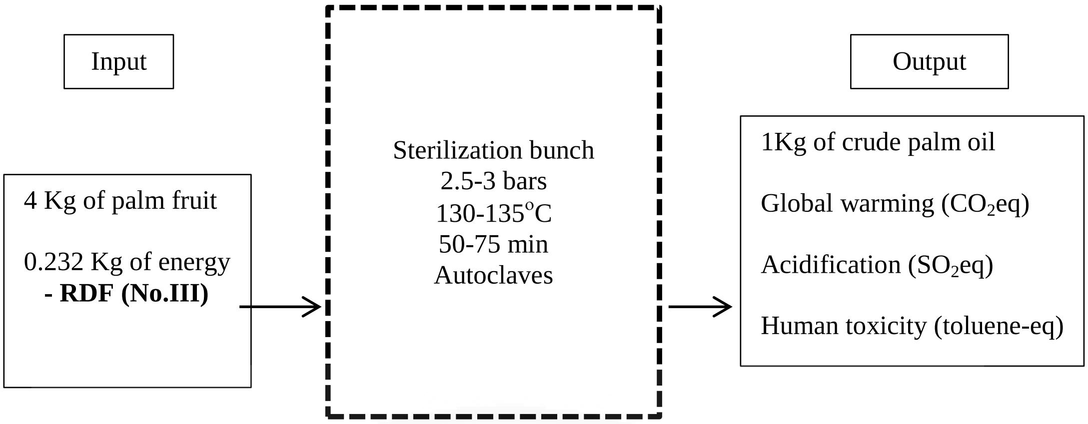
A life cycle approach was used to calculate the environmental impacts from burning the RDF and CF (see appendix)[89, 118, 119]. The study considered the amount of CO_2 equivalents, SO_2 equivalents, and toluene equivalents per 1 kg of crude palm oil produced. The quantification of the environmental impacts of the 7 cases for alternative energy source was compared. In cases no.I-V the RDF was produced from municipal solid waste mixed between: 100% of paper, 0% of LDPE; 75% of paper, 25% of LDPE; 50% of paper, 50% of LDPE; 25% of paper, 75% of LDPE; and 0% of paper, 100% of LDPE, respectively. In cases no.VI-VII the CF produced from the rubber wood and palm oil bunch respectively. The scope of this LCA study was divided into three different kinds of input energy as shown in Fig. 4.2.The data were collected by direct measurements and literature review. The data analysis includes materials and energy inputs as well as outputs for each stage as follows; RDF production was located in Lamae Municipality, Chumphon province. The materials and energy input data measured are municipal solid waste, rubber wood and palm oil bunch.



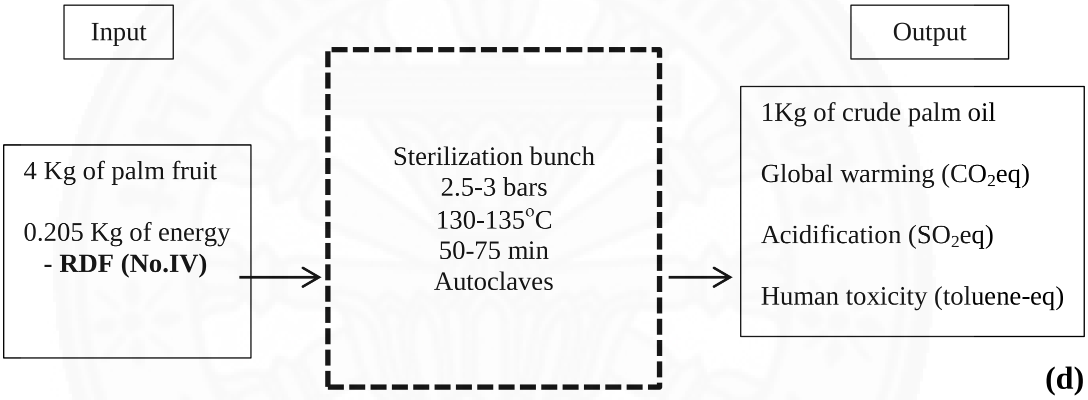
(a)



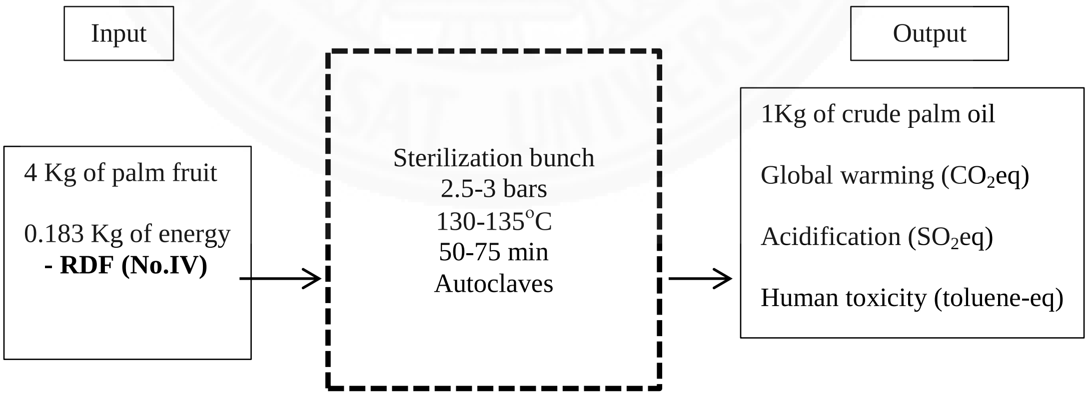
(b)


Input
Output
4 Kg of palm fruit
0.232 Kg of energy
- RDF (No.III)
Sterilization bunch
2.5-3 bars
130-135°C
50-75 min
Autoclaves
1Kg of crude palm oil
Global warming (CO_2eq)
Acidification (SO_2eq)
Human toxicity (toluene-eq)

(c)


Input
Output
4 Kg of palm fruit
0.205 Kg of energy
- RDF (No.IV)
Sterilization bunch
2.5-3 bars
130-135°C
50-75 min
Autoclaves
1Kg of crude palm oil
Global warming (CO_2eq)
Acidification (SO_2eq)
Human toxicity (toluene-eq)

(d)


Input
Output
4 Kg of palm fruit
0.183 Kg of energy
- RDF (No.IV)
Sterilization bunch
2.5-3 bars
130-135°C
50-75 min
Autoclaves
1Kg of crude palm oil
Global warming (CO_2eq)
Acidification (SO_2eq)
Human toxicity (toluene-eq)

(e)

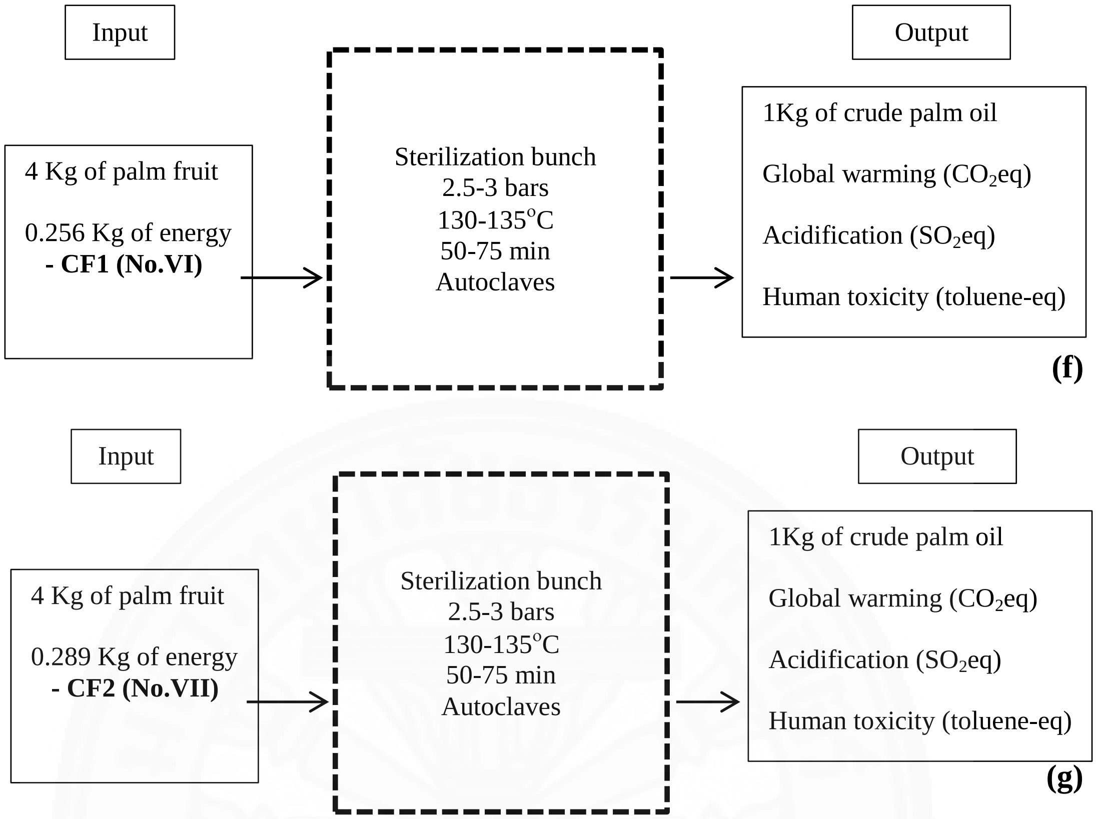


Fig. 4.2 The scope of LCA studyin the RDF and CF samples

4.3.1.1 Life cycle inventory

In the life cycle inventory analysis, the actual data in the production process at Lamae Municipality, Chumphon was collected. The preparation of the RDF and CF production was done by pelleting through a hydraulic machine. The pellet RDF and CF samples were 5 mm in thickness, and 13 mm in diameter**.**

4.3.1.2 Life cycle impact assessment

The global warming potential of carbon dioxide equivalent (kg $CO_{2\text{-eq}}$), acidification of sulfur dioxide equivalent (kg $SO_{2\text{-eq}}$) and human toxicity of toluene equivalent (kg $\text{toluene}_{\text{-eq}}$) for each type is shown in Table 4.5.

Table 4.5 Environmental impacts

Environmental impacts	Equivalence factor
Global warming	**(kg $CO_{2\text{-}eq}$)**
Carbon dioxide (CO_2)	1.0
Carbon monoxide (CO)	1.9
Acidification	**(kg $SO_{2\text{-}eq}$)**
Sulfur dioxide (SO_x)	1.0
Nitrogen oxide (NO_x)	0.7
Human Toxicity	**(kg $toluene_{\text{-}eq}$)**
Carbon dioxide (CO_2)	0.27
sulfur dioxide (SO_x)	6.0
Nitrogen oxide (NO_x)	4.3

The global warming potential of kg $CO_{2\text{-}eq}$, acidification of kg $SO_{2\text{-}eq}$ and human toxicity of kg $toluene_{\text{-}eq}$ for each sample are shown in Table 4.6 and Fig 4.3.

Table 4.6 Environmental impacts of RDF and CF samples

Samples	Environmental impacts	Amount (Kg)	Characterization	
			Equivalence factor	Impact indicator
No.I	**Global warming**		**(kg $CO_{2\text{-}eq}$)**	
100%paper: 0% LDPE	Carbon dioxide (CO_2)	3.193	1.0	3.193x1.0 = 3.193
	Carbon monoxide (CO)	0.350	1.9	0.350x1.9 = 0.665
			Total	**= 3.858 kg $CO_{2\text{-}eq}$**
	Acidification		**(kg $SO_{2\text{-}eq}$)**	
	Sulfur dioxide (SO_x)	0.072	1.0	0.072x1.0 = 0.072
	Nitrogen oxide (NO_x)	0.080	0.7	0.080x0.7 = 0.056
			Total	**= 0.128 kg $SO_{2\text{-}eq}$**

	Human toxicity		**(kg toluene$_{-eq}$)**	
	Carbon monoxide (CO)	0.350	0.27	0.350x0.27 = 0.094
	Sulfur dioxide (SO_x)	0.072	6.0	0.072x6.0 = 0.432
	Nitrogen oxide (NO_x)	0.080	4.3	0.080x4.3 = 0.344
			Total	**= 0.870 kg toluene$_{-eq}$**
No.II	**Global warming**		**(kg CO_{2-eq})**	
75% paper: 25% LDPE	Carbon dioxide (CO_2)	2.624	1.0	2.624x1.0 = 2.624
	Carbon monoxide (CO)	0.310	1.9	0.310x1.9 = 0.589
			Total	**= 3.213 kg CO_{2-eq}**
	Acidification		**(kg SO_{2-eq})**	
	sulfur dioxide (SO_x)	0.069	1.0	0.069x1.0 = 0.069
	Nitrogen oxide (NO_x)	0.070	0.7	0.070x0.7 = 0.049
			Total	**= 0.118 kg SO_{2-eq}**
	Human toxicity		**(kg toluene$_{-eq}$)**	
	Carbon monoxide (CO)	0.310	0.27	0.310x0.27 = 0.084
	sulfur dioxide (SO_x)	0.069	6.0	0.069x6.0 = 0.414
	Nitrogen oxide (NO_x)	0.070	4.3	0.070x4.3 = 0.301
			Total	**= 0.799 kg toluene$_{-eq}$**
No.III	**Global warming**		**(kg CO_{2-eq})**	
50% paper: 50% LDPE	Carbon dioxide (CO_2)	1.942	1.0	1.942x1.0 = 1.942
	Carbon monoxide (CO)	0.280	1.9	0.280x1.9 = 0.532
			Total	**= 2.474 kg CO_{2-eq}**
	Acidification		**(kg SO_{2-eq})**	
	Sulfur dioxide (SO_x)	0.065	1.0	0.065x1.0 = 0.065
	Nitrogen oxide (NO_x)	0.050	0.7	0.050x0.7 = 0.035
			Total	**= 0.100 kg SO_{2-eq}**
	Human toxicity		**(kg toluene$_{-eq}$)**	
	Carbon monoxide (CO)	0.280	0.27	0.280x0.27 = 0.076
	Sulfur dioxide (SO_x)	0.065	6.0	0.065x6.0 = 0.390
	Nitrogen oxide (NO_x)	0.050	4.3	0.500x4.3 = 0.215
			Total	**= 0.681 kg toluene$_{-eq}$**

No.IV	**Global warming**		**(kg CO_{2-eq})**	
25% paper: 75% LDPE	Carbon dioxide (CO_2)	1.513	1.0	1.513x1.0 = 1.513
	Carbon monoxide (CO)	0.250	1.9	0.250x1.9 = 0.475
			Total	**= 1.988 kg CO_{2-eq}**
	Acidification		**(kg SO_{2-eq})**	
	Sulfur dioxide (SO_x)	0.066	1.0	0.066x1.0 = 0.066
	Nitrogen oxide (NO_x)	0.070	0.7	0.070x0.7 = 0.049
			Total	**= 0.115 kg SO_{2-eq}**
	Human toxicity		**(kg $toluene_{-eq}$)**	
	Carbon monoxide (CO)	0.250	0.27	0.250x0.27 = 0.068
	Sulfur dioxide (SO_x)	0.066	6.0	0.066x6.0 = 0.396
	Nitrogen oxide (NO_x)	0.070	4.3	0.070x4.3 = 0.301
			Total	**= 0.765 kg $toluene_{-eq}$**
No.V	**Global warming**		**(kg CO_{2-eq})**	
0% paper: 100% LDPE	Carbon dioxide (CO_2)	1.274	1.0	1.274x1.0 = 1.274
	Carbon monoxide (CO)	0.200	1.9	0.200x1.9 = 0.380
			Total	**= 1.654 kg CO_{2-eq}**
	Acidification		**(kg SO_{2-eq})**	
	Sulfur dioxide (SO_x)	0.062	1.0	0.062x1.0 = 0.062
	Nitrogen oxide (NO_x)	0.060	0.7	0.060x0.7 = 0.042
			Total	**= 0.104 kg SO_{2-eq}**
	Human toxicity		**(kg $toluene_{-eq}$)**	
	Carbon monoxide (CO)	0.200	0.27	0.200x0.27 = 0.054
	Sulfur dioxide (SO_x)	0.062	6.0	0.062x6.0 = 0.372
	Nitrogen oxide (NO_x)	0.060	4.3	0.060x4.3 = 0.258
			Total	**= 0.684 kg $toluene_{-eq}$**
No.VI	**Global warming**		**(kg CO_{2-eq})**	
100% rubber wood	Carbon dioxide (CO_2)	2.380	1.0	2.380x1.0 = 2.380
	Carbon monoxide (CO)	0.320	1.9	0.320x1.9 = 0.608
			Total	**= 2.988 kg CO_{2-eq}**

	Acidification		**(kg $SO_{2\text{-eq}}$)**	
	Sulfur dioxide (SO_x)	0.074	1.0	0.074x1.0 = 0.074
	Nitrogen oxide (NO_x)	0.120	0.7	0.120x0.7 = 0.084
			Total	**= 0.158 kg $SO_{2\text{-eq}}$**
	Human toxicity		**(kg toluene$_{\text{-eq}}$)**	
	Carbon monoxide (CO)	0.320	0.27	0.320x0.27 = 0.086
	Sulfur dioxide (SO_x)	0.074	6.0	0.074x6.0 = 0.444
	Nitrogen oxide (NO_x)	0.120	4.3	0.120x4.3 = 0.516
			Total	**= 1.046 kg toluene$_{\text{-eq}}$**
No.VII	**Global warming**		**(kg $CO_{2\text{-eq}}$)**	
100% palm oil bunch	Carbon dioxide (CO_2)	2.481	1.0	2.481x1.0 = 2.481
	Carbon monoxide (CO)	0.340	1.9	0.340x1.9 = 0.646
			Total	**= 3.127 kg $CO_{2\text{-eq}}$**
	Acidification		**(kg $SO_{2\text{-eq}}$)**	
	Sulfur dioxide (SO_x)	0.073	1.0	0.073x1.0 = 0.073
	Nitrogen oxide (NO_x)	0.090	0.7	0.090x0.7 = 0.063
			Total	**= 0.136 kg $SO_{2\text{-eq}}$**
	Human toxicity		**(kg toluene$_{\text{-eq}}$)**	
	Carbon monoxide (CO)	0.340	0.27	0.340x0.27 = 0.092
	Sulfur dioxide (SO_x)	0.073	6.0	0.073x6.0 = 0.438
	Nitrogen oxide (NO_x)	0.090	4.3	0.090x4.3 = 0.387
			Total	**= 0.917 kg toluene$_{\text{-eq}}$**

The analysis of the results reflected the GHG emissions and acidification of the RDF and CF production from municipal solid waste, rubber wood and palm oil bunch by means of life cycle assessment approach. The results obtained in this study are based on 1 kg of crude palm oil production. In case no.I it corresponded to GHG's emission of 3.858 kg $CO_{2\text{-eq}}$, 0.128 kg $SO_{2\text{-eq}}$ and 0.870 kg toluene$_{\text{-eq}}$ because it was produced from 100% paper. No.I result corresponds to no.VI and VII because all of them were produced from biomass. In case no.II-V there was shown as decreasing value of

GHG's emission from 3.213 to 1.654 kg $CO_{2\text{-eq}}$, acidification from 0.118 to 0.104 kg $SO_{2\text{-eq}}$ while the human toxicity was quite constant as it was derived from plastic bag and paper. In the case of CF, case no.VI and VII presented the GHG emissions higher than RDF due to it was produced from a suitable ratio of LDPE and paper.

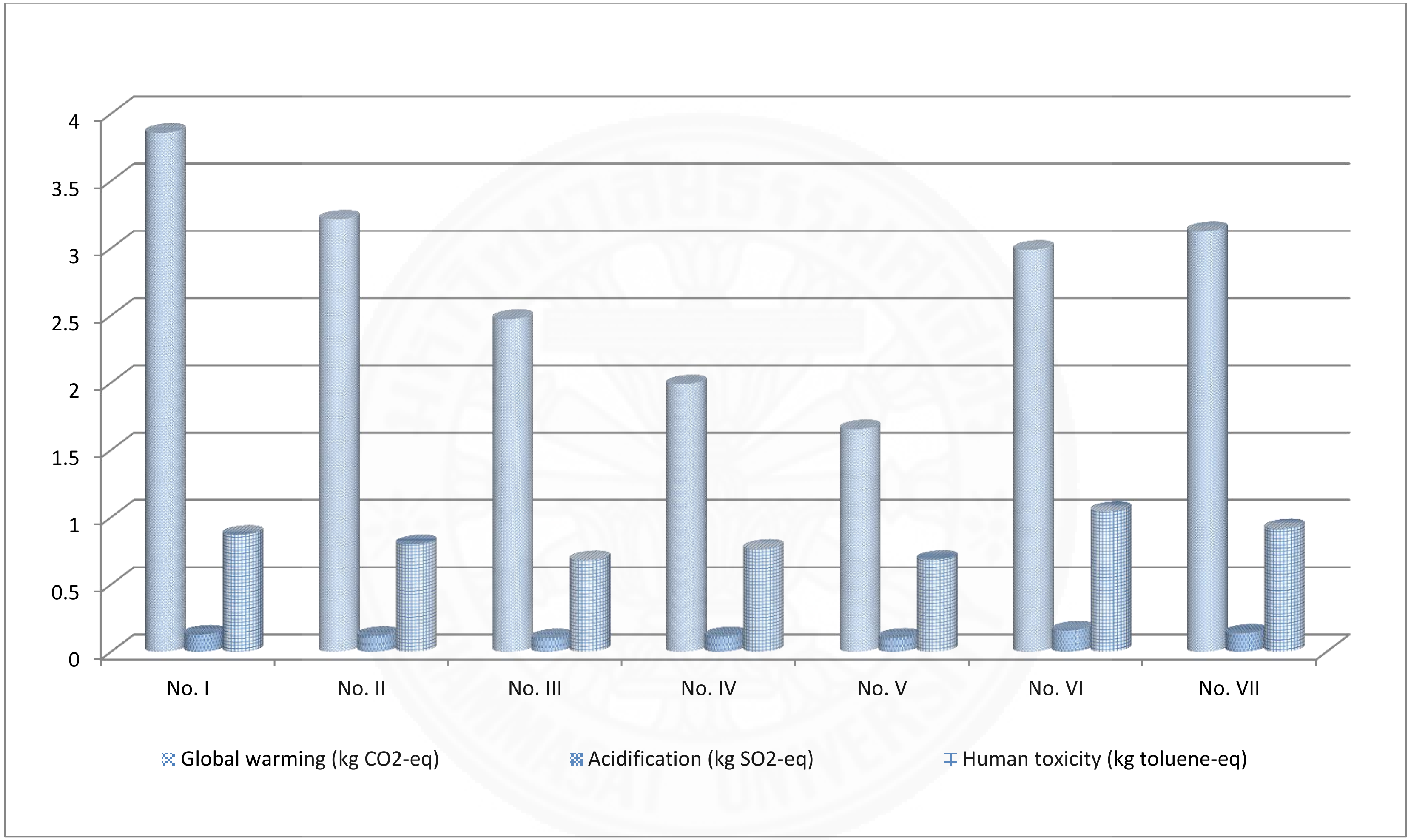


Fig. 4.3 Global warming, acidification and human toxicity of samples

The results of the LCA characterization analysis for each impact category of all RDF and CF are shown in Fig. 4.3. The results investigated for each impact category were as follows:

Global warming potential for a time horizon of 100 years (GWP100) is expressed in kg carbon dioxide/kg emission [120]. In case of No.I (100%paper: 0% LDPE) and No.VI (100% rubber wood), carbon dioxide was the main contributor to global warming. While the percentage of paper waste decreased in No. II-V it caused the emitted carbon dioxide to decrease correspondingly. These results can be referred to by Volker's research [121]. He studied specific carbon dioxide emissions from various fuels. He found that the specific carbon dioxide emissions of wood (0.39 kg CO_2/ kWh) were higher than fossil carbon (0.26kg CO_2/ kWh). Even natural fuels such as wood have high specific emissions, if it is not used sustainably. Hence, deforestation has an adverse impact on climate change. On the other hand, if the wood used is replaced the balance of nature is restored then the carbon dioxide is neutral because it binds as much carbon dioxide during growing as it emits during burning. There are many ways to prevent and/or reduce the CO_2 emissions from a combustion plant. For example, fuel switching [122, 123] - replacing part or all of the fuel with a lower carbon fuel, efficiency improvement [124, 125] - increasing the efficiency of the industrial plant, and carbon capture strategies [126, 127] – capturing the CO_2 in the fuel gas and storing it.

Human Toxicity Potentials (HTP) describe fate, exposure and effects of toxic substances for an infinite time horizon and are expressed as toluene equivalents/kg emission [120]. Sulfur dioxide and nitrogen oxide are the main concerns for HTP. Sample No.I has the highest human toxicity effect due to nitrogen oxide that was produced from pulp paper [128]. Samples No.II-V released the human toxicity less than No.I as it was mixed with LDPE. No.V is the best alternative in this impact category.

The acidification potential is defined as the number of H^+ ions produced per kg substance relative to SO_2 [120]. The major of acidifying pollutants are SO_2, NO_x.

CFs that are used in the palm oil industry have a bigger impact than RDF samples due to emissions released during the incineration of wood. Incineration had a greater impact on the environment due to air emissions, such as carbon dioxide, sulfur dioxide and nitrogen dioxides.

When the data is compared to the RDF and CF samples the impact categories are shown in Fig. 4.4. We can conclude that CF samples create a detrimental environmental impact while RDF samples create environmental benefits. As expected, RDF No.V is the best option, but No.IV also performs well.

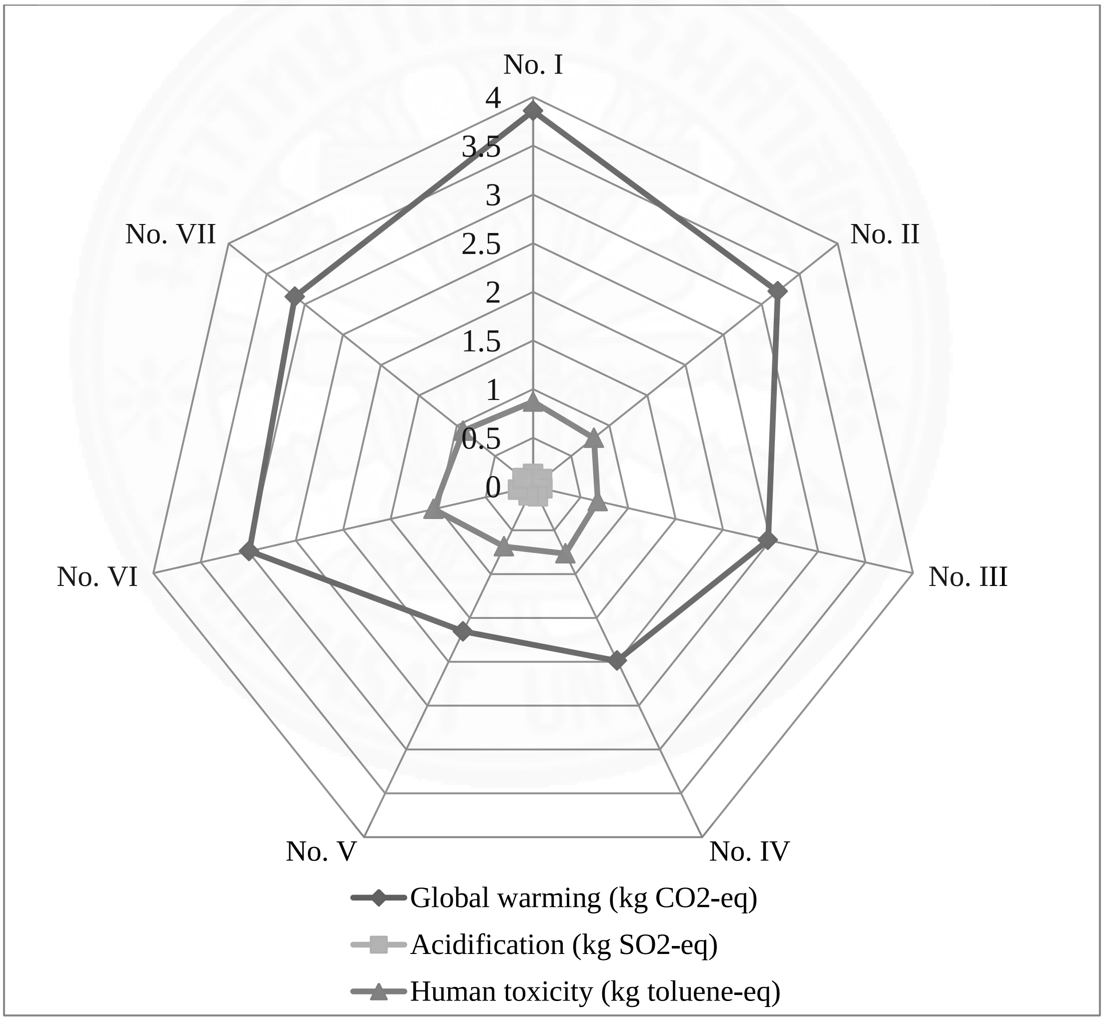


Fig. 4.4 Comparison of impact category

4.3.1.3 Comparison of GHG emission

The GHG emission results were calculated by IPCC method. Comparison of GHG emission is shown in Table 4.7.

Table 4.7 GHG emission in Lamae municipality

GHG emission, ton CO_2-eq/year	Actual situation	RDF situation
CH_4	205.588	110.32
CO_2	5.961	1.729
NO_2	0.717	0.154
Total	212.266	112.203
GHG reduction (%)		47.140

Table 4.7 shows the greenhouse gas emissions for actual situations (all compositions of generated solid waste were directly dumped to landfill) and in the case of the RDF instance (paper and LDPE were separated out of generated solid waste before dumping into landfill) in Lamae municipality. The data represents the reduced GHG emissions due to the composition of paper and LDPE that were removed from generated solid waste. . According to results, GHG emissions were reduced much more in case that RDF situation. The IPCC calculation of total GHG emissions of the RDF situation was 112.203 ton CO_2-eq/year (110.32 ton CO_2-eq for CH_4, 1.729 ton CO_2-eq for CO_2, 0.154 ton CO_2-eq for NO_2)., The IPCC calculation of the total GHG emissions from the actual situation was 212.266 ton CO_2-eq/year (205.588ton CO_2-eq for CH_4, 5.961ton CO_2-eq for CO_2, 0.717ton CO_2-eq for NO_2).The final analysis concluded that greenhouse gas emissions were reduced 47.14% for the RDF situation, s as a direct result of removing paper and LDPE waste at the landfill.

Chapter 5
Conclusions and Recommendations

The present study was an evaluation of RDF as alternative energy source for the palm oil industry as well as an investigation of its potential environmental impacts. The heating value of RDF produced from MSW (paper and LDPE plastic waste) is suitable for use as fuel in the palm oil industry, as indicated by its characteristics. The heating value of RDF products can be estimated accurately by a weighted average of the different heating values of raw components. TG analysis was carried out to study the combustion behavior of RDF samples of different ratios of paper and plastic (LDPE). This provides the information on temperature ranges for various reactions taking place during the combustion or pyrolysis of the fuel as alternative energy source for the palm oil industry. According to the potential environmental analysis in this study, the evidence concludes that the RDF production and use in the palm oil industry, instead of wood, offers environmental benefits in terms of lowering combustion gas emissions. The findings of this research provide key data points with regards to long term environmental impacts of MSW treatment that should be used as a basis for the long term MSW plan in Lamae Municipality in Chumphon, Thailand.

As seen in the characterization study, the majority of the municipal solid waste of Lamae consists of LDPE plastic waste (47%). With a detailed investigation on plastic waste, it is possible to benefit from the combustion process as an ideal disposal method. Within solid waste composition, LDPE waste is followed by recyclable waste such as paper/cardboard 24%, organic waste 15%, HDPE 5%, textile 4%, metal 3%, and glass 2%. Solid waste recycling activities should be improved by separation at the source also an aggressive communication/education plan needs to be developed to raise the public's consciousness with regards to their personal responsibility to recycling issue. Hazardous metals (for human health) such as chromium, copper and lead were not part of this study.

The study was conducted to determine the high heating value and the less impactful RDF production by using life cycle assessment (LCA). An analytical comparison between 5 cases of RDF production from municipal solid waste (paper and LDPE waste) and 2 cases of CF (rubber wood and palm oil bunch) were assessed by the internationally standardized method.

Heating values results of RDF showed that the heating value of RDF0:100 was found to be much higher (6,046 cal/g) in comparison to the other samples which is due to the main component of sample LDPE. Recently, Rubber wood has been used as fuel in the palm oil industry that presents the heating value amount 4,327 cal/g. So there were 3 ratios of RDF namely: RDF50:50, RDF25:75, and RDF0:100, that can replace CF in the palm oil industry because the heating value of those RDFs are higher than CF.

This study represented the GHG's emission in terms of kg CO_2-eq, acidification in terms of kg SO_2-eq and human toxicity in terms of kg toluene-eq/1 kg of crude palm oil. The amount from7 samples were used as fuel for producing 1 kg of crude palm oil. All of the RDF fuel showed that the environmental impacts were lower than that of CF. Comparing suitable ratio of RDF, the environmental impacts in terms of acidification and human toxicity were lowest while the GHGs emission was also low and ranked second. . From this analysis it was concluded that the highest environmental impact was derived from paper, which was one of the major material components. Meanwhile, cases no. III, IV, and V contributed to the lowest environmental impact due to soft plastic component. The highest environmental impacts arise from the RDF that was produced from 100% paper without LDPE in No.I and the most environmentally friendly RDF option is No.V, which produced from 100% of LDPE. No. V therefore is the best option with higher environmental benefits but may not be economically sustainable. The economic impacts should be identified for future work.

According to the characteristics and environmental impact of RDF and CF, the feasibility of the RDF can be established as alternative energy source for the palm oil industry. However the results of this study are specific to the waste composition and waste generation in Lamae Municipality in Chumphon, Thailand.

The results of the alternative energy source evaluation in other areas may result in different findings.

IPCC was applied to calculate greenhouse gas (GHG) emissions of MSW from Lamae Municipality. The data represented that GHG emissions can be reduced by 47.14% due to the composition of paper and LDPE that were removed from generated solid waste for using as RDF.

It is clear that no technology of WtE in Thailand can deal with all materials in environmentally sustainable way. The requirement for a reasonable and sustainable MSW management is one of the most common complaints, especially when there is a growing concern of the increasing rate of solid waste generation due to the extent of urbanization and varying income levels. A suitable approach in converting the MSW into energy should be an integrated approach that can deliver both environmental and economic sustainability. With increasing environmental concerns, WtE technologies have a potential to maximize the usable solid waste materials as well as to reduce GHG emissions. In Thailand, the compositions of solid waste (63%) are mainly organic waste, paper, plastic, glass, and metal. As a result, the solid waste in Thailand is very suitable for WtE with suitable technologies and reducing the disposal cost based on the amount of MSW generated, such as incineration, RDF, anaerobic digestion, pyrolysis, gasification, and landfill gas recovery.

The following conclusions are drawn from this study:

1. The composition of the solid waste generated in Thailand is dominated by (63%) of organic material. The purpose of anaerobic digesters is to utilize the biogas produced by decomposing refuse as a source of fuel for generators, which is a sustainable way of managing solid wastes. The composition of organic waste in this study site, Lamae municipality, was 15% by weight. So this site was suitable for preparing RDF from solid waste because organic waste that can be easily separated from burnable composition solid waste.

2. The second and third compositions of the solid waste generated in Thailand are dominated by (18 and 8%) of plastic and paper materials, respectively, which are suitable for incineration. The RDF, as a byproduct is suitable as well as for producing energy and ash for cement plants. According to the results from this research, Lamae municipality showed higher percentage in LDPE and paper waste composition than the normal composition of Thailand's solid waste.

3. Plastic material as can be converted to fuel gas by pyrolysis and gasification technologies. Currently there is pyrolysis of community solid wastes in Thailand: Warin Chamrap, Ubon Ratchathani Province, as well as the Nakhon Ratchasima City Municipality (NRCM). At this facility MSW has been mixed to convert to renewable energy such as RDF and biogas production. However, heating value of mixed RDF is varies greatly to due to the various compositions and is challenging at best to apply in industry. For this study the composition was a fixed percentage of LDPE and paper. Therefore, RDF production did show a stable heating value.

4. Source separation of the recyclable materials such as metals, glass and HDPE plastics by increasing awareness among the Lamae community is important to reduce solid waste treatment costs before producing RDF from solid waste for palm oil industry.

Recommendation:

- Solid waste recycling activities must be improved by separation of materials at source and also an aggressive communication/education plan must be developed and widely decimated throughout the country at all levels in order to raise the public consciousness of the serious solid waste issue now present in Thailand for the good of the country.

- In conclusion regarding RDF. It should be incinerated or sold to industries. An additional study is highly recommended to establish the financial viability.

- The incineration plant could operate the for palm oil industry due to its local industry. For another area, it should be investigated for each local industry.

- Future research should be carried out on RDF production and its co-combustion to determine if it is economically favorable compared to direct utilization of RDF in a dedicated plant on a small-scale; vice-versa for large-scale ones, where the economies of scale of a large WtE plant allow for treatment cost to be significantly lower than the cost for RDF production, thus requiring the RDF to be paid for by the final utilization.

Will the use of RDF solve all of Thailand's energy and environmental issues? The answer is no. However; by making this small change in the Palm Oil Industry by moving forward with the transition to Refuse Derived Fuel (RDF) as opposed to the use of Conventional fuel (CF) it will have a tremendous impact on solving Thailand's current waste disposal, energy security, and environmental issues moving The Kingdom of Thailand to take a leadership position amongst the other developing countries faced with the same issues. Is this the answer for every Municipality in Thailand? The answer is maybe. Further research is highly recommended to determine the economic feasibility and economies of scale that could be brought to bear to increase RDF use in the alternative energy market through the development of a standardize model and processes. Currently the Southern region of Thailand where the palm oil industry is thriving, the move to RDF does solve their current and future problems with regards to solid waste disposal, alternative energy reuse, and environmental issues. It is therefore highly recommended that Thailand adopts a policy on the use of RDF for the palm oil industry. Because even the smallest step to reduce solid waste, conserve energy resources and the environment is a giant leap forward for the betterment of the people who call the Kingdom of Thailand home.

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Appendix

Raw data

FM

ภาควิชาเคมีเทคนิค คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย	เอกสาร: ScFM-CT-06-002-A	โทร 0-2218-7523-5 โทรสาร 0-2255-5831
	แบบรายงานผลการวิเคราะห์และทดสอบ	ลำดับการแก้ไข 0 หน้าที่ 1

วันที่ 18 กุมภาพันธ์ 2557

รายงานผลการวิเคราะห์และทดสอบ

เรื่อง รายงานผลการวิเคราะห์ Heating Value

ผู้ส่งตัวอย่าง : สถาบันเทคโนโลยีนานาชาติสิรินธร ม.ธรรมศาสตร์ ศูนย์รังสิต
ใบเสนอราคาเลขที่ : CT031/57
หน่วยงาน : เทคโนโลยีนานาชาติสิรินธร ม.ธรรมศาสตร์ ศูนย์รังสิต
ชนิดตัวอย่าง : เชื้อเพลิงแข็งจากขยะ
วันที่รับตัวอย่าง : 31 มกราคม 2557
เครื่องมือวิเคราะห์/ทดสอบ : 1. BOMB CALORIMETER MODEL 6200 ยี่ห้อ PARR
สภาวะการวิเคราะห์ : อ้างอิงตามมาตรฐาน ASTM 5865 (Heating Value)
มาตรฐานอ้างอิงสำหรับการทดสอบ : อ้างอิงตามมาตรฐาน ASTM 5865 (Heating Value)

ผลการวิเคราะห์และทดสอบ

ชื่อตัวอย่าง	ค่า HEATING VALUE (cal /g)
No.1	3320.3 0 $\pm$ 52.01
No.2	3964.36 $\pm$ 19.95
No.3	4787.58 $\pm$ 48.70
No.4	5419.14 $\pm$ 22.54
No.5	6046.28 $\pm$ 28.43

รับรองผลการวิเคราะห์ถูกต้อง

(นางสาวอภิญญา ลาญาติ)
นักวิทยาศาสตร์
วันที่ 18 กุมภาพันธ์ 2557

(ผศ.ดร.ชวลิต งามจรัสศรีวิชัย)
หัวหน้าเครื่องมือวิเคราะห์
วันที่ 18 กุมภาพันธ์ 2557

หมายเหตุ : 1. ผลการวิเคราะห์ในรายงานฉบับนี้ใช้อ้างอิงสำหรับตัวอย่างที่ส่งมาเท่านั้น
2. ห้ามทำสำเนารายงานฉบับนี้เพียงบางส่วนโดยไม่ได้รับอนุญาตอย่างเป็นทางการ

เอกสาร	ผู้จัดเก็บ	วิธีการจัดเก็บ	สถานที่เก็บ/แฟ้มที่เก็บ	ระยะเวลาที่เก็บ	ผู้อนุมัติให้ทำลาย	วิธีการทำลาย	ผู้มีหน้าที่ทำลาย
ScFM-CT-06-002-A	เจ้าหน้าที่ผู้วิเคราะห์	เข้าแฟ้ม	แฟ้มบริการวิชาการของเจ้าหน้าที่ผู้วิเคราะห์	1 ปี	QMR	ทิ้ง	เจ้าหน้าที่ผู้วิเคราะห์

ภาควิชาเคมีเทคนิค คณะวิทยาศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย	เอกสาร: ScFM-CT-06-002-A	โทร 0-2218-7523-5 โทรสาร 0-2255-5831
	แบบรายงานผลการวิเคราะห์และทดสอบ	ลำดับการแก้ไข 0 หน้าที่ 1

วันที่ 26 มิถุนายน 2557

รายงานผลการวิเคราะห์และทดสอบ

เรื่อง รายงานผลการวิเคราะห์ Heating Value

ผู้ส่งตัวอย่าง : คุณศิริพร บุญพา

ใบเสนอราคาเลขที่ : CT045/57

หน่วยงาน : สถาบันเทคโนโลยีนานาชาติสิรินธร (SIIT) มหาวิทยาลัยธรรมศาสตร์ ศูนย์รังสิต

ชนิดตัวอย่าง : Bio-mass

วันที่รับตัวอย่าง : 4 มิถุนายน 2557

เครื่องมือวิเคราะห์/ทดสอบ : 1. BOMB CALORIMETER MODEL AC500 ยี่ห้อ LECO

สภาวะการวิเคราะห์ : อ้างอิงตามมาตรฐาน ASTM 5865 (Heating Value)

มาตรฐานอ้างอิงสำหรับการทดสอบ : อ้างอิงตามมาตรฐาน ASTM 5865 (Heating Value)

ผลการวิเคราะห์และทดสอบ

ชื่อตัวอย่าง	ค่า HEATING VALUE (cal /g)
1.	4327.50±92.76
2.	3978.17±49.09
3.	3831.145±13.58
4.	4313.87±57.39

รับรองผลการวิเคราะห์ถูกต้อง

(นางสาวคุนัญญา ทัดเทียมพร)
นักวิทยาศาสตร์
วันที่ 27 มิถุนายน 2557

(ผศ.ดร.ศิริลักษณ์ พุ่มประดับ)
หัวหน้าห้องปฏิบัติการ Physico Lab
วันที่ 27 มิถุนายน 2557

หมายเหตุ : 1. ผลการวิเคราะห์ในรายงานฉบับนี้ใช้อ้างอิงสำหรับตัวอย่างที่ส่งมาเท่านั้น
2. ห้ามทำสำเนารายงานฉบับนี้เพียงบางส่วนโดยไม่ได้รับอนุญาตอย่างเป็นทางการ

เอกสาร	ผู้จัดเก็บ	วิธีการจัดเก็บ	สถานที่เก็บ/แฟ้มที่เก็บ	ระยะเวลาที่เก็บ	ผู้อนุมัติให้ทำลาย	วิธีการทำลาย	ผู้มีหน้าที่ทำลาย
ScFM-CT-06-002-A	เจ้าหน้าที่ผู้วิเคราะห์	เข้าแฟ้ม	แฟ้มบริการวิชาการของเจ้าหน้าที่ผู้วิเคราะห์	1 ปี	QMR	ทิ้ง	เจ้าหน้าที่ผู้วิเคราะห์

Curve Name:
No.1_RDF.Pa, 03.02.2014 09:58:20
Performed 03.02.2014 09:58:20
Curve Values:

Index	t [s]	Ts [°C]	Tr [°C]	Value [mg]
0	0	34.4665	25	7.10506
28	28	40.4389	34.3333	7.2182
56	56	48.7978	43.6667	7.21309
84	84	57.1055	53	7.19385
112	112	65.4348	62.3333	7.15964
140	140	73.7978	71.6667	7.11343
168	168	82.2645	81	7.06078
196	196	90.8222	90.3333	7.01061
224	224	99.4762	99.6667	6.96904
252	252	108.245	109	6.93783
280	280	117.078	118.333	6.91662
308	308	126.005	127.667	6.90387
336	336	134.993	137	6.89733
364	364	144.039	146.333	6.89501
392	392	153.122	155.667	6.895
420	420	162.26	165	6.89596
448	448	171.441	174.333	6.89697
476	476	180.663	183.667	6.898
504	504	189.947	193	6.90051
532	532	199.243	202.333	6.90199
560	560	208.551	211.667	6.903
588	588	217.901	221	6.90277
616	616	227.278	230.333	6.90114
644	644	236.666	239.667	6.89757
672	672	246.078	249	6.89001
700	700	255.53	258.333	6.87467
728	728	265.063	267.667	6.85088
756	756	274.644	277	6.81233
784	784	284.291	286.333	6.74957
812	812	294.028	295.667	6.64676
840	840	303.913	305	6.47593
868	868	313.97	314.333	6.20288
896	896	324.179	323.667	5.80164
924	924	334.79	333	5.19678
952	952	345.906	342.333	4.21166
980	980	356.775	351.667	3.36125
1008	1008	366.865	361	3.03225
1036	1036	376.168	370.333	2.87203
1064	1064	384.81	379.667	2.74771
1092	1092	393.324	389	2.63909
1120	1120	402.026	398.333	2.53802
1148	1148	410.989	407.667	2.43741
1176	1176	420.209	417	2.33187
1204	1204	429.59	426.333	2.21865
1232	1232	439.192	435.667	2.09116
1260	1260	449.121	445	1.93684
1288	1288	459.09	454.333	1.74878
1316	1316	468.508	463.667	1.58071
1344	1344	477.117	473	1.44805
1372	1372	484.99	482.333	1.38455
1400	1400	493.058	491.667	1.36965
1428	1428	501.721	501	1.37078
1456	1456	510.735	510.333	1.37281
1484	1484	519.917	519.667	1.37488
1512	1512	529.152	529	1.37716
1540	1540	538.426	538.333	1.3792
1568	1568	547.707	547.667	1.38093
1596	1596	556.997	557	1.38204

Curve Name:
No.2_RDF.Pa, 03.02.2014 11:32:10
Curve Values:

Index	t [s]	Ts [ºC]	Tr [ºC]	Value [mg]
0	0	34.7543	25	10.595
28	28	40.8445	34.3333	10.7279
56	56	49.2692	43.6667	10.7214
84	84	57.6539	53	10.6977
112	112	66.0104	62.3333	10.654
140	140	74.4089	71.6667	10.5915
168	168	82.864	81	10.5152
196	196	91.4237	90.3333	10.4368
224	224	100.079	99.6667	10.3668
252	252	108.874	109	10.3118
280	280	117.75	118.333	10.2731
308	308	126.703	127.667	10.247
336	336	135.729	137	10.2333
364	364	144.823	146.333	10.228
392	392	153.952	155.667	10.227
420	420	163.114	165	10.2281
448	448	172.311	174.333	10.2306
476	476	181.539	183.667	10.2325
504	504	190.814	193	10.2341
532	532	200.118	202.333	10.2355
560	560	209.44	211.667	10.236
588	588	218.802	221	10.2341
616	616	228.194	230.333	10.2298
644	644	237.617	239.667	10.221
672	672	247.07	249	10.2055
700	700	256.561	258.333	10.178
728	728	266.107	267.667	10.1307
756	756	275.725	277	10.0503
784	784	285.435	286.333	9.9129
812	812	295.326	295.667	9.67498
840	840	305.506	305	9.26964
868	868	316.166	314.333	8.60907
896	896	327.452	323.667	7.3784
924	924	339.642	333	5.665
952	952	352.36	342.333	4.71724
980	980	362.18	351.667	4.35182
1008	1008	369.358	361	4.15669
1036	1036	376.657	370.333	4.01688
1064	1064	384.668	379.667	3.89241
1092	1092	393.305	389	3.76828
1120	1120	402.371	398.333	3.63736
1148	1148	411.738	407.667	3.49334
1176	1176	421.466	417	3.32512
1204	1204	434.048	426.333	3.06632
1232	1232	442.742	435.667	2.66656
1260	1260	450.987	445	2.49214
1288	1288	459.293	454.333	2.34598
1316	1316	467.317	463.667	2.24931
1344	1344	475.348	473	2.20536
1372	1372	483.695	482.333	2.19149
1400	1400	492.416	491.667	2.19192
1428	1428	501.476	501	2.19432
1456	1456	510.679	510.333	2.19714
1484	1484	519.944	519.667	2.19989
1512	1512	529.215	529	2.20247
1540	1540	538.5	538.333	2.20481
1568	1568	547.776	547.667	2.20692
1596	1596	557.07	557	2.20895
1624	1624	566.347	566.333	2.21

Curve Name:
No.3_RDF_3:1, 03.02.2014 13:06:00
Curve Values:

Index	t [s]	Ts [°C]	Tr [°C]	Value [mg]
0	0	34.6982	25	10.4202
28	28	41.0461	34.3333	10.5533
56	56	49.4705	43.6667	10.5485
84	84	57.8258	53	10.5287
112	112	66.2031	62.3333	10.4953
140	140	74.6408	71.6667	10.453
168	168	83.1138	81	10.4089
196	196	91.7033	90.3333	10.37
224	224	100.412	99.6667	10.34
252	252	109.181	109	10.3191
280	280	118.027	118.333	10.3061
308	308	126.953	127.667	10.3004
336	336	135.951	137	10.2989
364	364	144.981	146.333	10.3
392	392	154.084	155.667	10.3025
420	420	163.221	165	10.3048
448	448	172.406	174.333	10.3069
476	476	181.628	183.667	10.3086
504	504	190.895	193	10.3097
532	532	200.169	202.333	10.3091
560	560	209.485	211.667	10.3065
588	588	218.845	221	10.301
616	616	228.228	230.333	10.2898
644	644	237.694	239.667	10.269
672	672	247.127	249	10.2052
700	700	256.609	258.333	10.0289
728	728	266.213	267.667	9.67936
756	756	275.994	277	9.02727
784	784	285.972	286.333	7.90533
812	812	296.248	295.667	6.38762
840	840	306.957	305	5.27469
868	868	317.918	314.333	4.71254
896	896	327.81	323.667	4.47383
924	924	336.926	333	4.32527
952	952	345.825	342.333	4.21105
980	980	354.749	351.667	4.11179
1008	1008	363.781	361	4.01825
1036	1036	372.939	370.333	3.92465
1064	1064	382.217	379.667	3.82731
1092	1092	391.574	389	3.72434
1120	1120	401.021	398.333	3.61271
1148	1148	410.623	407.667	3.48604
1176	1176	420.435	417	3.33422
1204	1204	432.63	426.333	2.96217
1232	1232	442.182	435.667	2.6684
1260	1260	451.482	445	2.46058
1288	1288	460.775	454.333	2.20797
1316	1316	470.091	463.667	1.94978
1344	1344	478.473	473	1.84934
1372	1372	487.252	482.333	1.69324
1400	1400	496.214	491.667	1.58667
1428	1428	503.933	501	1.4812
1456	1456	512.333	510.333	1.44572
1484	1484	521.091	519.667	1.41723
1512	1512	529.996	529	1.39827
1540	1540	538.982	538.333	1.38805
1568	1568	548.067	547.667	1.38172
1596	1596	557.237	557	1.37727
1624	1624	566.426	566.333	1.37406

Curve Name:
No4_RDF 3:1, 06.02.2014 09:22:41
Performed 06.02.2014 09:22:40
Curve Values:

Index	t [s]	Ts [§C]	Tr [§C]	Value [mg]
0	0	34.237	25	6.90581
28	28	40.3375	34.3333	7.03121
56	56	48.7835	43.6667	7.01732
84	84	57.1684	53	6.98759
112	112	65.5619	62.3333	6.94456
140	140	74.0216	71.6667	6.89491
168	168	82.5664	81	6.84634
196	196	91.1866	90.3333	6.80565
224	224	99.9144	99.6667	6.77682
252	252	108.723	109	6.75768
280	280	117.594	118.333	6.74549
308	308	126.529	127.667	6.73999
336	336	135.529	137	6.73798
364	364	144.561	146.333	6.73828
392	392	153.653	155.667	6.739
420	420	162.809	165	6.7409
448	448	172.001	174.333	6.74222
476	476	181.246	183.667	6.74283
504	504	190.516	193	6.74248
532	532	199.812	202.333	6.74076
560	560	209.146	211.667	6.73803
588	588	218.51	221	6.7341
616	616	227.916	230.333	6.7256
644	644	237.365	239.667	6.71074
672	672	246.807	249	6.67669
700	700	256.296	258.333	6.59713
728	728	265.857	267.667	6.4295
756	756	275.542	277	6.09983
784	784	285.428	286.333	5.48225
812	812	295.588	295.667	4.34735
840	840	306.72	305	3.59601
868	868	317.419	314.333	3.30227
896	896	327.246	323.667	3.12061
924	924	336.445	333	2.98818
952	952	345.389	342.333	2.88317
980	980	354.288	351.667	2.7963
1008	1008	363.239	361	2.7203
1036	1036	372.314	370.333	2.64902
1064	1064	381.511	379.667	2.57861
1092	1092	390.815	389	2.50598
1120	1120	400.244	398.333	2.4275
1148	1148	409.823	407.667	2.33923
1176	1176	419.567	417	2.23361
1204	1204	429.604	426.333	2.09953
1232	1232	439.858	435.667	1.91998
1260	1260	449.718	445	1.72739
1288	1288	458.604	454.333	1.58299
1316	1316	467.052	463.667	1.48573
1344	1344	475.716	473	1.4211
1372	1372	486.796	482.333	1.20908
1400	1400	494.029	491.667	1.17955
1428	1428	502.488	501	1.16406
1456	1456	511.447	510.333	1.14568
1484	1484	520.475	519.667	1.13119
1512	1512	529.585	529	1.12214
1540	1540	538.741	538.333	1.11608
1568	1568	547.935	547.667	1.11202
1596	1596	557.159	557	1.10952

Curve Name:
No.5_RDF 1:1, 04.02.2014 14:27:16
Curve Values:

Index	t [s]	Ts [°C]	Tr [°C]	Value [mg]
0	0	34.5602	25	10.7149
28	28	40.5725	34.3333	10.8306
56	56	48.917	43.6667	10.8295
84	84	57.2116	53	10.8162
112	112	65.5448	62.3333	10.793
140	140	73.9347	71.6667	10.7624
168	168	82.4195	81	10.7319
196	196	90.9975	90.3333	10.7053
224	224	99.6882	99.6667	10.685
252	252	108.436	109	10.6712
280	280	117.265	118.333	10.6626
308	308	126.138	127.667	10.6583
336	336	135.098	137	10.6542
364	364	144.238	146.333	10.628
392	392	153.469	155.667	10.6097
420	420	162.735	165	10.6028
448	448	172.036	174.333	10.6009
476	476	181.33	183.667	10.6
504	504	190.645	193	10.599
532	532	199.976	202.333	10.5968
560	560	209.342	211.667	10.5931
588	588	218.72	221	10.587
616	616	228.153	230.333	10.5767
644	644	237.642	239.667	10.5587
672	672	247.044	249	10.4872
700	700	256.544	258.333	10.2834
728	728	266.165	267.667	9.90996
756	756	275.947	277	9.25416
784	784	285.916	286.333	8.17841
812	812	296.113	295.667	6.87461
840	840	306.207	305	5.62659
868	868	316.57	314.333	4.85415
896	896	326.673	323.667	4.47952
924	924	336.188	333	4.285
952	952	345.37	342.333	4.15869
980	980	354.469	351.667	4.06503
1008	1008	363.587	361	3.98463
1036	1036	372.784	370.333	3.90869
1064	1064	382.088	379.667	3.83055
1092	1092	391.48	389	3.74743
1120	1120	400.948	398.333	3.65692
1148	1148	410.494	407.667	3.55724
1176	1176	420.159	417	3.44353
1204	1204	430.337	426.333	3.29709
1232	1232	441.822	435.667	3.013
1260	1260	451.888	445	2.74526
1288	1288	461.097	454.333	2.52773
1316	1316	469.966	463.667	2.35114
1344	1344	478.925	473	2.19695
1372	1372	488.854	482.333	2.03239
1400	1400	500.318	491.667	1.73929
1428	1428	511.209	501	1.13493
1456	1456	515.407	510.333	1.113
1484	1484	522.66	519.667	1.08301
1512	1512	530.832	529	1.06008
1540	1540	539.488	538.333	1.04706
1568	1568	548.415	547.667	1.03765
1596	1596	557.492	557	1.03097
1624	1624	566.619	566.333	1.02633

Curve Name:
No6_RDF 1:1, 05.02.2014 09:20:30
Curve Values:

Index	t [s]	Ts [§C]	Tr [§C]	Value [mg]
0	0	34.0243	25	10.2342
28	28	40.1296	34.3333	10.3646
56	56	48.5855	43.6667	10.3594
84	84	56.9938	53	10.3398
112	112	65.3934	62.3333	10.3096
140	140	73.8543	71.6667	10.2707
168	168	82.381	81	10.2296
196	196	90.9986	90.3333	10.194
224	224	99.7121	99.6667	10.1652
252	252	108.517	109	10.145
280	280	117.379	118.333	10.1328
308	308	126.327	127.667	10.1279
336	336	135.33	137	10.125
364	364	144.375	146.333	10.1263
392	392	153.485	155.667	10.1287
420	420	162.653	165	10.1316
448	448	171.841	174.333	10.134
476	476	181.091	183.667	10.1363
504	504	190.351	193	10.138
532	532	199.68	202.333	10.139
560	560	209.017	211.667	10.1382
588	588	218.398	221	10.135
616	616	227.821	230.333	10.1283
644	644	237.307	239.667	10.1119
672	672	246.731	249	10.0385
700	700	256.238	258.333	9.83732
728	728	265.871	267.667	9.45867
756	756	275.661	277	8.79971
784	784	285.587	286.333	7.75685
812	812	295.787	295.667	6.51244
840	840	305.947	305	5.40823
868	868	316.427	314.333	4.69931
896	896	326.723	323.667	4.33954
924	924	336.385	333	4.14544
952	952	345.608	342.333	4.01565
980	980	354.687	351.667	3.91416
1008	1008	363.783	361	3.82503
1036	1036	372.942	370.333	3.74016
1064	1064	382.22	379.667	3.6527
1092	1092	391.594	389	3.56009
1120	1120	401.039	398.333	3.46083
1148	1148	410.577	407.667	3.35118
1176	1176	420.269	417	3.22665
1204	1204	430.423	426.333	3.05822
1232	1232	440.973	435.667	2.82922
1260	1260	451.858	445	2.53475
1288	1288	461.203	454.333	2.2921
1316	1316	470.131	463.667	2.10192
1344	1344	479.614	473	1.90904
1372	1372	489.073	482.333	1.654
1400	1400	498.001	491.667	1.4782
1428	1428	510.176	501	1.32067
1456	1456	514.828	510.333	1.10234
1484	1484	522.228	519.667	1.07819
1512	1512	530.545	529	1.05641
1540	1540	539.245	538.333	1.04321
1568	1568	548.204	547.667	1.03452
1596	1596	557.282	557	1.02834
1624	1624	566.438	566.333	1.02368

Curve Name:
No7_RDF 1:3, 05.02.2014 10:54:41
Curve Values:

Index	t [s]	Ts [§C]	Tr [§C]	Value [mg]
0	0	34.6504	25	9.78895
28	28	40.6933	34.3333	9.92427
56	56	49.0958	43.6667	9.9261
84	84	57.4876	53	9.91855
112	112	65.8893	62.3333	9.90555
140	140	74.3705	71.6667	9.89363
168	168	82.9124	81	9.88232
196	196	91.5419	90.3333	9.87498
224	224	100.242	99.6667	9.87152
252	252	109.007	109	9.87002
280	280	117.838	118.333	9.87044
308	308	126.724	127.667	9.87295
336	336	135.709	137	9.87609
364	364	144.728	146.333	9.87933
392	392	153.807	155.667	9.88244
420	420	162.95	165	9.88533
448	448	172.14	174.333	9.88769
476	476	181.368	183.667	9.889
504	504	190.62	193	9.89
532	532	199.934	202.333	9.88965
560	560	209.255	211.667	9.88818
588	588	218.608	221	9.88484
616	616	228.015	230.333	9.87828
644	644	237.505	239.667	9.86465
672	672	246.903	249	9.79696
700	700	256.4	258.333	9.61382
728	728	266.03	267.667	9.30625
756	756	275.785	277	8.79569
784	784	285.659	286.333	7.98264
812	812	295.623	295.667	6.94692
840	840	305.526	305	5.57876
868	868	315.298	314.333	4.5504
896	896	325.124	323.667	4.05034
924	924	334.781	333	3.82163
952	952	344.185	342.333	3.69721
980	980	353.478	351.667	3.61931
1008	1008	362.745	361	3.56122
1036	1036	372.047	370.333	3.50953
1064	1064	381.388	379.667	3.45768
1092	1092	390.775	389	3.40178
1120	1120	400.213	398.333	3.34221
1148	1148	409.692	407.667	3.27733
1176	1176	419.207	417	3.20537
1204	1204	429.024	426.333	3.10789
1232	1232	439.325	435.667	2.94041
1260	1260	450.07	445	2.71999
1288	1288	460.305	454.333	2.4825
1316	1316	469.587	463.667	2.29405
1344	1344	478.636	473	2.13621
1372	1372	488.017	482.333	1.9836
1400	1400	498.226	491.667	1.7724
1428	1428	509.796	501	1.44459
1456	1456	518.828	510.333	1.164
1484	1484	527.185	519.667	0.975156
1512	1512	534.081	529	0.840143
1540	1540	541.07	538.333	0.79861
1568	1568	549.308	547.667	0.780563
1596	1596	558.074	557	0.76575
1624	1624	567.059	566.333	0.754188

Curve Name:
No8_RDF 1:3, 05.02.2014 12:28:58
Curve Values:

Index	t [s]	Ts [°C]	Tr [°C]	Value [mg]
0	0	34.6399	25	9.54511
28	28	40.7537	34.3333	9.67944
56	56	49.1692	43.6667	9.67865
84	84	57.53	53	9.66802
112	112	65.9487	62.3333	9.65232
140	140	74.4227	71.6667	9.63383
168	168	82.9657	81	9.6181
196	196	91.5953	90.3333	9.60522
224	224	100.284	99.6667	9.59779
252	252	109.046	109	9.59319
280	280	117.883	118.333	9.59142
308	308	126.788	127.667	9.59263
336	336	135.746	137	9.59569
364	364	144.766	146.333	9.59891
392	392	153.844	155.667	9.602
420	420	162.976	165	9.60381
448	448	172.161	174.333	9.605
476	476	181.389	183.667	9.606
504	504	190.643	193	9.606
532	532	199.945	202.333	9.605
560	560	209.279	211.667	9.60305
588	588	218.647	221	9.59933
616	616	228.069	230.333	9.59157
644	644	237.541	239.667	9.57144
672	672	246.929	249	9.48008
700	700	256.425	258.333	9.28796
728	728	266.025	267.667	8.96378
756	756	275.781	277	8.41785
784	784	285.694	286.333	7.54201
812	812	295.683	295.667	6.46018
840	840	305.548	305	5.20916
868	868	315.502	314.333	4.36194
896	896	325.449	323.667	3.97602
924	924	335.056	333	3.79908
952	952	344.377	342.333	3.69442
980	980	353.608	351.667	3.62095
1008	1008	362.822	361	3.55907
1036	1036	372.087	370.333	3.5013
1064	1064	381.418	379.667	3.44267
1092	1092	390.808	389	3.37921
1120	1120	400.253	398.333	3.31078
1148	1148	409.758	407.667	3.23556
1176	1176	419.33	417	3.15218
1204	1204	429.239	426.333	3.03918
1232	1232	439.503	435.667	2.85581
1260	1260	450.374	445	2.61641
1288	1288	460.534	454.333	2.37374
1316	1316	469.778	463.667	2.18009
1344	1344	478.952	473	2.0082
1372	1372	489.352	482.333	1.79286
1400	1400	500.664	491.667	1.42
1428	1428	507.735	501	1.19667
1456	1456	515.546	510.333	1.09322
1484	1484	522.909	519.667	1.02272
1512	1512	531.325	529	0.977383
1540	1540	540.398	538.333	0.904956
1568	1568	548.882	547.667	0.891595
1596	1596	557.821	557	0.878096
1624	1624	566.9	566.333	0.866063

Curve Name:
No9_RDF.Pl, 05.02.2014 14:07:15
Curve Values:

Index	t [s]	Ts [ºC]	Tr [ºC]	Value [mg]
0	0	34.6904	25	10.4581
28	28	40.7591	34.3333	10.5972
56	56	49.1922	43.6667	10.6084
84	84	57.6061	53	10.6164
112	112	66.0208	62.3333	10.6231
140	140	74.4837	71.6667	10.6299
168	168	83.0294	81	10.6358
196	196	91.6441	90.3333	10.6418
224	224	100.311	99.6667	10.647
252	252	109.052	109	10.652
280	280	117.853	118.333	10.6567
308	308	126.728	127.667	10.6608
336	336	135.681	137	10.6648
364	364	144.692	146.333	10.6685
392	392	153.764	155.667	10.6719
420	420	162.875	165	10.6746
448	448	172.055	174.333	10.6769
476	476	181.275	183.667	10.6778
504	504	190.517	193	10.678
532	532	199.8	202.333	10.678
560	560	209.114	211.667	10.6768
588	588	218.484	221	10.6734
616	616	227.882	230.333	10.6683
644	644	237.353	239.667	10.6553
672	672	246.748	249	10.6048
700	700	256.25	258.333	10.501
728	728	265.811	267.667	10.3334
756	756	275.541	277	10.023
784	784	285.364	286.333	9.41573
812	812	295.253	295.667	8.36256
840	840	305.449	305	6.75105
868	868	315.194	314.333	5.08999
896	896	324.503	323.667	4.19455
924	924	333.918	333	3.84478
952	952	343.288	342.333	3.68946
980	980	352.625	351.667	3.61205
1008	1008	361.948	361	3.57006
1036	1036	371.288	370.333	3.54149
1064	1064	380.625	379.667	3.51652
1092	1092	389.989	389	3.48998
1120	1120	399.365	398.333	3.46099
1148	1148	408.769	407.667	3.4296
1176	1176	418.192	417	3.39553
1204	1204	427.654	426.333	3.35632
1232	1232	437.595	435.667	3.26659
1260	1260	447.539	445	3.11655
1288	1288	457.336	454.333	2.96135
1316	1316	467.072	463.667	2.80504
1344	1344	476.671	473	2.65427
1372	1372	486.28	482.333	2.50234
1400	1400	495.969	491.667	2.35532
1428	1428	505.978	501	2.18079
1456	1456	517.002	510.333	1.929
1484	1484	528.356	519.667	1.55609
1512	1512	538.632	529	1.21074
1540	1540	548.036	538.333	0.864438
1568	1568	556.513	547.667	0.598679
1596	1596	562.859	557	0.444682
1624	1624	569.8	566.333	0.379778

Curve Name:
No10_RDF.Pl, 05.02.2014 15:41:27
Curve Values:

Index	t [s]	Ts [§C]	Tr [§C]	Value [mg]
0	0	34.7056	25	10.2972
28	28	40.7743	34.3333	10.4364
56	56	49.1632	43.6667	10.4471
84	84	57.5633	53	10.4553
112	112	65.9576	62.3333	10.4628
140	140	74.4172	71.6667	10.4691
168	168	82.9612	81	10.4751
196	196	91.5524	90.3333	10.4808
224	224	100.225	99.6667	10.486
252	252	108.945	109	10.491
280	280	117.752	118.333	10.4957
308	308	126.633	127.667	10.4997
336	336	135.579	137	10.5037
364	364	144.582	146.333	10.507
392	392	153.654	155.667	10.5099
420	420	162.791	165	10.512
448	448	171.956	174.333	10.5139
476	476	181.174	183.667	10.5143
504	504	190.427	193	10.517
532	532	199.711	202.333	10.5164
560	560	209.025	211.667	10.5133
588	588	218.378	221	10.5093
616	616	227.775	230.333	10.5035
644	644	237.221	239.667	10.4889
672	672	246.635	249	10.441
700	700	256.125	258.333	10.3368
728	728	265.702	267.667	10.1708
756	756	275.408	277	9.866
784	784	285.22	286.333	9.27153
812	812	295.093	295.667	8.24457
840	840	305.285	305	6.65354
868	868	314.956	314.333	5.02018
896	896	324.348	323.667	4.13371
924	924	333.809	333	3.77609
952	952	343.19	342.333	3.6243
980	980	352.536	351.667	3.54952
1008	1008	361.873	361	3.50943
1036	1036	371.188	370.333	3.48292
1064	1064	380.526	379.667	3.45778
1092	1092	389.895	389	3.43139
1120	1120	399.271	398.333	3.4035
1148	1148	408.684	407.667	3.37311
1176	1176	418.106	417	3.33963
1204	1204	427.603	426.333	3.29992
1232	1232	437.63	435.667	3.19473
1260	1260	447.471	445	3.04521
1288	1288	457.371	454.333	2.88032
1316	1316	467.167	463.667	2.71376
1344	1344	476.719	473	2.56578
1372	1372	486.271	482.333	2.42511
1400	1400	496.032	491.667	2.27348
1428	1428	506.432	501	2.07988
1456	1456	518.673	510.333	1.71353
1484	1484	529.349	519.667	1.3087
1512	1512	544.228	529	0.943583
1540	1540	548.042	538.333	0.417038
1568	1568	552.065	547.667	0.388313
1596	1596	559.019	557	0.377001
1624	1624	567.272	566.333	0.369674