POTENTIAL OF REFUSE DERIVED FUEL PRODUCTION FROM BANGKOK MUNICIPAL SOLID WASTE

by

Jidapa Nithikul

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Examination Committee: Prof. C. Visvanathan (Chairperson)
Prof. Chongrak Polprasert
Dr. Animesh Dutta

Nationality: Thai
Previous Degree: Bachelor of Environmental Engineering
Chulalongkorn University
Bangkok, Thailand

Scholarship Donor: HM Queen Thailand

Asian Institute of Technology
School of Environment, Resources and Development
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Abstract

Global warming is one of the most critical environmental problems that humankind is facing. Kyoto protocol aims to reduce green house gas emission, lessen dependency on fossil fuel and encourage the use of renewable energy. It also enhances the collaboration between developed and developing country to use clean development mechanism (CDM). Meanwhile, municipal solid waste management in Bangkok is marked as one of five serious environmental problems in Thailand. In this regard, production and utilization of refuse derived fuel (RDF) can positively contribute to both global and local environment.

However, currently, there is no RDF production plant in Thailand due to lack of information for decision makers and investors. Therefore, this study aims to provide information about RDF users, characteristics, production process and driving mechanisms. Three main potential RDF users were investigated namely, cement industries, power producers and industrial boilers. Field data collection and laboratory analysis were conducted to find out RDF characteristics and compared with users' requirement.

The result illustrates that cement industries have positive opinion and are ready to use RDF at 40% substitution (energy basis) which is about 2.7 Mt of RDF/y. Whereas power producers and industrial boilers, which have bigger potential RDF market size (more than 12.2 Mt of RDF/y), are not ready to use RDF. However, potential RDF production in Thailand is around 2.46 Mt/y. Therefore, RDF receiving capacity of cement industries is sufficient to manage RDF from the whole country. Although, power producers and industrial boilers are not ready to use RDF at present, their barriers are pointed out and possible solving strategies are provided for RDF utilization in the future.

Appropriate RDF production process consists of manual sorting, magnetic separation, bag breaking/homogenization, screening with the opening of 40 mm, air drying, shredding and palletizing. This process can produce RDF that has average lower heating value (LHV) around 19.6 MJ/kg at 12% moisture content. Chlorine and sulfur contents are 0.6% and 0.2% respectively. Heavy metals such as Cd, Cr, Hg and Pb do not exceed European RDF standard. The RDF consists of more than 40% plastic, 30% yard waste, less than 10% paper, 10% food waste and 10% noncombustible fraction. Cost of RDF production to get required characteristics mentioned earlier is also provided for decision makers and investors.

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List of Abbreviations

ADB	Asian Development Bank
AFR	Alternative Fuels and Raw Materials
APC	Air Pollution Control
ASTM	American Society for Testing and Materials
BMA	Bangkok Metropolitan Administration
BOI	The Board of Investment of Thailand
BOOT	Built-Own-Operate-Transfer
BOT	Built-Operate-Transfer
C&D	Construction and Demolition
CDM	Clean Development Mechnism
DPC	Department of Public Cleansing
DPPEA	Division of Pollution Prevention and Environmental Assistance
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
EURITS	European Association of Waste Thermal Treatment Companies for Specialized Waste
FTI	Federation of Thai Industries
GDF	Fuel derived from municipal solid waste
GHG	Green House Gas
GTZ	Gesellschaft für Technische Zusammenarbeit
GWF	Green World Foundation
HCl	Hydrochloric acid gas
HDPE	High Density Poly Ethylene
HHV	Higher Heating Value
IPP	Independent Power Producer
ISWM	Integrated Solid Waste Management
KMUTT	King Mongkut's University of Technology Thonburi
LHV	Lower Heating Value
LWDF	Fuel derived from liquid waste
MBT	Mechanical Biological Treatment
MIS	Management Information System
MSW	Municipal Solid Waste
MSWM	Municipal Solid Waste Management
MTPA	Million Tonnes Per Annum
NESDB	The National Economic and Social Development Board
O&M	Operating and Maintenance
ONEP	Office of National Resources and Environmental Policy and Planning
PCC	Pulverized Coal Combustion
PCD	Pollution Control Department
PDF	Packaging Derived Fuel
PEF	Process Engineered Fuel
PETE	Polyethylene Terephthalate
PPF	Paper and Plastic Fraction
PPP	Polluter Pays Principle
RDF	Refuse Derived Fuel
REF	Recovered Fuel
SPP	Small Power Producer
SWDF	Fuel derived from sawdust and paper residues mixed with solvents

TDF	Fuel derived from used tyres
TEENET	Thailand Energy and Environment Network
TPA	Tonne Per Annum
UK	United Kingdom
UNEP	United Nations Environment Programme

Chapter 1

Introduction

1.1 Background

Global warming is one of the most critical environmental problems that humankind is facing. It causes many severe changes such as increasing frequency and intensity of windstorms, hurricanes, floods, droughts and forest fires. Glaciers and polar ice become rapid melting. Some pest and disease vectors are extended in range and activity. Also water supplies become disrupted in some regions. All would lead to loss of lives and properties.

The cause of global warming is the increase of greenhouse gases (GHG) concentrations in the atmosphere. One of the major greenhouse gases from human activities is carbon dioxide (CO_2). Its concentration in the atmosphere is rapidly increasing from combustion of fossil fuel-oil, coal and gas.

Kyoto Protocol aims to reduce greenhouse gases emission, lessen dependency on fossil fuel and encourage development and use of renewable energy. It also enhances collaboration between developed and developing countries in order to achieve sustainable development by using clean development mechanism (CDM). Refuse derived fuel (RDF) production is designed to divert combustible fractions from municipal solid wastes (MSW) to produce fuel and then to be used as substitution or supplementary energy. In this regard, RDF utilization can be considered as CDM and conforms to Kyoto Protocol.

In Thailand, especially in mega city like Bangkok, MSW generation in Bangkok metropolitan administration area (BMA) has increased from 8,000 tons/day in year 1996 to 9,300 tons/day in year 2004 and expected to reach 18,000 tons/day in the year 2015 (PCD, 2005a). Recently, municipal solid waste management (MSWM) is marked to be one of five serious environmental problems in Thailand. It is estimated that MSWM causes the national loss in term of money around 5,000 millions baht per year (Isarangkul Na Ayudhaya, 2006).

In addition, Thailand has committed in the Kyoto Protocol. Therefore, the 10^{th} (2007-2011) National Economic and Social Development Plan of Thailand has indicated several development mechanisms toward the better quality of lives and sustainable development including MSWM (NESDB, 2006)

RDF becomes one of the interesting alternatives to solve both global warming and MSWM problems. Its benefits are not only to improve world environmental quality, but also reduce local economical loss. However, due to high moisture content, low calorific value and high ash content of raw MSW, it is needed to segregate the raw MSW and produce RDF. The advantage of RDF over raw MSW is that RDF has higher calorific value and more consistency in quality.

Presently, there is no RDF production to serve as supplementary fuel for industries in Thailand. This is due to lack of information for decision makers and investors to introduce RDF plant. Moreover, RDF can be served as supplementary fuel for specific types of industry. Therefore, it is needed to investigate the industries which can use RDF and have ability to handle with emission. RDF specification from potential users has to be investigated in order to make RDF that conforms to users' requirement. Waste separation and RDF production technologies have to be selected and the cost associated has to be considered. To make this project feasible, financial analysis between cost of RDF production and market demand has to be carried out.

This study aimed to survey on potential RDF users, their requirement together with their demand on RDF. Appropriate waste separation and RDF production processes were selected. Finally, simple financial analysis was conducted. All information was provided for decision makers, investors and further study on RDF.

1.2 Objectives of the Study

The objectives of study were;

1. To investigate the potential end users together with their expectation on RDF and quantify RDF market size in Thailand;

2. To find out the possible RDF composition which conforms to end users' requirements;

3. To select the appropriate technology which can produce required quality RDF;

4. To identify the driving mechanisms of RDF utilization in Thailand

1.3 Scope of the Study

This study focused on RDF from MSW only. On-Nuch solid waste transfer station in Bangkok was selected to be the representative of mixed MSW and sampling site for RDF production. Laboratory analysis for RDF samples was carried out. Potential end users in Thailand were investigated by secondary data collecting and interviewing. Then the overall potential of RDF was identified by using simple financial analysis.

Chapter 2

Literature Review

2.1 Introduction to Municipal Solid Waste Management (MSWM)

The increasing amount of MSW in developing countries, especially in municipal area, currently, becomes severe problem and needs proper management. There are many barriers to proper MSWM, such as the lack of management capacity, financial resources, expertise and knowledge. MSWM affects the local, regional and global environments. The major concern is releasing of pollutants such as acid and greenhouse gases (EPA, 2005).

Overall integrated MSWM strategies base on the four-tier solid waste management hierarchy. Their components are source reduction and reuse, recycling/composting, combustion with energy recovery and landfilling (EPA, 2006a; Tchobanoglous et al., 1993; GWF, 2005). Municipal solid waste should be managed under ISWM hierarchy (shown in Figure 2.1). Source reduction and reuse are the most desirable solid waste management since they are the most effective way to reduce the quantity of waste and resource consumption, followed by recycling/composting. However, after waste is reduced, reused and recycled, waste is still leftover and must be managed further. Here, combustion with energy recovery comes. Combustion can reduce the quantity of waste being sent to landfill by 90% and hence saves landfill space. In this regard, RDF is one form of energy recovery from waste. Therefore it is in the third rank of integrated MSWM hierarchy. More details about RDF will be explained in section 2.2.

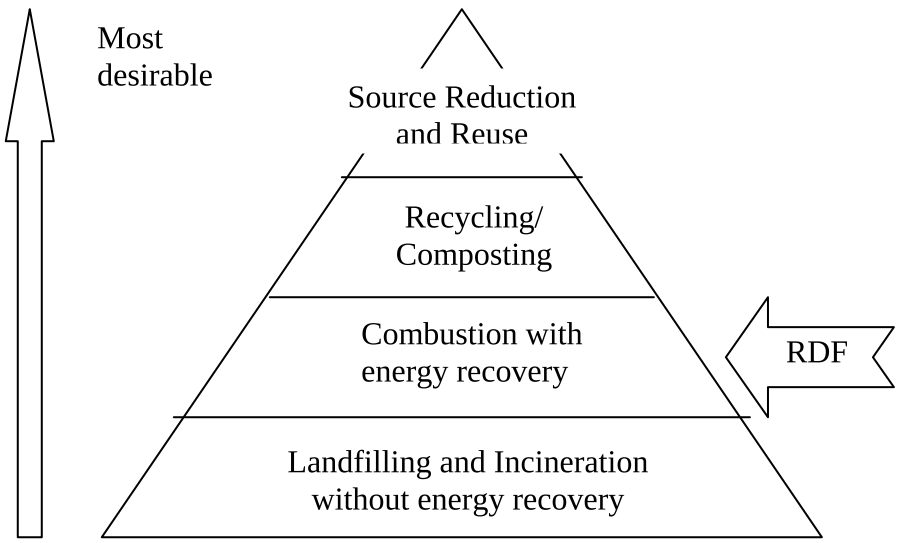


Figure 2.1 Integrated SWM hierarchy

2.2 Basic Knowledge about RDF

This section provides all basic knowledge about RDF such as definition, classification, standard, production process and applications.

2.2.1 Definition and Why RDF

RDF is combustible or, in other word, high calorific fraction recovered from MSW. There are other terms used for MSW derived fuel such as Recovered Fuel (REF), Packaging Derived Fuel (PDF), Paper and Plastic Fraction (PPF) and Process Engineered Fuel (PEF) (UNEP, 2005; Gendebien et al., 2003).

There is another definition defined by ASTM standard (2006) that RDF is a shredded fuel derived from MSW which metal, glass and other inorganic materials have been removed and has particle size 95 weight % passes through a 2-in square mesh screen.

MSW composition is varied from different sources, seasons and living behaviors. Raw MSW has high moisture content, low calorific value, wide range of particle size distribution and high ash content. These reasons make using raw MSW as fuel difficult and unattractive. RDF presents several advantages as a fuel over raw MSW. The main advantages are higher calorific value which also remains fairly constant, more uniformity of physical and chemical composition, ease of storage, handling and transportation, lower pollutant emissions and reduction of excess air requirement during combustion (Caputo and Pelagagge, 2002).

2.2.2 Classification of RDF

According to ASTM standards E856-83 (2006), RDF can be classified into 7 categories as follows;

- RDF-1: Wastes used in as discarded form;
- RDF-2: 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: 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 wastes processed into powder form, 95 weight % passes through a 10 mesh screen (0.035 in square), namely Powder RDF;
- RDF-5: Combustible wastes densified (compressed) into the form of pellets, slugs, cubettes or briquettes, namely Densified RDF;
- RDF-6: Combustible wastes processed into liquid fuels, namely RDF slurry;
- RDF-7: Combustible wastes processed into gaseous fuels, namely RDF syngas.

2.2.3 RDF Standards

Quality assurance in the production of RDF requires that RDF should have high calorific value and have low concentration of toxic chemicals especially for heavy metals and chlorine. Quality aspect also influences the economic success or failure of RDF and is led by three participating groups; RDF producers, potential RDF customers and the respective authorities. Due to their different point of view, suggested RDF quality is vary from one to another group (Rotter et al., 2004).

Although there is no RDF quality regulation in Asia right now. We can follow European standard as a guideline and develop our own standard according to Asian situation later on. The results of a survey of quality standards for RDF in Europe by Rotter et al. (2000) are shown in Table 2.1.

Table 2.1 Survey of quality standards for RDF in Europe

	Country (references)			
	Switzerland (Buwal, 1998)	Finland[d] (SFS, 2000)	Italy[d] (Ministero dell'ambiente, 1998)	Germany[d] (RAL, 2001)
	mg/MJ[a]	mg/MJ[b]	mg/MJ	mg/MJ[c]
As	0.6	n.a.	0.5	0.7
Be	0.2	n.a.	n.a.	0.1
Cd	***0.1***	***0.3***	***0.4***	***0.5***
Co	0.8	n.a.	n.a.	0.7
Cr	***4***	***n.a.***	***6***	***14***
Cu	***4***	***n.a.***	***17***	***56***
Hg	***0.02***	***0.03***	***n.a.***	***0.07***
Ni	4	n.a.	2	8.9
Pb	8	n.a.	11	n.a.
Sb	***0.2***	***n.a.***	***n.a.***	***3.3***
Se	0.2	n.a.	n.a.	0.3
Sn	***0.4***	***n.a.***	***n.a.***	***3.9***
Te	n.a.	n.a.	n.a.	0.3
Tl	0.12	n.a.	n.a.	0.11
V	4	n.a.	n.a.	1.4
Zn	16	n.a.	28	n.a.
Chlorine	***n.a.***	***1.5% by weight***	***0.9% by weight***	***Only declaration***

[a] Restriction: Swiss guideline of waste disposal in cement kilns
[b] Restriction: Quality class III
[c] Restriction: 80% RDF from MSW
[d] Basis for conversion of mg/kg_{dry} into mg/MJ: LHV (dry) 18,000 kJ/kg

Source: Rotter et al. (2004)

Rotter et al. (2004) also mentioned that cadmium, chromium, copper, mercury, lead, antinomy and tin (in bold and italic) can be used as guide parameters of pollutant in household waste. Chlorine is also limiting factor for RDF quality not only for ecological reason but also technical reason (by plant operators to < 1% by weight). One main reason that users are reluctant to use RDF is that background concentration of chlorine is about 0.5-3% (dry basis).

There is also another RDF standard according to calorific value, moisture content, ash content as shown in Table 2.2.

Table 2.2 Standard quality of RDF

Parameters	Finland[a]	Italy	United Kingdom
Calorific Value (MJ/kg)	13-16	15	18.7
Moisture content %w	25-35	25 max	7-28[b]
Ash content %w	5-10	20	12
Sulfur %w	0.1-0.2	0.6	0.1-0.5
Chlorine %w	0.3-1.0	0.9	0.3-1.2

[a] Restriction for household wastes
[b] 7-28 for densified-RDF and 28 for coarse-RDF

Source: Modified from Gendebien et al. (2003)

Heating value can be determined by using laboratory bomb calorimeter or by calculation if % C, H, O, N and S of substance are known. The formula used for calculating heating value is known as modified Dulong formula and shown below;

$$MJ/kg = 337C + 1419(H_2 - 0.125O_2) + 93S + 23N \qquad \text{Equation 2.1}$$

Where; C, H_2, O_2 , S, and N are given in percent by weight

Percent C, H, O, N, S, Cl, H_2O and ash depend on components in RDF and are shown in Table 2.3.

Table 2.3 Chemical composition, by weight, of RDF component class

RDF components	%C	%H	%O	%N	%S	%Cl	%H_2O	%Ash
Paper	34.4	4.72	32.4	0.16	0.21	0.24	21	4.62
Plastic	56.4	7.79	8.05	0.85	0.29	3	15	8.59
Wood	41.2	5.03	34.5	0.02	0.07	0.09	16	2.82
Textile	37.2	5.02	27.1	3.1	0.28	0.27	25	1.98
Leather, Rubber	43.1	5.37	11.6	1.34	1.17	4.97	10	22.5

Source: Maria & Pavesi, 2006

There are 2 types of heating value used in different industries, namely Higher Heating Value (HHV) and Lower Heating Value (LHV).

- Higher Heating Value (HHV), also known as Gross Calorific Value, takes into account the latent heat of vaporization of water in the combustion products, and is useful in calculating heating values for fuels where condensation of the reaction products is practical.
- Lower Heating Value (LHV), also known as Net Calorific Value, assumes the latent heat of vaporization of water in the fuel and the reaction products is not recovered. It is useful in comparing fuels where condensation of the combustion products is impractical.

In this regard, heating value used in combustion of RDF is LHV or Net Calorific Value since water does not condense after combustion. However, if HHV is known, LHV can be calculated by the following formula;

$$LHV = HHV\ (MJ/kg) - 0.0244(W+9H) \qquad \text{Equation 2.2}$$

Where; W = Water content (% by weight)
H = Hydrogen content (% by weight)

As RDF can be used for supplementary fuel in cement kiln, there are some criteria for RDF for co-combustion in cement industry as shown in Table 2.4.

Table 2.4 Criteria of RDF for co-incineration in cement kilns

Parameter	Unit	Value		
		EURITS[a]	Sweden (Specialbransie A)[b]	Sweden (Lattbransie)[c]
Calorific Value	MJ/kg	15	23.9-31.4	25.1-31.4
Cl	%	0.5	<1	<1
S	%	0.4	N/A	<0.5
Br	%	0.01	N/A	N/A
N	%	0.7	N/A	N/A
F	%	0.1	N/A	N/A
Be	mg/kg	1	N/A	N/A
Hg/Ti	mg/kg	2	N/A	<5
As, Se (Te), Sb	mg/kg	10	N/A	N/A
Cd	mg/kg	10	<10	<5
Mo	mg/kg	20	N/A	N/A
Co, Cu, Mn, Sn	mg/kg	200	N/A	N/A
V	mg/kg	200	N/A	N/A
Cr	mg/kg	200	<300	N/A
Pb	mg/kg	200	<350	<100
Ni	mg/kg	200	N/A	<10
Zn	mg/kg	500	<2000	N/A
Ash content	%	5	5-10	0.6-0.8

[a] European Association of Waste Thermal Treatment Companies for Specialized waste
[b] and [c] different cement kilns in Sweden

Source: Modified from Gendebien et al. (2003)

2.2.4 RDF Production Process

RDF production process has two subsystems called front end and back end. Front end or pre-processing subsystem is to receive the MSW and separate it into combustible and noncombustible fractions in order to produce feed stock for back end system. Back end system refers to the conversion process which can be either thermal or biological system (UNEP, 2005).

RDF production line consists of several unit operations in series in order to separate unwanted components and condition the combustible matter to obtain required RDF characteristics. General unit operations are screening, shredding, size reduction, classification, separation either metal, glass or wet organic materials, drying and densification. These unit operations can be arranged in different sequences depending on coming MSW composition and required RDF quality (Caputo and Pelagagge, 2002).

1) Unit operations in RDF production process

- **Manual separation**

In mixed MSW, bulky item such as appliances, furniture, etc. and specified contaminants (e.g. hazardous waste) can be removed manually by workers (sorters) before mechanical processing. Manual sorting also serves as recycling process for paper, glass/plastic containers and aluminium cans. Ranges for recycled materials that recovered by sorters are presented in Table 2.5.

Table 2.5 Manual sorting rates and efficiencies

Material	Sorting Rate (kg/h/sorter)	Recovery Efficiency (%)
Newspaper*	700 – 4,500	60 – 95
Corrugated*	700 – 4,500	60 – 95
Glass containers** (mixed color)	400 – 800	70 – 95
Glass containers** (by color)	200 – 400	80 – 95
Plastic containers** (PET, HDPE)	140 – 280	80 – 95
Aluminium cans**	45 – 55	80 – 95

* From a paper stream of predominantly one or two paper grades
** From a processing stream of predominantly metal, glass and plastics

Source: UNEP (2005)

Equipment involved in manual separation usually includes a sorting belt or table. Sorters are stationed on one or both sides of the belt or table to pick up the recycled materials. Design of manual separation requires good understanding of time and motion, waste composition and comfortable/safety operation of the sorters.

- **Size reduction**

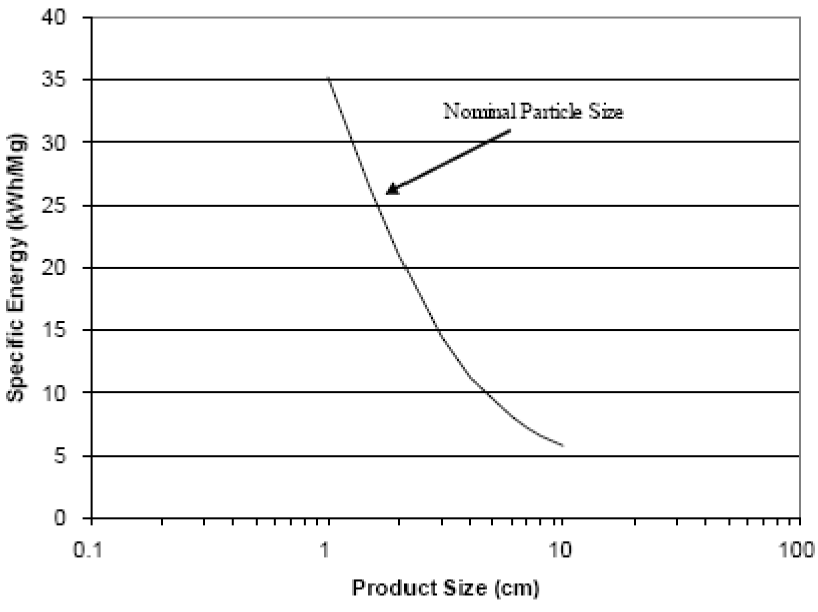
The term “size reduction” in solid waste management is similar to “shredding” and “grinding”. But the term “shredding” often refers to size reduction of the mixed wastes. The term “grinding” is sometimes used for glass. Size reduction is an essential unit operation in mechanical processing of mixed wastes since it gives a certain degree of size uniformity. Shredding of mixed waste to the size of about 10 cm. is common in many waste processing facilities. Sometimes, secondary or tertiary shredding to the size of smaller than 10 cm. is required for production of RDF.

There are many types of shredder as follows;

Hammermills
There are two types of hammermills, horizontal and vertical rotors. The horizontal hammermill is commonly used for mixed wastes. Its principal parts are rotor, hammer, grates, frame and fly wheel. Objects to be size reduced are fed into the opening of the machine. They interact with the hammers and each other until the size are small enough to pass through the grates.

Shear shredder
This type of size reduction machine has high torque and low rpm. It consists of two horizontal cutting shafts that rotate in opposite directions. Due to its high torque and shearing action, this machine is commonly used for materials that are difficult to shred such as tire, aluminium and plastic.

Energy consumption is an important parameter in designing size reduction equipment. Experiments and field test conducted by Diaz and Savage (2006) indicated that the specific energy requirement for size reduction depends on the required product size, the less the size, the more the specific energy requirement as illustrated in Figure 2.2.



Source: Diaz and Savage, 2006

Figure 2.2 Specific energy requirements for size reduction of municipal solid waste

- **Screening**

The purpose of screening is size separation. It divides the feed stock into at least two streams called oversize (retained on the screen) and undersize (passed through the screen) fractions.

There are many types of screen as follows;

Trommel screen
Trommel is inclined downwardly, rotary, cylindrical screen. Its screening surface is either wire mesh or perforated plate. It can be use for mixed MSW prior to size reduction called pre-trommeling or after shredding called post-trommeling. Trommel screen has been proven to be quite effective and efficient for processing mixed MSW and hence it is the commonly used type of screen (UNEP, 2005).

Disc screen
The predominant application of disc screen is for separation of inorganic fraction from RDF, from paper or from wood waste. A disc screen consists of evenly spaced shafts in horizontal plane fitted with discs. The openings between the discs allow the undersize to fall down. All shafts rotate in the same direction and carry the wastes from one end to another end.

- **Air classification**

Air classification is a separation process by the differences in aerodynamic characteristics of waste. Aerodynamic characteristic of a particular material is a function of size, geometry and density. The process consists of the interaction between moving stream of air, shredded wastes and gravitational force. The fraction which is suspended in the air stream referred to light fraction and the settle materials are referred to heavy fraction.
In air classification of shredded mixed MSW, paper and plastic materials tend to be concentrated in the light fraction and metals, glasses are the main components of the heavy fraction.

There are many types of air classifier according to the air flow patterns. Typical operating and performance characteristics of air classifier in the production of RDF from mixed MSW are given in Table 2.6.

Table 2.6 Typical operating and performance characteristics of air classifiers used for recovery of RDF

Parameter	Typical range
Paper and plastic in heavy fraction (%)	5 – 30
Light fraction composition (%)	
- Ferrous metals	0.1 – 1
- Non-ferrous metals	0.2 – 1
- Fines	15 – 30
- Paper and plastic	55 – 80
- Ash	10 – 35

Source: Modified from UNEP (2005)

- **Magnetic separation**

Magnetic separation is used to segregate ferrous metals from mixed MSW. There are three configurations of magnetic separator namely magnetic head pulley, drum and magnetic belt

In terms of yield, the magnetic metal recovery per unit weight of total magnetic metal in mixed MSW is about 80% for single stage of magnets. Higher rate of recovery can be achieved by using multiple stages magnetic separation. The percentage of recovery will be higher up to 85-90% when magnetic separator is used after air classifier. This is due to light contaminants such as paper and plastic which interfere with magnetic separation process have been removed.

- **Drying an densification**

Drying and densification are used in specific purposes such as RDF production and volume reduction of waste prior to landfill. The objective of drying is to improve the quality of RDF. Densification is used for production of densified-RDF by the way of briquetting, pelletising or cube formation.

2) RDF production lines

As mentioned earlier, RDF production lines are the combination of several unit operations in different sequences. There are some examples of reference RDF plants in Table 2.7.

Table 2.7 Reference plants and computation results

Plant	Sequence of unit operations	Lower Heating Value of RDF (MJ/kg)
AREA	S-T-MS-M-MS-ACC-T-E	12.2
CIRSU	PT-HS-MS-S-T-MS-M-T	16.8
Consorzio Alessandrino	S-T-MS-T-MS-T	18.3
Consorzio Smaltimento Rifiuti Bassa Friulana	M-PT-ACC-M-D-P	16.8
Macomer	M-MS-T-BC	8.8
RECLAS	T-MS-ACC-T-MS-ACC	16.8
SAO	M-MS-PT-MS	12.6
SIEM	M-T-M-ACC-P	13.2

Note:
ACC air classifier with cyclone
BC Ballistic classifier
D Dryer
E Extruder
HS Hand sorting
M Mill
MS Magnetic separator
P Pelletizer
PT Pre-Trommel screen
S Shredder
T Trommel screen

Source: Modified from Caputo and Pelagagge (2001)

Cost of RDF production depends on line configuration. Caputo and Pelagagge (2001) had estimated RDF production cost of different unit operations based on hourly amortization cost plus energy expenses shown in Table 2.8. Amortization cost was evaluated according to 10 years life time, operating 6 days/week, two 7-h shifts/day. Electricity cost was estimated at 0.0723 Euro/kWh (3.62 Baht/kWh). Two operators per shift were used for hand sorting.

Table 2.8 Line equipment cost data

Equipment	(a) Capacity (t/h)	(b) Amortization (Euro/h)	(c) Operating Cost (Euro/h)	Production Cost [(b)+(c)]/(a) (Euro/t)
Densifier	6	4.73	3.62	1.39
Air Classifier	5	0.95	0.87	0.36
Dryer	6	7.09	10.12	2.87
Belt conveyor		0.35	0.43	-
Hammer mill	6	3.55	21.69	4.21
Pelletizer	4	4.73	3.62	2.09
Eddy current separator	15	1.14	0.48	0.11
Magnetic separator	15	0.34	0.16	0.03
Hand sorting			23.65	-
Shredder	15	2.96	3.62	0.44
Trommel screen	15	2.36	1.45	0.25

Source: Modified from Caputo and Pelagagge (2001)

3) RDF production technologies in Europe

There are two technologies which have been developed and produce high calorific fraction to be used as RDF as follows;

- **Mechanical Biological Treatment (MBT) plant**

In a mechanical biological pre-treatment plant (MBT) (Figure 2.3), metals and inerts are separated out and organic fractions are screened out for further stabilization using composting processes, either with or without a digestion phase. It also produces a residual fraction which has a high-calorific value as it is composed mainly of dry residues of paper, plastics and textiles.

- **Dry Stabilization Process**

RDF can also be produced through a ‘dry stabilization’ process, in which residual waste (excludes inerts and metals) are effectively dried (and stabilized) through a composting process, leaving the residual mass with higher calorific value and suitable for combustion. The high calorific output of this process developed in Germany has the trade name of ‘Trockenstabilat’.

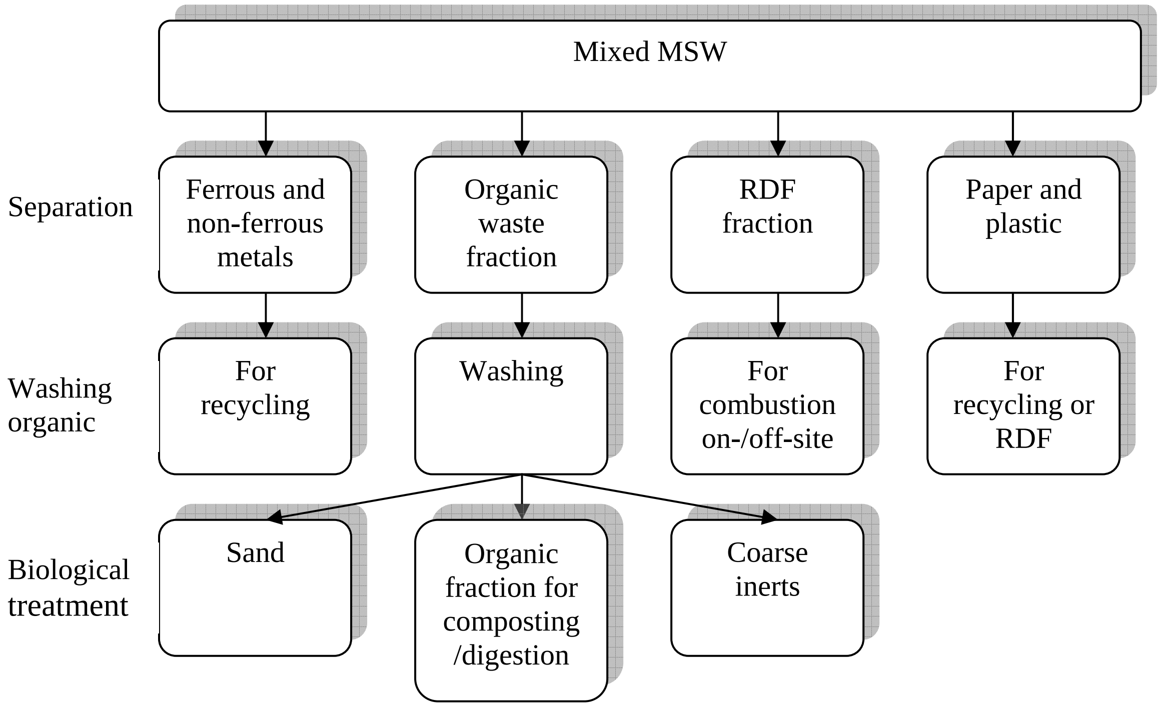


Figure 2.3 Schematic presentation of MBT process

Visvanathan et al. (2005) pointed out that MSW stream in most Asian countries contains high biodegradable fraction and moisture. Direct landfill without pretreatment is not environmental friendly approach. Also incineration is not suitable. Therefore, pretreatment of MSW by MBT will bring sustainable SWM in Asia.

2.2.5 RDF Applications

Currently, it has been experienced in Germany that target RDF users are energy-intensive industries such as cement, power generation either co-combustion or mono-combustion (Rotter et al., 2004).

- **Cement kiln**

Most cement plants do not directly burn mixed MSW due the heterogeneous nature of the waste and components which could lead to quality and environmental concerns. Therefore, MSW is used after sorting and processing into RDF in cement kilns in Austria, Belgium, Denmark, Italy and Netherlands (Gendebien et al., 2003).

In cement kilns, combustion takes place under very high flame temperatures about 1,450ºC and relatively long residence times. These conditions are favourable for burning of RDF. Base on technical and environmental considerations, the analysis of burning RDF in a cement kiln shows that no special firing technology has to be installed except RDF handling system. However, there is an upper limit to the total fuel consumption (not more than 30 percent) for firing RDF in order that there is no increment in the emission levels of air pollutant such as acid gases, dioxins, furans, etc. (Lockwood and Ou, 1993)

Cement manufacturing consists of six components which are described below and illustrated in Figure 2.5. There are 2 fuel feeding points, namely precalciner and main burner (also see Figure 2.4)

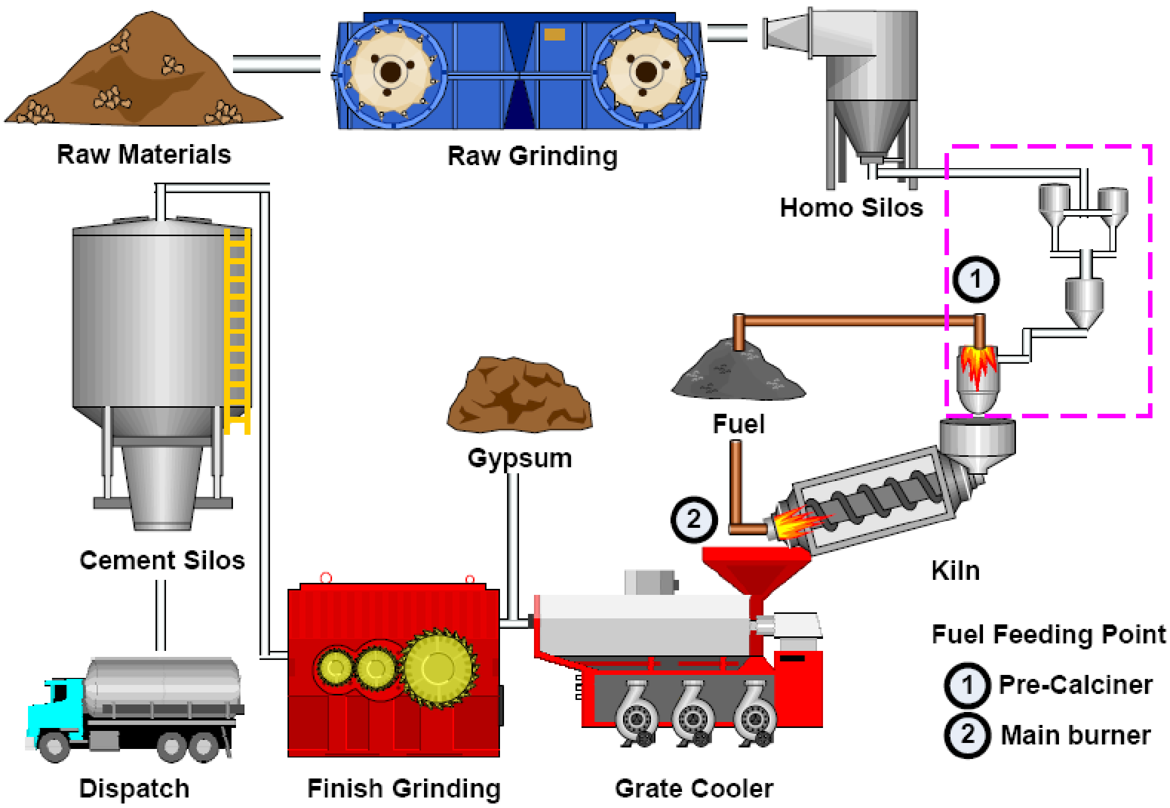


Figure 2.4 Cement production process and fuel feeding points

1) Raw mill

Raw materials are dried and finely ground in the Raw Mill to form an intermediate product, called “raw meal”. The grinding provides an increased surface area to enhance the heat exchange in the downstream heating process.

2) Homo silos

The “raw meal” is then stored in a homogenizing silo in which the chemical variation is reduced. This homogenizing process is important to stabilize the downstream sintering process as well as to provide a uniform quality product. The “raw meal” is then transferred to the Preheater Tower.

3) Preheater

In the Preheater, the raw meal undergoes a series of concurrent heat exchanges with the hot exhaust gas from the kiln system. The gas and material stream are separated by cyclones after each heat exchange process. The raw meal temperature increases from 80°C to 1000°C within 40 seconds. The first chemical reaction also takes place in the Precalciner of the Preheater, where limestone $CaCO_3$ is decomposed into lime (CaO).

4) Rotary Kiln

The calcinated material entering the kiln, then undergoes a long heating process. The material temperature rises from 1000°C to 1450°C. Mineral matrixes of raw material are totally destroyed and cement minerals are formed at the sintering temperatures. A semi-product called "clinker" is formed. Coal and other alternative fuels are used as energy sources for the process. The ash from fuels is absorbed into the clinker matrix. The residual heat from the clinker leaving the kiln is recovered by a grate cooler to reduce the energy requirement.

5) Grate cooler

The residual heat from the clinker leaving the kiln, is recovered by a grate cooler (consisting of rows of grates). Cooling air is injected from the bottom of the grate, and is forced into the clinker which is traveling slowly on the grate. The heated air is then recycled as secondary air for combustion in the kiln, or in the Precalciner.

6) Finish mill

The final process of cement making is called finish grinding. Clinker dosed with controlled amount of gypsum is fed into a finish mill. Typically, a finish mill is a horizontal steel tube filled with steel balls. As the tube rotates, the steel balls are lifted, tumble and crush the clinker into a super-fine powder. The particle size is controlled by a high efficiency air separator. Other additives may be added during the finish grinding process to produce specially formulated cement.

It has been proved that RDF and coal co-combustion in cement kiln has several advantages as follows (Tangkaew, 2007);

- High temperature (1,800ºC at main burner and 1,000ºC at pre-calciner) and long residence time (5-6 s at 1,800ºC and 2-6 s at > 800ºC) yields complete combustion
- Self cleaning process of acid gas by lime
- No ash since ash will be melt and becomes part of final product

RDF quality for co-incineration in cement kiln is illustrated in Table 2.9.

Table 2.9 Typical quality parameters for co-firing in cement kilns

Quality parameter	Main burner feeding	Calciner feeding
Calorific value (MJ/kg)	Min. 20	Min. 15
Particle size (mm)	< 20	< 25 as soft pellet
Ash content (%)	low	Can be higher up to 20%
Chlorine (%)	In general < 1%	In general < 1%

Source: Ibbetson & Wengenroth (2007)

- **Power Plant**

Co-firing waste derived fuels in coal-fired power and district heating plants is relatively common in Denmark, Finland, Germany, Netherlands and Sweden. RDF is only co-incinerated in boilers producing steam. The substitution varies between 0 and 100% (Gendebien et al., 2003).

However, the main drawback of RDF combustion is the corrosion on the surface of heat exchanger in the boiler caused by acidic gas such as HCl. Moreover, the presence of HCl may also stimulate the formation of dioxin (Liu et al., 2001).

RDF quality used in power plant depends on type of power plants. For example, hard coal-fired power plant needs higher quality of RDF than fluidized bed incinerator or lignite fired power plants (Table 2.10).

Table 2.10 Quality parameters for coal-fired power plants

Quality parameter	Hard coal power plant	Lignite power plant
Calorific value (MJ/kg)	Min. 20	Min. 11
Particle size (mm)	< 20	< 25 as soft pellet
Ash content (%)	low	Can be high
Chlorine (%)	Depends on S content, in general < 1%	Depends on S content, in general < 1%

Source: Ibbetson & Wengenroth (2007)

Typical process of coal-fired power plant is described below;

Coal is first milled to a fine powder, which increases the surface area and allows it to burn more quickly. In these pulverised coal combustion (PCC) systems, the powdered coal is blown into the combustion chamber of a boiler where it is burnt at high temperature (see Figure 2.5). The hot gases and heat energy produced converts water – in tubes lining the boiler – into steam.

The high pressure steam is passed into a turbine containing thousands of propeller-like blades. The steam pushes these blades causing the turbine shaft to rotate at high speed. A generator is mounted at one end of the turbine shaft and consists of carefully wound wire coils. Electricity is generated when these are rapidly rotated in a strong magnetic field. After passing through the turbine, the steam is condensed and returned to the boiler to be heated once again.

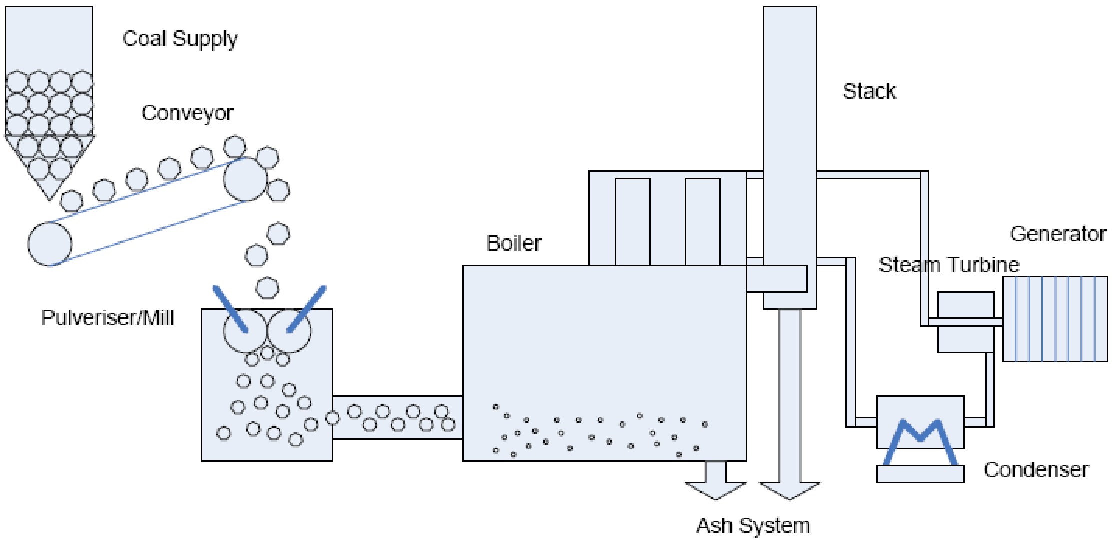
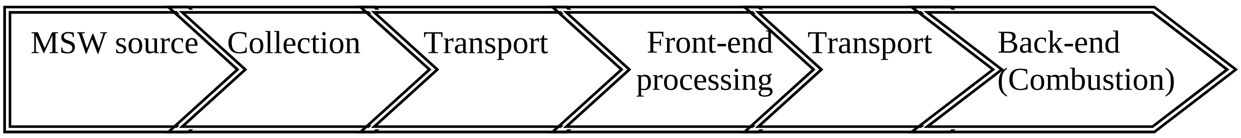


Figure 2.5 Typical coal-fired power plant diagram

Concept from waste to energy for combustion is shown in figure 2.6.

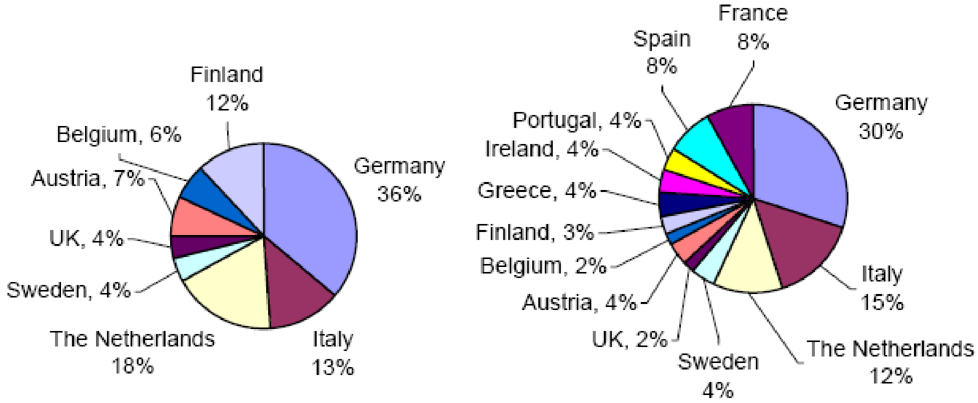


Source: Modified from GTZ & Holcim (2006)

Figure 2.6 From waste to energy concept

2.3 Situation of RDF in Europe

RDF production and utilization have been well developed in Europe as landfill directive 1999/31/EC requires diversion of biodegradable wastes prior to landfill. The growth of RDF in Europe is tremendously fast from 1.4 million tonnes per annum (Mtpa) in year 2000 to 12.4 Mtpa in year 2005 (Figure 2.7). There are many countries using RDF as follows (Gendebien et al., 2003);



Year 2000: 1.4 Mt **Year 2005: 12.4 Mt**

Source: Bilitewski, 2006

Figure 2.7 Growth of RDF in Europe

2.3.1 Austria

In Austria, MSW has been increased to total 3.1 million tonnes per annum (tpa). Around 45% of MSW is recycled, 40% is landfilled, and 15% is incinerated in 3 incinerators with energy recovery. MSW is processed/treated in 526 composting plants with a total capacity of 1.1 million tpa and in 10 mechanical biological treatment plants. In 2000, the capacity of the existing MBT plants was about 340,000 tpa of input waste. Two additional plants are in construction which will bring the total capacity of MBT in Austria to 400,000 tpa

Some of the 10 mechanical-biological treatment plants (MBT) are producing a high calorific waste fraction. In 2000 more than 70,000 tpa of RDF were produced from these plants, representing 23% of recovery.

In Austria there are around 180 industrial facilities which co-incinerate more than 1.8 million tpa of secondary fuels and/or RDF. The most important industries for co-incineration of wastes are the pulp and paper industry and the wood industry, followed by the saw-mill industry. However, these industries mainly co-incinerate their own production residues such as waste wood, paper sludge, bark or spent liquor.

2.3.2 Belgium

It is estimated that the recovery rate for RDF production, the high calorific fraction left from MSW treatment in MBT plants, varies between 40 to 50% of the incoming stream. The quantities of RDF produced in the Flemish Region are expected to rise to 240,000 to 300,000 tonnes with the planned construction of 4 new MBT plants with a total capacity of 600,000 tonnes per annum (tpa). Currently, there is only one plant, INDAVER in Antwerpen, producing high calorific value pellets in the Flemish Region. The RDF produced in the Flemish Region is exported to cement kilns in the Walloon Region, France or Germany as there are no cement plants located in the region and no other industry prepared to accept RDF even with the strict standards imposed on this secondary fuel.
The costs of producing RDF is reported to amount to 50 – 75 Euro per tonne and for combustion in cement plant, the waste company has to pay the cement company around 100 Euro per tonne.

2.3.3 Denmark

There have been several attempts by Danish waste companies to manufacture RDF pellets from MSW but they all failed because of the high costs compared with bales or other forms of storage. The RDF pellets can only be used in waste incineration plants, and incinerator operators are not prepared to pay for such materials.

2.3.4 Finland

Domestic waste is sorted for householders at source and separate collections are provided for paper, glass, metals and biowaste. The remaining dry fraction can be processed for RDF, referred to as Recovered Fuel (REF) in Finland.

In 2000, there were 12 RDF production plants in operation, processing household, commercial and C & D waste with a total capacity for approximately 200,000 – 300,000 tpa operating between 70% and 100 % of their capacity depending on the final use and thus the required quality of RDF being produced.

There are only three cement kilns in Finland using limited quantities of RDF. It was reported that about 500,000 tpa of REF was used as secondary fuel in Finland and produced 1% of the primary energy supply which could increase to 3 to 5%.

2.3.5 France

In the past there were several installations producing RDF after sorting, grinding MSW. These facilities were not successful in securing outlets for the fuel and ceased operation. One installation under construction will produce charcoal from MSW using a thermolysis process. MSW will be ground, sorted, dried, heated to 500°C, sorted again and washed before being used in a cement plant.

2.3.6 Germany

In Germany, some plants for the treatment of waste are especially designed for the production of a high calorific fraction such as some mechanical-biological treatment (MBT) plants or the "*Herhof-Trockenstabilat®-Verfahren* plants processing municipal solid waste (MSW). In many other cases no high calorific value fraction is extracted but waste fractions are just ground or ground and pelletised.

In Germany, the total capacity of MBT plants producing RDF is just above 1 million tpa, about half of the total capacity of the MBT park. The utilization of the RDF is secured not in all cases so in some plants the high calorific fractions are just stored. Producers of secondary fuels in Germany have created a label, called "*RAL Gütezeichen Sekundärbrennstoffe*". It is like a guideline for producers to guarantee specific input limits for pollutants such as heavy metals. There are hopes to get a better market position by the introduction of the RAL-seal.

There are more than 70 plants in operation that are authorised and which are co-incinerating waste derived fuels in Germany. The main user of secondary fuels in Germany is the cement industry.

2.3.7 Greece

It is reported that a new MBT plant is being built for Athens. This could potentially generate RDF from MSW.

In Greece, three out of the 8 cement plants have run trials in 1998 with small volumes of secondary fuels. No results or future decision was reported. It is unclear if any large-scale use of secondary fuels is taking place in Greece in the cement industry or any other industrial facilities.

2.3.8 Ireland

Ireland produces about 1.5 million tonnes of municipal solid waste (MSW) per year of which 1.2 millions tonnes is household, 0.7 million tonnes commercial waste and 0.08 million tones street cleaning wastes. Most of this waste is landfilled (about 92%) with the most of the remainder recycled. Currently there is no incineration of municipal wastes with or without energy recovery.

This means a big challenge for Ireland in view of meeting the proposed target to reduce landfilling of MSW and the necessity to find alternative treatments. This situation may mean a move towards more use of waste as a secondary fuel. Most Local Authorities are considering using thermal treatments of MSW including incineration and gasification as part of their local waste management plans. Therefore the situation regarding RDF from MSW may change significantly in the future. The use of composting at home and at central locations as well as anaerobic digestion of MSW are also being considered and encouraged as part of the waste management plans.

2.3.9 Italy

In Italy, there are 41 mechanical biological treatment plants (MBT) with a total capacity of 4.3 million tonnes (t). In 1999, around 2.3 million t of MSW (8.2% of MSW arising) were treated in these plants. In 1999, the quantities of MSW treated amounted to nearly 1 million t. Even though regulatory framework is getting stricter for the use of RDF, there is still a high interest in constructing more plants to produce RDF.

RDF produced in Italy is co-incinerated mainly in cement kilns. There are also plans to use RDF in dedicated incinerators and power plants.

2.3.10 The Netherlands

RDF pellets are produced from the mechanical recovery of plastics/paper fractions (PPF) of household waste and this is widely practiced on a commercial scale by the Dutch waste company VAM. There are 13 plants producing RDF from MSW in the Netherlands. Their total input capacity is about 2 million tpa with a 35% production rate (700,000 tpa) of RDF. There are plans for more plants to be constructed in order to bring the overall input capacity up to 3.3 million tpa.
The main industrial sector relying on secondary fuels is the power industry, followed by cement industry, as the paper industry only co-incinerates their own production residues.

2.3.11 Spain

In Spain four types of RDF have been identified;

- Fuel derived from liquid waste (LWDF)
- Fuel derived from sawdust and paper residues mixed with solvents (SWDF)
- Fuel derived from MSW waste (GDF)
- Fuel derived from used tyres (TDF)

They are mainly used in cement and brick industry.

2.3.12 Sweden

The average household waste production in Sweden amounts to 300 kg/person/annum, of which 50% is used as secondary fuel. The most energy dense part of the MSW is sorted out and further processed to a refined waste fuel, so called RDF. The average energy content of household waste is 2.8 kWh/kg. The total amount of household waste used as fuel is approximately 1.35 million tonnes per annum (tpa).

Main RDF utilization is for district heating plants and cement kilns.

2.3.13 United Kingdom

The production of fuel from municipal or commercial waste for co-combustion in dedicated or adapted power plants is rare in the UK while co-incineration of high calorific value industrial or difficult wastes as secondary fuels is more common.

In the UK the term refuse derived fuel (RDF) is generally reserved for the processed paper, card, wood and plastic fractions of municipal, commercial or industrial wastes. Typical RDF composition is: 84% paper/board, 11% plastic and 5% glass, wood, textiles and metals etc.

2.4 Situation of RDF in Thailand

Presently, there is no RDF production plant in Thailand. There is one on-going study on RDF production using Mechanical Biological Treatment (MBT) in Phitsanulok municipality. This project has been carried out by GTZ in cooperation with Pollution Control Department (PCD). The selected municipality is Phitsanulok, a province in northern part of Thailand. Applied MBT technology is FABOR-AMBRA which is one of MBT technologies from Germany. The work concept of GTZ is categorized into 3 main categories as follows;

1. Community Based Management (CBM) which is the program that aims to educate people to separate the waste at source. By using money as incentive, total solid waste transferred to the disposal site in Phitsanulok Municipality reduced by 40% (from 150 tonnes/day before year 2000 to 90 tonnes/day at present) by recovery of recyclable materials.
2. Waste treatment prior to landfill by using FABOR-AMBRA technology can reduce the waste 60% by weight after 5 to 9 months of treatment.

3. Setting up Management Information System (MIS) which aims to increase waste collection efficiency and collection fee by Polluter Pays Principle (PPP) concept.

Waste treatment process at landfill site is shown in figure 2.8.

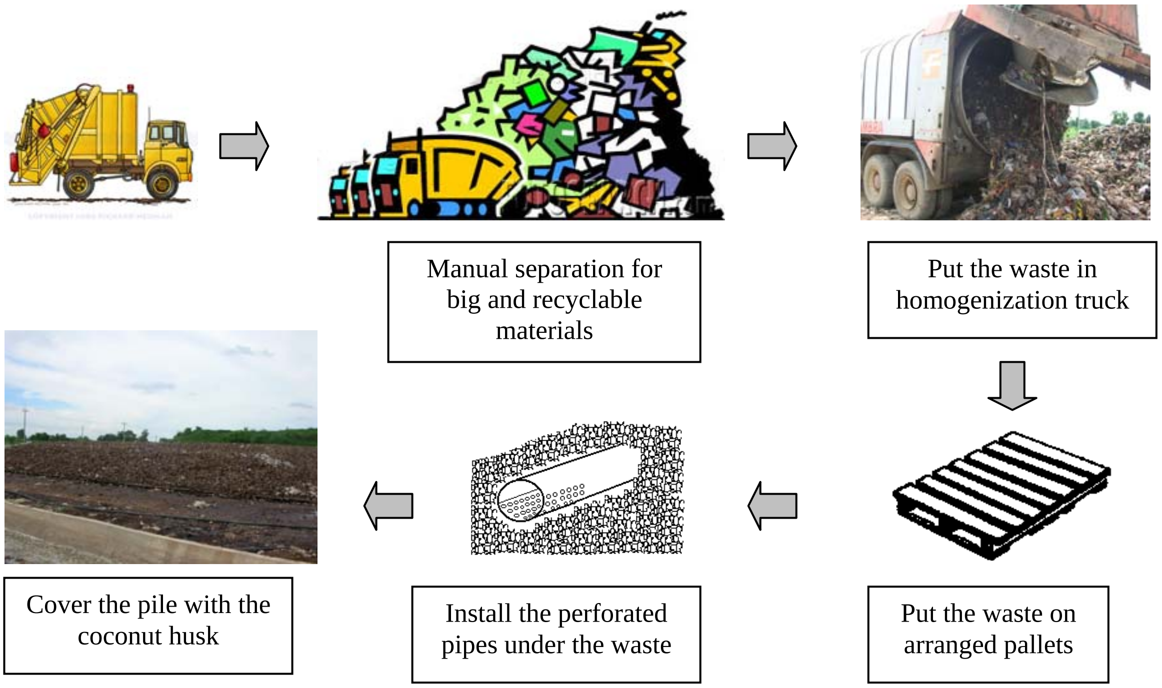


Figure 2.8 MBT process at Phitsanulok

This MBT uses passive aeration by using natural air ventilation. No air blower is needed. The concept is that introducing the cool air inlet at the bottom of the pile. The hot air from decomposition reaction will go up and replace by cool air from the bottom as illustrated in Figure 2.9.

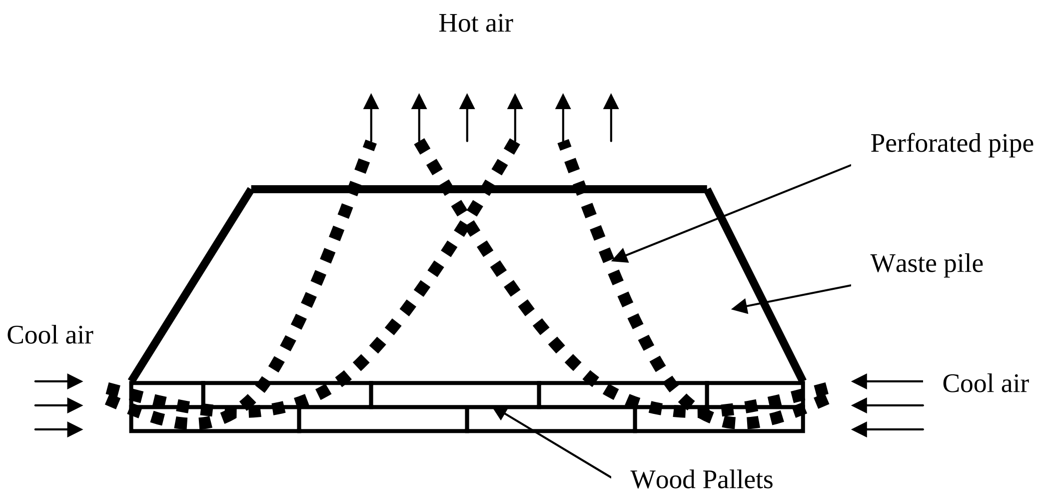


Figure 2.9 Passive aeration applied for MBT

The height of the pile depends on moisture content in solid waste, more the moisture, less the height. The maximum height for Phitsanulok's waste was conducted at 2.5 meters. The leacheate generated was collected in a pond during the wet season and sprayed over the pile in order to keep suitable moisture content for decomposition in the pile during dry season. So for this reason, there is no leachate treatment for this MBT method.

After MBT for 5 and 9 months, the wastes were separated into 3 groups as follows;

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 characteristics of wastes with the size bigger than 40 mm. were analyzed for the potential of using as RDF. The results are shown is Table 2.11.

Table 2.11 Comparison of RDF characteristics between BMT and standard

Parameter	MBT 5 months*	MBT 9 months*	RDF Standard**
Moisture content (%)	16	13	25***
Ash content (%)	21	16	5
Chlorine (%)	0.88	0.66	<0.5
Sulfur (%)	0.12	0.39	<0.4
Calorific Value (MJ/kg)	33.9	38.3	15
Cd (mg/kg)	ND	ND	10
Cr (mg/kg)	1,932	12.5	200
Hg (mg/kg)	ND	0.455	2
Pb (mg/kg)	13.3	36.1	200

* From Naresuan University, 2006
** Standard RDF for co-incineration in Cement kiln
*** Typical RDF property of UK

The result shows that solid particles after MBT with the size bigger than 40 mm. have characteristics conformed to RDF standard except chlorine and ash content.

MBT for 5 and 9 months do not give so much difference in high calorific fraction quality. Therefore, MBT for 5 months is enough for RDF production. However, it still needs further treatment to produce RDF such as size reduction and compaction. Transportation cost to users is an important factor that has to be considered.

This is a successful solid waste management that has been done in Thailand due to low cost and equipment requirement. However, this method is proved to be suitable for the municipality which generates the waste not more than 300 tonnes per day and has land availability. It is not applicable for Mega city like Bangkok which generates the waste around 10,000 tonnes daily and has limited of land. Therefore, appropriate technology for MSWM in Bangkok has to be further investigated.

2.5 Overview of target RDF users in Thailand

According to the information retrieved from The Federation of Thai Industries (FTI) (2007), there are two groups of industry which could be target users of RDF as follows;

2.5.1 Cement kiln

At present, there are 13 cement plants with approximately 11,000 workers. The production capacity in the year 2002 is 47.17 million tons while the local demand is approximately 20 million tons. The export of clinker will be 10 million tons and cement 6.4 million tons. According to the data base from FTI, there are nine members in cement production group.

2.5.2 Power producer

Electrical power is the infrastructure for industrial development. Price and quality of electrical power also affect to industrial competitive performance. Nowadays, more than 40% of electrical power comes from private power producers including small power producer (SPP) and independent power producer (IPP). According to data from FTI, there are 21 members in this industrial group.

2.6 Emission Standards

Emission standard is an important aspect when using RDF. Different emission standards are applied for different industries as shown in Table 2.12.

Table 2.12 Emission standards for different industries

Parameter	Coal Fire Power Plants	Cement Kilns	Coal Boiler Industries	Biomass Boiler Industries	Municipal Waste Incinerator*	German Waste Incineration**
SO_2 (ppm)	700	50	700	60	30	50
NOx as NO_2 (ppm)	400	600	400	200	180	200
Particulate (mg/m^3)	320	300	320	320	120	10
HCl (ppm)	N/A	N/A	N/A	N/A	25	10
Dioxin (ng/m^3)	N/A	N/A	N/A	N/A	30	0.1

***Capacity > 50 ton/d
**from Bilitewski, 2006

Source: PCD, 2007

From Table 2.12, it is noticed that emission standard for MSW incinerator is the most stringent. In addition, HCl and dioxin standards are applied only for incineration and not applicable for other industries.

Chapter 3

Methodology

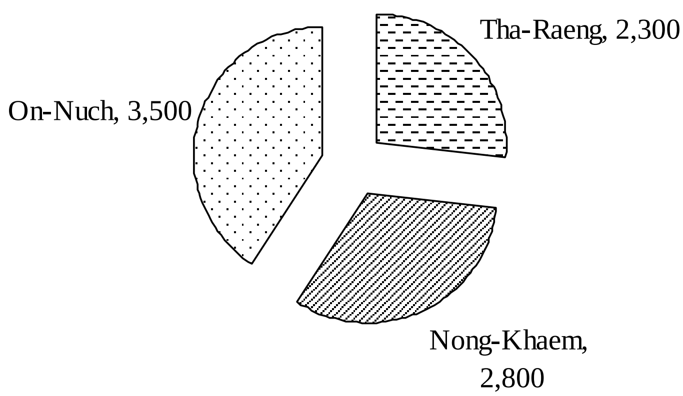
3.1 Introduction

The study focused on potential of RDF from MSW only. MSW is collected from residential and commercial areas within the municipality including general and hazardous wastes. But the hazardous fractions were not considered in the study due to many reasons listed in Table 3.1.

Table 3.1 Hazardous wastes and reasons why they are excluded from RDF production

Type	Reasons
Electronic wastes	• They contain mainly metal (about 45%) which can give more profit by recycling • They contain high concentration of harmful substances such as Cl, Br, Cd, Ni, Hg which are normally higher than threshold limit
Entire Batteries	• They contain harmful substances such as lead which would lead to undesirable concentration of pollutants in products and air emissions
Infectious wastes	• It requires special precautions on occupational health and safety in handling with such this waste.

Presently, there are three solid waste transfer stations receiving MSW from Bangkok Metropolitan Administration Area (BMA), namely, Tha-Raeng, Nong-Khaem and On-Nuch. The quantity of waste collection for each station is shown in Figure 3.1.



Source: Visvanathan et al., 2004

Figure 3.1 MSW collection (ton/d) in BMA

MSW from On-Nuch solid waste transfer station was selected to be the representative of MSW generated in Bangkok because of two reasons. Firstly, MSW collection at On-Nuch contributes around 40% of total MSW collection in Bangkok. Therefore, its volume is big enough to be a good representative. Secondly, there is one composting plant that is now in operation at On-Nuch. The capacity of the composting plant is 1,200 ton/day. It means that 1,200 tons/day of mixed MSW come and decomposable organic fraction is separated for composting. It is better to separate organic fraction out of waste stream because major component of MSW in Thailand is food waste which contributes about 35-50% of total waste. Moisture content in MSW is also high mainly from organic fraction, ranging from 40-60% (DPC, 2004). In addition, removal of noncombustible and wet organic fraction from the raw waste stream will increase the heating value of RDF by 20%. So the study used the waste after separation of organic fraction as the feedstock for RDF production. Current solid waste management at the composting plant in On-Nuch transfer station is illustrated in Figure 3.2.

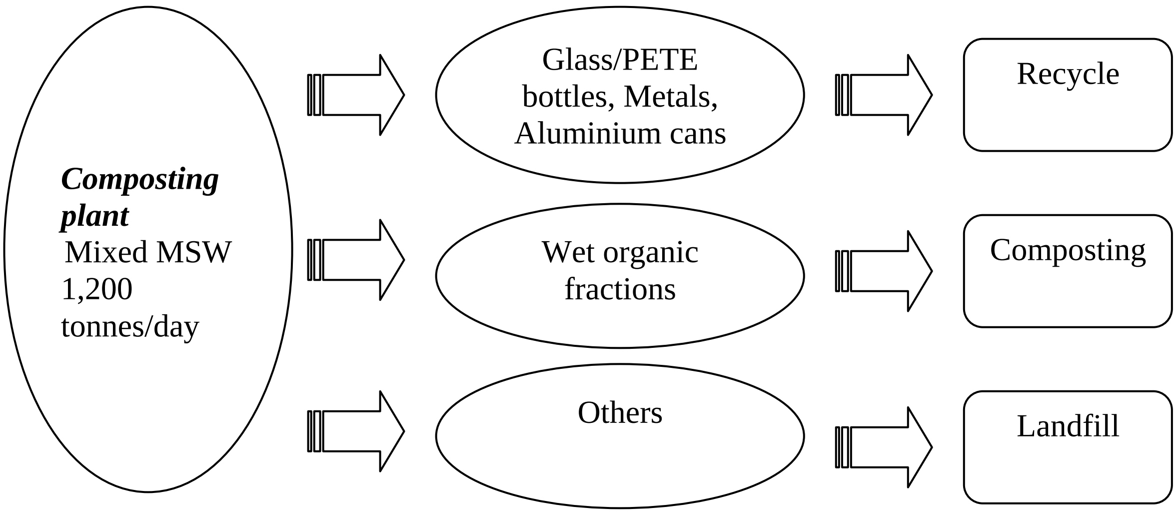


Figure 3.2 SWM at composting plant in On-Nuch transfer station

3.2 Study Framework

In order to achieve the objectives, the study was divided into two main paths namely, target users path and RDF production path. The target users and their requirements on RDF were investigated and then compared with the RDF produced from On-Nuch MSW transfer station. The results from the comparison were interpreted. There were nine main steps in the study as shown in Figure 3.3. Details of each step are described below;

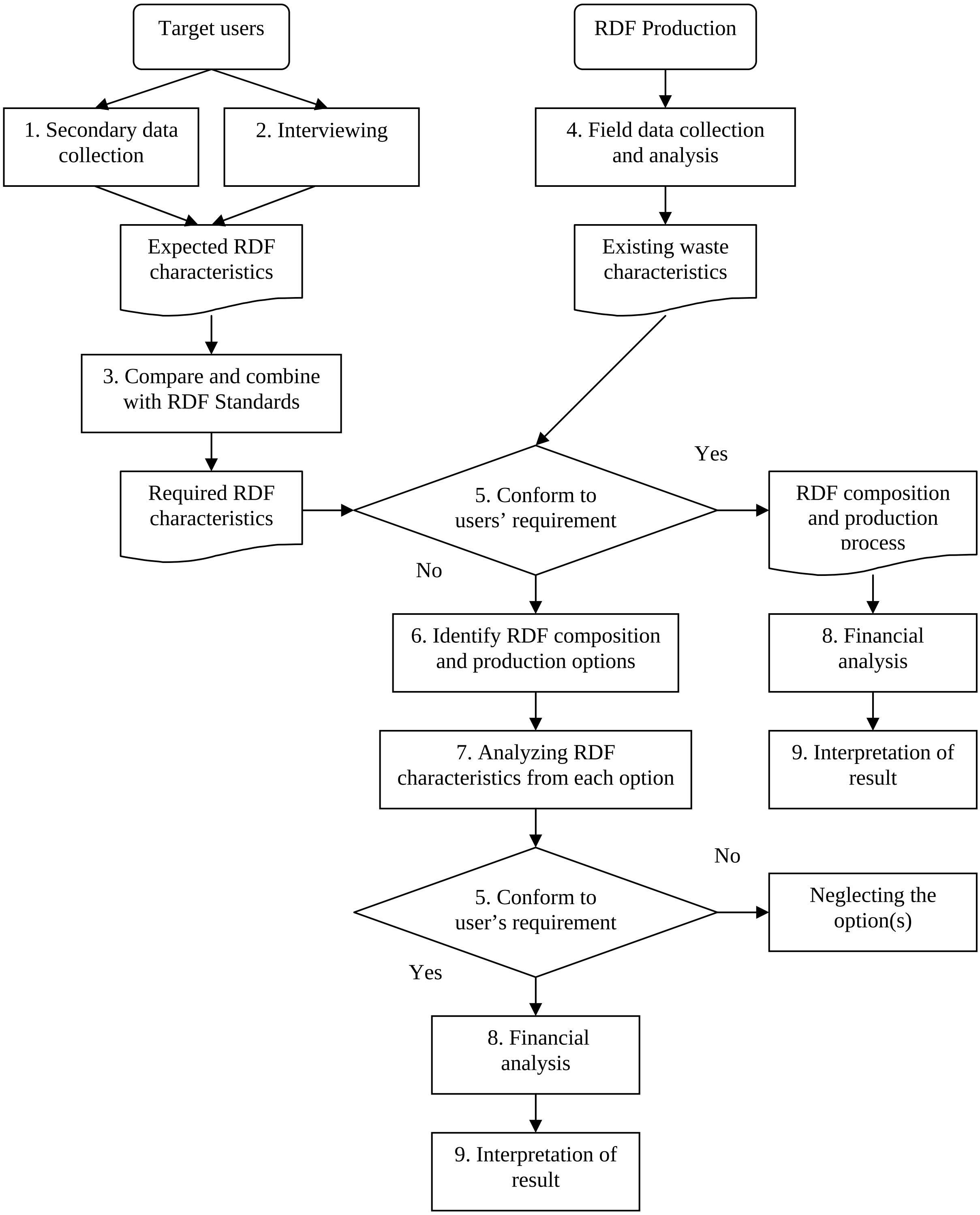


Figure 3.3 Diagram of study framework

3.2.1 Secondary data collection

According to the experiences in Europe and available information from FTI, there are two main industrial groups those should be the target users of RDF in Thailand, namely, cement industries and power producers. However, boiler industries were considered as additional potential RDF users and were included. The name list of the companies in cement and power producer groups are available in FTI website. Secondary information from cement industries and power producers was obtained from company's website and annual report. In case of industrial boilers, secondary data was available on institutional websites regarding to energy consumption. Secondary data obtained is listed below;

- Production capacity
- Type of fuel used
- Air Pollution Control (APC) equipments
- Environmental protection program
- Future plan of expansion

3.2.2 Interviewing

The aim of interviewing was to obtain users' opinion of using RDF, detailed information of fuel consumption, fuel cost as well as combustion process in each company. This information leaded to the required RDF characteristics and cost of RDF production. The interviewing was conducted only for cement industries and power producers because their names and contact information are available in FTI website and listed below. Details of contact persons, address are shown in Appendix D. In case of industrial boilers, only secondary data collection was conducted.

- Cement kilns
    1. Jalaprathan Cement Public Co., Ltd.
    2. Cemex (Thailand), Co. Ltd.
    3. TPI Polene Public Co., Ltd.
    4. Siam Cement Public Co., Ltd.
    5. Siam City Cement Public Co., Ltd.
    6. Asia Cement Public Co., Ltd.

- Power Producers
    1. Gulf Electric Public Company Limited
    2. Glow Energy Public Co., Ltd.
    3. Tri Energy Co., Ltd.
    4. Thai National Power Co., Ltd.
    5. Thai Oil Power Co., Ltd.
    6. Bangkok Co-generation Co., Ltd.
    7. BLCP Power Co., Ltd.
    8. Biomass Power Co., Ltd.
    9. Satuk Biomass Co., Ltd.
    10. Saha Co-gen (Chonburi) Public Co., Ltd.
    11. Laem Chabang Power Co., Ltd.
    12. Eastern Power and Electric Co., Ltd.
    13. A T Bio-power Co., Ltd.

However, not all power producers can be target RDF users. Only power producers those use solid fuels can be target RDF users.

3.2.3 Compare and combine with RDF standards

Information obtained from secondary data and interviewing was compared with RDF standards mentioned in literature review. The differences were marked and the lack standard parameters were fulfilled from European standards. Then users' requirement on RDF was developed and used as criteria for comparison in the next step.

3.2.4 Field data collection and analysis

MSW after separation of wet organic out (for composting) was the sample of base case RDF. Parameters those were analyzed are shown in Table 3.2.

Table 3.2 Analytical parameters

Parameter	Unit	Analytical Standard
Composition	% by weight	ASTM E 889-82*
Moisture content	% by weight	ASTM E 790
Calorific Value	MJ/kg	ASTM E 711
Ash content	% by weight	ASTM E 830-87
Chlorine	% by weight	ASTM E 776-87
Sulfur	% by weight	ASTM E 775-87
Cd	mg/kg	EPA SW-846**
Cr	mg/kg	EPA SW-846
Pb	mg/kg	EPA SW-846
Hg	mg/kg	EPA SW-846

* From ASTM, 2006
**From EPA, 2006b

The waste separation process used in composting plant at On-Nuch transfer station was surveyed and marked as base case RDF production process.

3.2.5 Compare with user's requirement

All parameters analyzed in Table 3.2 were compared with users' requirements obtained from step 3.2.3. If all parameters conform to the requirements then that option is selected for further study on financial analysis. In case of not, that option is neglected.

3.2.6 Identify RDF composition and production options

In case of base case RDF does not conform to users' requirement, other RDF composition and production options are identified. The options are obtained by searching from literatures, manufacturing catalogs and consultation with experts. At least three options are identified.

3.2.7 Analyzing RDF characteristics from each option

RDF samples for each option were made up by manual sorting and then analyzed all parameters mentioned in Table 3.2. After that the analytical results were compared with users' requirement. If all parameters conform to the requirements then that option is selected for further study on financial analysis. In case of not, that option is neglected.

3.2.8 Financial analysis

The details of option that can give required quality RDF were identified. The cost was assigned to all unit operations and summed up. Net cost of RDF production was expressed in term of Baht per GJ and then compared with the price of fossil fuel obtained from users.

3.2.9 Interpretation of result

According to results obtained from step 3.2.8, if the cost of RDF is less than that of fossil fuel, the RDF production is financially feasible. But if not, the subsidies or other means are required and become driving force of RDF production (see Figure 3.4).

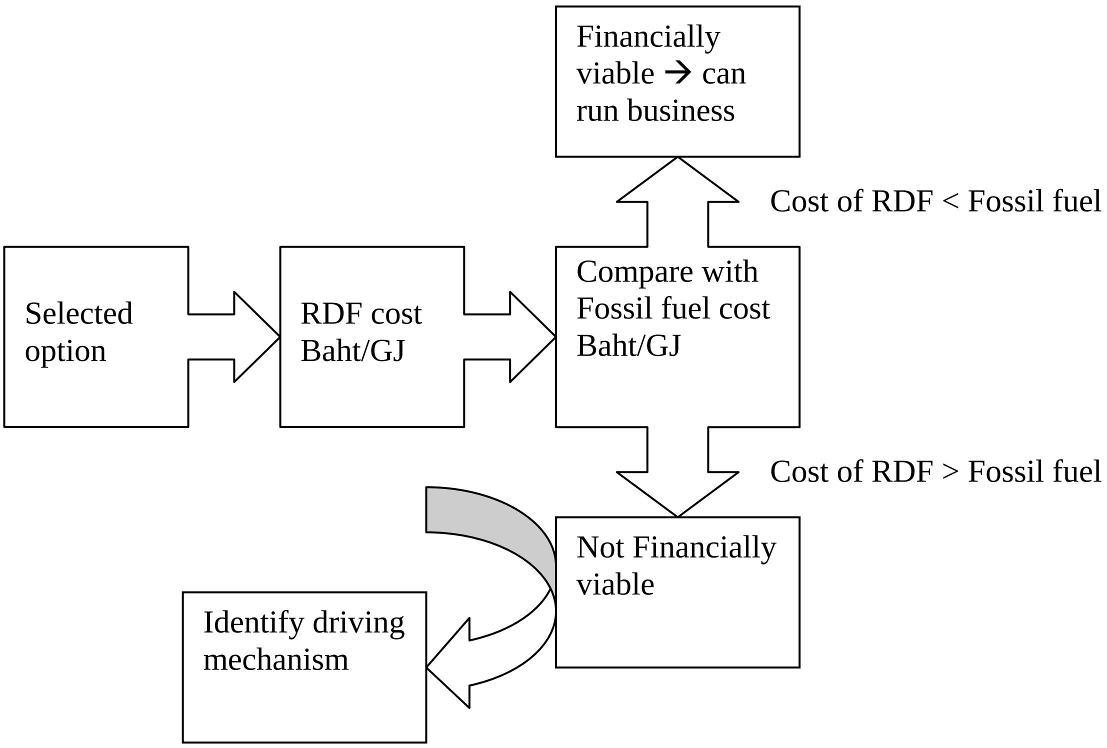


Figure 3.4 Interpretation of results

Chapter 4

Results and Discussions

4.1 Information of On-Nuch's Composting Plant

On-Nuch's composting plant has been operated by Eurowaste Engineering Co., Ltd. under the control of Bangkok Metropolitan Administration (BMA). It is located in On-Nuch solid waste transfer station. Maximum designed capacity of the composting plant is 1,200 tonnes of MSW per day. Presently, it is operated at an average of 1,100 tonnes MSW daily. The collected wastes are MSW from 8 districts in Bangkok. Information of collected waste characteristics and composting process are shown in this section.

4.1.1 Compost production process

Compost production process consists of 3 main units namely, pretreatment, aerobic composting and fine separation. The diagram of overall process and mass balance is simplified in Figure 4.1 below.

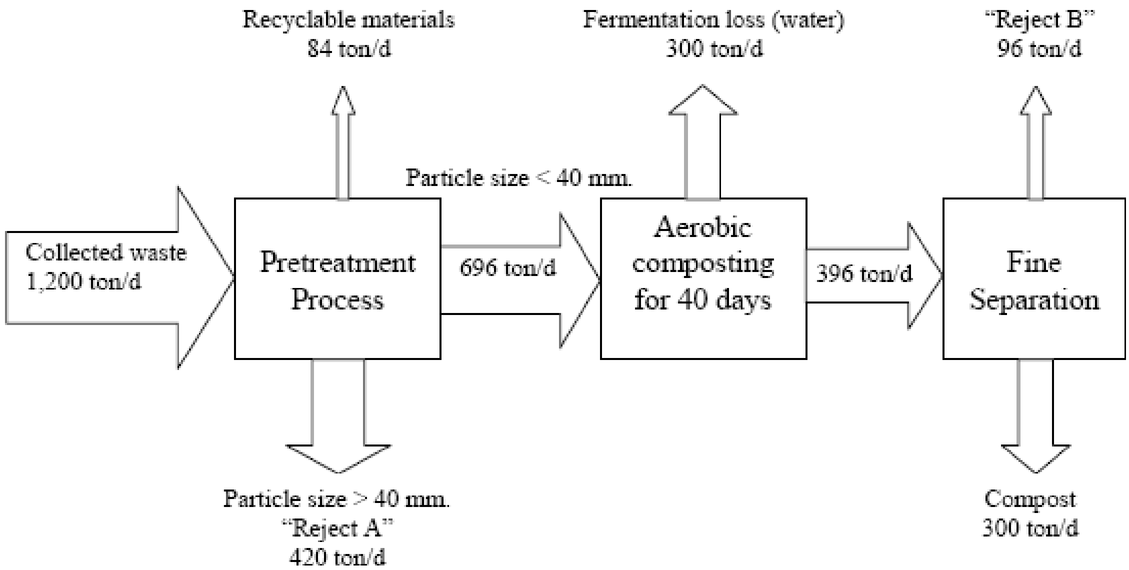


Figure 4.1 Mass balance of compost production process

Pretreatment processes of collected waste prior to composting stage are manual separation, magnetic separation, bag breaking/homogenization and screening. The detail of pretreatment processes is described in the section 4.1.2.

At the end of pretreatment process, waste is sent to a screen with the opening of 40 mm. The undersize is sent to aerobic composting process while the oversize is sent to landfill. Here, oversize, namely Reject A, was selected to study for the potential to make RDF.

In aerobic composting process, the wastes with the size smaller than 40 mm are aerated from the bottom for 40 days. After that there is a fine separation process which generates high calorific value fraction namely, reject B as the by product. Reject B is now collected and transported to test burn at cement kiln by Siam City Cement Public Company limited.

4.1.2 Pretreatment process

In this study, pretreatment process in On Nuch composting plant was used as base case of RDF production process. The pretreatment process consists of 4 unit operations namely, manual separation, magnetic separation, bag breaking/homogenization and screening. The diagram of pretreatment process and mass balance is illustrated in Figure 4.2.

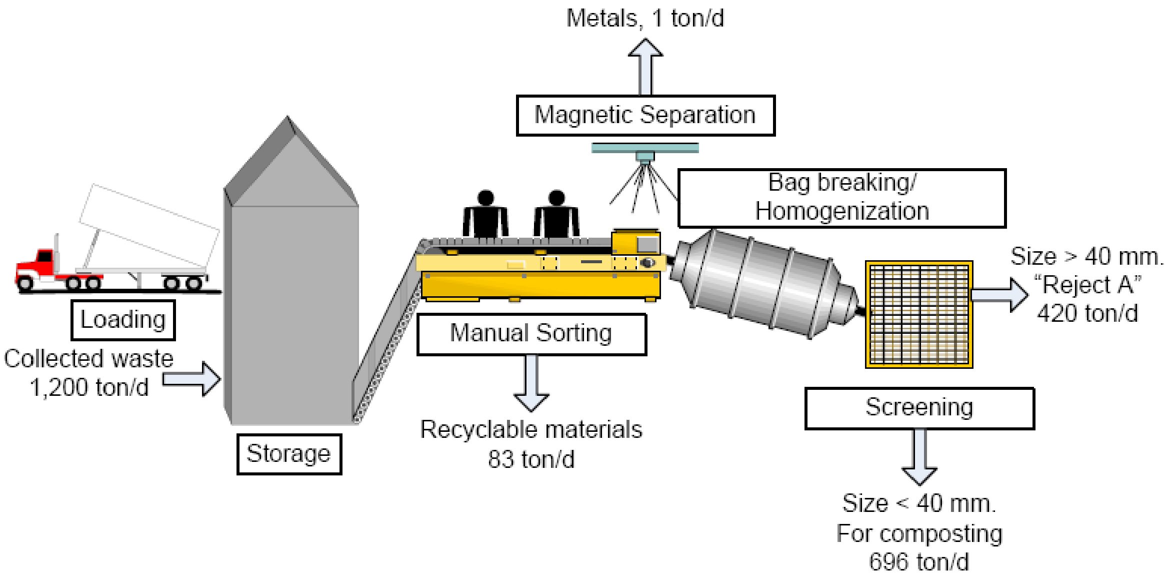


Figure 4.2 Pretreatment process prior to composting and mass balance

In manual separation, the wastes are put on the belt conveyor while the workers separate out the big and recyclable materials such as electrical appliances, furniture, plastic/glass bottles, aluminum cans, etc. The weight of recyclable materials collected daily is approximately 83 tonnes, which is around 7% of collected waste. This unit operation is working efficiently since there are no such mentioned materials in the downstream wastes.

At the end of the belt conveyor, there is a magnetic separator which separates the metals out of the waste stream. Average metal recovery is around 1 ton/d which is only 0.08% of collected waste. But total metal in collected waste is around 0.44% (see Table 4.1). In this regard, magnetic separation does not work properly because its recovering efficiency is only 19%. Therefore, there are still a lot of metals left in the downstream wastes. Recovered metals are sold for recycling purpose.

In bag breaking/homogenization process, the composting plant uses horizontal cylindrical drum to break the plastic bags and mix the wastes thoroughly. Inside, there are cutting blades attached to inner surface of the drum to break plastic bag. The drum is kept slowly rotating in order to enhance the bag breaking and waste homogenization. The retention time in the drum is 12 hours so that partial decomposition of organic matters takes place, so called pre-fermentation. Since there is no aeration in the drum, the decomposition here should be anaerobic fermentation. However, the air can go inside the drum through the opening, so it is not completely anaerobic process. Some water is generated from biological reaction and accumulated inside the drum.

Then the pre-fermented waste is sent to the screen with the opening of 40 mm. The oversize is now sent to landfill and the undersize is sent to process further for composting as mentioned earlier.

4.1.3 Waste characteristics

On-Nuch has been collected the highest portion (40%) of MSW generated in Bangkok. In this regard, waste characteristics here can be used as representative of Bangkok's MSW. Physical and chemical characteristics of collected waste are shown in Table 4.1.

In collected waste, food waste contributes the highest portion in waste stream. It causes high moisture content and hence gives low calorific value. The second rank is plastic. It was observed that it is mainly plastic bag. This is because people usually dispose their wastes in plastic bag. Then the plastic bag is contaminated and too dirty to recycle. So it is left in the waste stream.

From Figure 4.1, there are two points which generate high calorific value fractions. One is the oversize that is sent to landfill, namely reject A and another one is the by product from fine separation, namely reject B. These rejects were analyzed and compared with the collected waste. The result is shown in Table 4.1.

Table 4.1 Comparison of collected waste with Reject A and B

1. Composition	**Collected Waste (% by weight)**	**Reject A (% by weight)**	**Reject B* (% by weight)**
Food waste	42.11	9.48	N/A
Wood and leave	12.72	27.28	N/A
Paper	14.04	9.61	N/A
Plastic	16.23	41.06	N/A
Leather and rubber	5.26	0.39	N/A
Cloth	3.07	4.21	N/A
Bone and Shell	0.44	0.08	N/A
Stone and Ceramic	0.44	6.23	N/A
Metal	0.44	1.01	N/A
Glass	2.19	0.65	N/A
Hazardous waste	1.52	ND	N/A
Others	1.54	ND	N/A
Total	100	100	N/A
2. Bulk density (kg/m^3)	405	141	N/A
3. Moisture content (%)	50.8	60	6.2
4. Ash content (%)	10.8	11.8	15.1
5. Calorific value (MJ/kg) dry basis	6.0	21	29.5

*From Siam City Cement Public Co., Ltd., 2006

It was observed that pretreatment process can reduce food waste from 42% to 9% and increase plastic fraction from 16% to 41% (see the source of information in Appendix A). These values show high wet organic (food waste) separation efficiency. Calorific value is increased from 6 to 21 MJ/kg (dry basis) due to higher plastic fraction. Reject B is the by product from fine separation process after air drying for 40 days. It consists mainly of plastics and wood chips (details of composition are not available) together with low moisture content (6.2%). Therefore, it gives higher calorific value (29.5 MJ/kg) than Reject A. However, it is noted that both reject A and B have relatively high calorific value and can be potentially used as RDF. Increase of %metal in Reject A shows the low metal recovery efficiency of magnetic separation process. Moisture content is increased from 50.8 to 60% because of the accumulation of water from biological reaction mentioned earlier. Ash content is also increase from 10.8 (in collected waste) to 11.8% (in Reject A). This is because of unusual increase in % stone and ceramic which could come from error in waste collection. Due to low moisture content in Reject B, % ash content is increased to 15.1%.

4.2 Potential of Utilizing Reject from Composting as RDF

In this study, three options to use reject A as RDF were developed in order to find out which one is the best option. These three options consist of;

- Option 1: Use reject A as RDF
- Option 2: Remove noncombustible parts from reject A and use as RDF
- Option 3: Select only plastics from reject A and use as RDF

Pretreatment process prior to use as RDF was air drying at 40-50ºC for 24 hours. It could reduce the moisture content from 60% to 11.5%. Noncombustible fractions such as glass, metal and ceramic were separated out manually. For option 3, only plastics were selected by hand. Then the physical and chemical characteristics of each option were analyzed and compared with RDF standard and users' requirement (see Table 4.2).

4.2.1 Technical aspect

In technical aspect, three indicators were used to identify which option is the best among there options. Three indicators consist of characteristics of various options in comparison with RDF standard and users' requirement, potential energy supply and ash/residue generation.

- **Comparison of various options' characteristics with RDF standard and users' requirement**

In this issue, three options of using Reject A as RDF were analyzed in comparison with Reject B, European RDF standard and users' requirement. The result is shown in Table 4.2.

Table 4.2 Comparison of various options with RDF standard and users' requirement

Parameter	Option 1	Option 2	Option 3	Reject B*	RDF Standard**	Users' Requirement***
Calorific Value (MJ/kg) (Dry basis)	20.8	21.3	33.2	29.5	N/A	N/A
Moisture content (%)	11.5			6.2	< 25	<30
LHV**** (MJ/kg)	19.4	19.9	31.8	N/A	> 15	Not specified
Ash content (%)	11.8	8.7	8.8	15.1	< 5	Not specified
Sulfur content (%)	0.20	0.18	0.13	0.17	< 0.4	< 1
Chlorine content (%)	0.58	0.66	0.68	2.46	< 0.5	< 1
Cd (mg/kg)	0.6	0.8	1.3	<0.01	< 10	Not specified
Cr (mg/kg)	79	120	50	162	< 200	Not specified
Hg (mg/kg)	0.56	0.59	0.63	<0.05	< 2	< 3
Pb (mg/kg)	28	78	67	50	< 200	Not specified

* From Siam City Cement Public Co., Ltd., 2006
**From European standard
***From cement industries
****Calculate from Table 2.3 and Equation 2.2, using H = 5% and moisture content = 11.5%

From Table 4.2, moisture content for all options was reduced from 60% to 11.5% by air drying at 40-50ºC for 24 hours. Ash content was reduced from 12% to 9% after separation of noncombustible parts. Anyway, ash content after separation of noncombustible fractions was still higher than RDF standard. Sulfur content for all options did not exceed RDF standard but chlorine content in all options was higher than standard. However, all options could produce RDF that has quality conformed to users' requirement. All heavy metal concentrations did not exceed standard. But it was noticed that all most all heavy metal concentrations tend to increase when increasing in plastic fraction. The reason is that plastic contains certain amount of heavy metals from dye (pigment) and it is normally contaminated by heavy metal when it was used for some chemical packaging.

Almost all parameters of Reject B conform to users' requirement except chlorine content. It is interesting that chlorine content in Reject B is relatively high compared with Reject A. The reasons why chlorine content is very high in Reject B may come from higher plastic fraction and low moisture content in Reject B. According to higher chlorine content than users' requirement, Reject B alone could not be used as RDF. However, Reject B can be mixed with Reject A to reduce chlorine content and used as RDF.

- **Potential energy supply**

Potential energy supply from each option was identified by simple calculation and then compared as shown in Table 4.3 (see detailed calculation in Appendix B).

Table 4.3 Potential energy supply from 1,100 ton/d of wastes

	Option 1	Option 2	Option 3
1. Waste quantity (ton/d) (wet basis)	385	354	158
2. Pretreatment	Air drying	Air drying + Manual sorting	Air drying + Manual sorting
3. Difficulty of pretreatment	Low	High	Moderate
4. Waste quantity (ton/d) (dry basis) = 1 * 40%	154	141.6	63.2
5. Calorific value (MJ/kg) (dry basis)	20.8	21.3	33.2
6. Potential energy supply (10^6 MJ/d) = 4 * 5	3.20	3.02	2.1

It was shown that option 1, using all Reject A as RDF, gives the highest energy supply (3.20 x 10^6 MJ/d) and relatively easy pretreatment. In this regard, option A is the best option in term of potential energy supply with ease of pretreatment.

- **Ash generation and residue to landfill**

The amount of ash generation and residue to land fill from each option was calculated and summarized in Table 4.4 (see detailed calculation in Appendix C).

Table 4.4 Ash generation and residue to landfill from 1,100 ton/d of wastes

	Option 1	Option 2	Option 3
1. Waste quantity (ton/d) (wet basis)	385	354	158
2. Ash content (%)	11.8	8.7	8.8
3. Ash generation (ton/d) = 1 * 2	45.43	30.8	13.9
4. Waste remaining (ton/d) (dry basis)	0	12.4 (154 – 141.6)	90.8 (154 – 63.2 – 56.6*)
5. Ash and residue to landfill (ton/d) = 3 + 4	45.43	43.2	48.1
6. Difficulty of pretreatment	Low	High	Moderate

* 56.6 ton/d is biodegradable fraction and can be sent back to compost production process

From Table 4.4, it is shown that option 2 gives the lowest ash and residue to landfill. However, the value of option 2 is not much different from option 1 (43.2 ton/d and 45.43 ton/d respectively) but more complicated manual separation is needed for option 2. Therefore, option 1 is more attractive than option 2 in term of ash and residue to landfill with ease of operation.

Based on the above discussed three issues, it can be concluded that option 1 is the best option of using reject A as RDF because it produces RDF conformed to user's requirement, gives the highest energy supply, easiest pretreatment and relatively low ash/residue generation to landfill. Therefore, %C, %H, %O, %N, %S of RDF from Option 1 were analyzed and compared with fossil fuels as follows;

Table 4.5 Comparison of elements and heating value in RDF and coal

	%C	%H	%O	%N	%S	%Ash	Heating Value (MJ/kg)
Reject A as RDF*	56.61	2.33	29.23	0.02	0.01	11.8	20.8
Lignite**	60-75	6.0-5.8	34-17	N/A	0.5-3	N/A	< 28.5
Anthracite**	> 91.5	< 3.5	< 2.5	N/A	Approx. 1	N/A	< 35.3

* See Appendix F
**From http://en.wikipedia.org/wiki/Coal

%C indicates the heating value of fuel, higher %C, higher heating value. From Table 4.5, it shows that RDF from Option 1 has relatively high %C which is closed to %C of Lignite. Therefore, RDF from Option 1 can be used as fuel, however, lower quality than Lignite.

From Dulong formala (Equation 2.1) mentioned in Chapter 2,

$$\text{Higher Heating Value (MJ/kg)} = 337C + 1419(H_2 - 0.125O_2) + 93S + 23N$$

By substitution with information from Table 4.5,

Theoretical HHV of RDF = 17.2 MJ/kg

Difference of calorific value from bomb calorimeter from theoretical value
= (20.8-17.2) / 17.2 x 100
= 21%

4.2.2 Potential RDF users and market size

In this study, two users namely, cement industries and power producers were investigated by interviewing (details of contact persons are in Appendix D) and one additional user namely, industrial boiler was investigated by secondary data collection and analysis.

- **Cement industries**

In this study, six cement companies in Thailand were interviewed. All of them are interested in using RDF as supplementary fuel because the price of coal has been increasing. Existing cement kilns can burn RDF without any modifications. In addition, operating temperature in cement kiln is also high up to 1,450 ºC which dioxin can not form. Acid gas is trapped by calcium oxide in the kiln. Moreover, all cement kilns are well equipped with air pollution control equipment such as bag house, electrostatic precipitator and scrubber. Therefore, they are ready to handle with air emissions, especially dioxin and acid gas.

According to information obtained from interviewing, required RDF qualities for cement industries are;

- Particle size < 30 mm.
- Sulfur content < 1%
- Chlorine content < 1%
- Moisture content < 30%
- Hg content < 3 mg/kg
- Cost of RDF < 300 Baht/Gcal (71.4 Baht/GJ)

The applicable feeding point is at pre-calciner which requires lower quality of fuel than that of main burner. However, RDF can be fed at main burner but the heating value of RDF has to be kept constant at not less than 20 MJ/kg and processed in power form.

Environmental Impact Assessment (EIA) of co-combustion of coal and RDF in cement kiln in Thailand done by Siam City Cement Public Company Limited proposed that RDF can be used to substitute coal up to 40% (energy basis). Although this figure has not been approved by Office of National Resources and Environmental Policy and Planning (ONEP), it can be used as a guide figure for estimation of RDF market size in Thailand. Therefore, potential RDF market size for cement industries can be estimated by multiplying fuel consumption with 40%. The results are shown in Table 4.6.

Table 4.6 National cement production capacity and potential RDF market size

Company	**Location**	**No. of Kiln**	**Clinker production capacity (Mt/y)**	**Energy consumption* (10^9 MJ/y)**	**RDF market size** (10^9 MJ/y)**
Siam Cement	Lampang	1	1.71	5.46	2.19
	Saraburi	7	11.47	36.71	14.68
	Nakorn Sri Thammarat	6	5.58	17.85	7.14
Siam City Cement	Saraburi	6	11.93	38.19	15.28
TPI Polene	Saraburi	3	7.28	23.31	9.32
Asia Cement	Saraburi	2	4.03	12.90	5.16
Jalaprathan Cement	Nakorn Sawan	2	0.93	2.98	1.19
	Petchburi	1	0.96	3.07	1.23
Cemex	Saraburi	2	0.53	1.68	0.67
Total		**30**	**44.42**	**142.15**	**56.86**

*3,200 MJ/ton of clinker
**40% of energy consumption

Potential cement plants to use RDF from Bangkok solid waste transfer stations are those who located in Saraburi because of the shortest distance. Therefore, total RDF market size for RDF from Bangkok is around 45.11 x 10^9 MJ/y.

Assuming RDF has calorific value of 21,000 MJ/t (dry basis) and moisture content in MSW is 60%. RDF receiving capacity of cement plants those are located in Saraburi is $2.15*10^6$ ton/y (45.11×10^9 MJ/y / 21,000 MJ/t) (dry basis). Bangkok solid waste generation is around 8,300 ton/d (wet basis) (PCD, 2005b). From Figure 4.1, RDF contributes 43% of MSW (Reject A + Reject B), thus RDF from BMA is approximately 43% * 8,300 ton/d * 365 d/y * 40% = $0.52* 10^6$ ton/y. It means that cement plants those are located in Saraburi have enough receiving capacity for RDF generated from BMA.

- **Power producers**

In this study, thirteen power producers were interviewed for the opinion of using RDF as supplementary fuel. Nine companies are using natural gas and diesel oil so they are not interested in using RDF. Only four companies using solid fuel such as bituminous and rice husk gave their opinions on using RDF. Interview summary from these four companies is shown in table 4.7.

Table 4.7 Interview summary from power producers

Company	Location	Fuels	Opinions
BLCP Power Ltd.	Chonburi	Bituminous	- now imports low sulfur (less than 0.4%) bituminous from Australia and Indonesia - burner is designed for bituminous and not applicable for RDF
Biomass Power Ltd.	Chainat	Rice husk	- concerns about toxic gas emission especially dioxin and acid gas, RDF handling and public acceptance - does not have dioxin, acid gas control equipments
Satuk Biomass Ltd.	Burirum	Rice husk, wood	- concerns about RDF storage, handling, occupational safety due to pathogens in RDF, public acceptance - unsure about consistency of pretreatment efficiency and RDF quality - need to have RDF dedicated boiler and special air pollution control equipments - municipality must pay for combustion of RDF
AT Biopower Ltd.	Phichit	Rice husk	- concerns about toxic gas emission especially dioxin and acid gas, RDF handling and public acceptance - does not have dioxin, acid gas control equipments

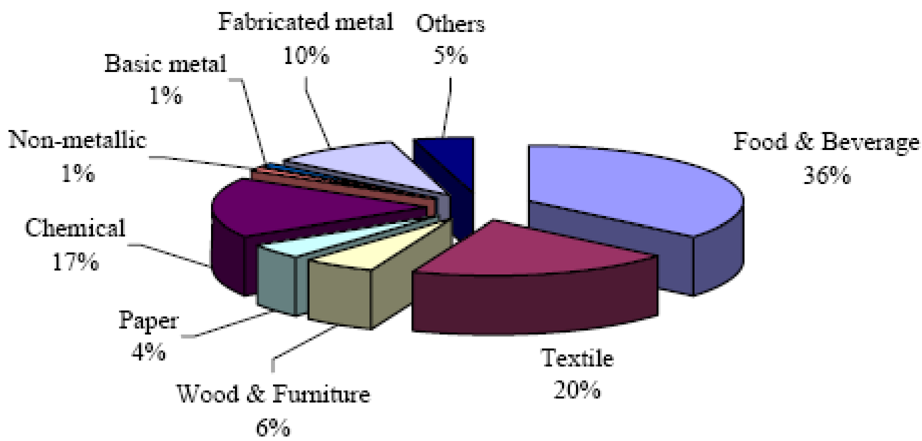
It can be concluded from Table 4.7 that power producers those use solid fuel in Thailand are not ready to use RDF as fuel because of the following reasons;

- existing burners are not designed for combustion of RDF
- they do not have air pollution control equipment especially for dioxin and acid gas
- concerns about occupational safety of RDF handling and public acceptance
- consistency of front end treatment efficiency and RDF quality

- **Industrial boilers**

Numbers of boilers registered in Thailand are 3,316 sets from 1,893 factories. The provinces those have boilers more than 100 sets are Bangkok (269), Chonburi (228), Nakorn Phathom (153), Pathumthani (228), Ayudhaya (145), Rayong (238), Samut Prakarn (591), Samut Sakorn (293).

Boilers are used in many industrial sectors such as food and beverage, textile, wood and furniture, paper, chemical, non-metallic, basic metal and fabricated metal industries. Percentage of boilers classified by type of industries is shown in Figure 4.3.



Source: kmutt, 2004

Figure 4.3 Percentage of boilers classified by manufacturing sector

Fuels used in boiler are coal and lignite, petroleum product, natural gas and biomass. In this study, it is focusing on solid fuels (coal and lignite and biomass) which RDF can be stituted. Energy consumption from solid fuels for each manufacturing sector is illustrated in Table 4.8.

Table 4.8 Solid fuels consumption of various manufacturing sectors

Industry	Coal & Lignite (ktoe*/y)	Biomass (ktoe*/y)
Food & Beverage	41	4,311
Textile	73	N/A
Wood & Furniture	N/A	11
Paper	301	N/A
Chemical	702	111
Non-metallic**	3,461	192
Basic metal	247	N/A
Fabricated metal	N/A	N/A
Others	50	N/A
Total	4,875	4,625

* kilo tonnes of oil equivalent (1 ktoe = 41,846,000 MJ)
** Including cement industries

Source: Modified from TEENET, 2004

Assuming that RDF can be substituted for coal and lignite and biomass by 100%, potential market size for boiler industries those use coal and lignite is approximately 204 x 10^9 MJ/y (4,875 ktoe * 41,846,000 MJ/ktoe) – 142 x 10^9 MJ/y (from cement industries) = 62 x 10^9 MJ/y and biomass is around 194 x 10^9 MJ/y (4,625 ktoe * 41,846,000 MJ/ktoe). Therefore, total RDF market size for industrial boilers is around 256 x 10^9 MJ/y (62 x 10^9 + 194 x 10^9 MJ/y).

However, currently, industrial boilers can not use RDF which contains 40% of plastic. This is because all combustors used in industrial boilers are not designed for plastic combustion and hence can not burn plastic. If we would like to apply RDF which contains high amount of plastics in industrial boilers, existing combustors have to be replaced with special type combustors.

Based on information described earlier, it can be concluded that among three potential RDF users, cement industries are ready to use RDF as substituted fuel by 40% of total energy consumption (57 x 10^9 MJ/y). On the other hand, currently, power producers and industrial boilers those use solid fuels are not ready to use RDF. But in the future, they might be potential RDF users those can use RDF as substituted fuel up to 100% of energy consumption (> 256 x 10^9 MJ/y) depending on the driving mechanisms.

Potential RDF market size for cement industries and industrial boilers are summarized and shown in Table 4.9 below;

Table 4.9 Summary of RDF market size

	Cement Industries	Industrial boilers
Energy demand (10^9 MJ/y)	57	256
RDF market size* (10^6 t/y) (dry basis)	2.7	12.2

*****21,000 MJ/t of RDF (dry basis)

From Table 4.9, overall RDF market size from cement industries and industrial boilers is approximately 14.9 million tonnes of RDF per year (dry basis), whereas total MSW generation in Thailand is around 14.3 million tonnes per year (PCD, 2005b) (wet basis). In this figure, RDF is accounting for 43% of MSW (from Figure 4.1, Reject A + Reject B) or 6.15 million tonnes yearly (wet basis). Assuming moisture content in the waste is 60% then RDF's weight is 2.46 million tonnes per year (dry basis). It means that Thailand is now having sufficient capability to handle with 100% RDF generated in the whole country by burning in cement kilns alone. However, industrial boilers could potentially be RDF users and manage the waste that will be increasing in the future.

4.2.3 Financial Aspect

From technical aspect, it is shown that option 1, using all reject A as RDF, is the best option due to the highest energy supply, relatively low residue to landfill and easiest operation. Therefore, financial aspect was conducted for option 1 only.

In this study, On-Nuch solid waste characteristics were used as representative of Bangkok municipal solid waste. Pretreatment of waste prior to composting was used as front end processing of RDF production. Therefore, financial aspect was conducted under these assumptions.

Plant construction and land cost

Assuming that;

- Plant life time = 20 years
- Linear depreciation is used
- Land cost at On-Nuch = 24 – 56 millions Baht/rai (Department of Lands, 2007)
  Select the average value = 40 millions Baht/rai

Plant construction cost	=	400 millions Baht (BMA, 1994)
Plant area	=	50 rai (1 rai = 1,600 m^2)
Land cost	=	50 rai x 40 millions Baht/rai
	=	2,000 millions Baht
Total	=	2,400 millions Baht
	=	2,400 millions/20 y/(365 d/y)/(1,100 ton/d)
	=	299 Baht/ton

Machine and Electricity cost

Unit operations used in pretreatment of On-Nuch composting plant are;

1) Belt conveyor
2) Manual sorting
3) Magnetic separation
4) Bag breaking/homogenization
5) Screen

Additional unit operations needed for production of RDF;

1) Drying
2) Shredding
3) Pelletizing

Utilizing cost of each unit operation from Table 2.8 with the following assumptions;

- Operating 6 days/week, 14 h/d (2 Shifts)
- Life time of equipment = 10 years
- Electricity cost = 0.0723 Euro/kWh (3.62 Baht/kWh)

Above assumptions are from Caputo and Pelagagge (2001) mentioned in section 2.2.4

- 200 baht/sorter, 4 sorters/shift
- Capacity of the plant = 1,100 tpd (14 h/d = 78.6 t/h)
- Bag breaking is equivalent to hammer mill

Cost of RDF production base on On-Nuch composting plant is shown in Table 4.10 (see detailed calculations in Appendix E).

Table 4.10 RDF production cost base on On-Nuch composting plant

Unit operation	Cost (Baht/t)*
Belt conveyor	0.04
Manual sorting	1.45
Magnetic separation	1.50
Hammer mill	210.50
Trommel screen	12.50
Drying	143.50
Shredding	22.00
Pelletizing	104.50
Total	495.99

*1 Euro = 50 Baht, the cost includes only machine's depreciation and electricity

Total Production Cost

Total Production cost	=	Plant construction + land + equipment + electricity
	=	299 + 495.99
	=	795 Bah/ton

Considering the case of using RDF for cement industries, RDF will be financially viable if the price at cement factory is less than 71.4 Baht/GJ (from section 4.2.2).

Assuming that transportation cost from On Nuch to cement plant in Saraburi by 10-wheel truck is 6,200 Baht (round trip) and carrying capacity is 14 ton/truck. Therefore, transportation cost is 443 Baht/t of RDF.

Production cost + transportation cost = 795 + 443 = 1,238 Baht/t. One tonne of RDF has 19,400 MJ or 19.4 GJ. Therefore, production and transportation cost of RDF from Bangkok to cement plants in Saraburi is around 1,238/19.4 = 63.8 Baht/GJ.

It can be concluded that RDF utilization in cement industries will be financially viable if

63.8 + Profit < 71.4 Baht/GJ

4.3 Possible RDF Composition and Production Process

In this section, possible RDF composition and production process were developed from information obtained from On Nuch composting plant.

4.3.1 Possible RDF composition and Characteristics

From section 4.1.3 and 4.2.1, it is shown that Reject A after treatment can be used as RDF and conforms to users' requirement. In this regard, Reject A's characteristics can be used as possible RDF characteristics as follows;

- Composition

- Plastic content		40%
- Wood and leave		30%
- Food waste	not more than	10%
- Paper	not more than	10%
- Others including noncombustible	not more than	10%

- Characteristics

- Particle size	not more than	30 mm.
- Moisture content		12%
- LHV		19.4 MJ/kg
- Ash content		12%
- Sulfur content		0.20%
- Chlorine content		0.60%
- Cd		0.60 mg/kg
- Cr		80 mg/kg
- Hg		0.60 mg/kg
- Pb		30 mg/kg

4.3.2 Appropriate RDF production process

Criteria for selecting appropriate RDF production process

- Produced RDF quality conforms to users' requirement
- Gives the highest energy supply from same amount of waste input
- Generates minimum and non-biodegradable residue to landfill
- Easy to operate
- Easy to transport and save transportation cost
- Financially viable

Based on technical and financial aspects, it was proved that pretreatment process prior to composting at On Nuch composting plant and some additional treatments (Option 1) are suitable for making RDF, because it serves all criteria mentioned above. Appropriate RDF production process is summarized in Figure 4.5.

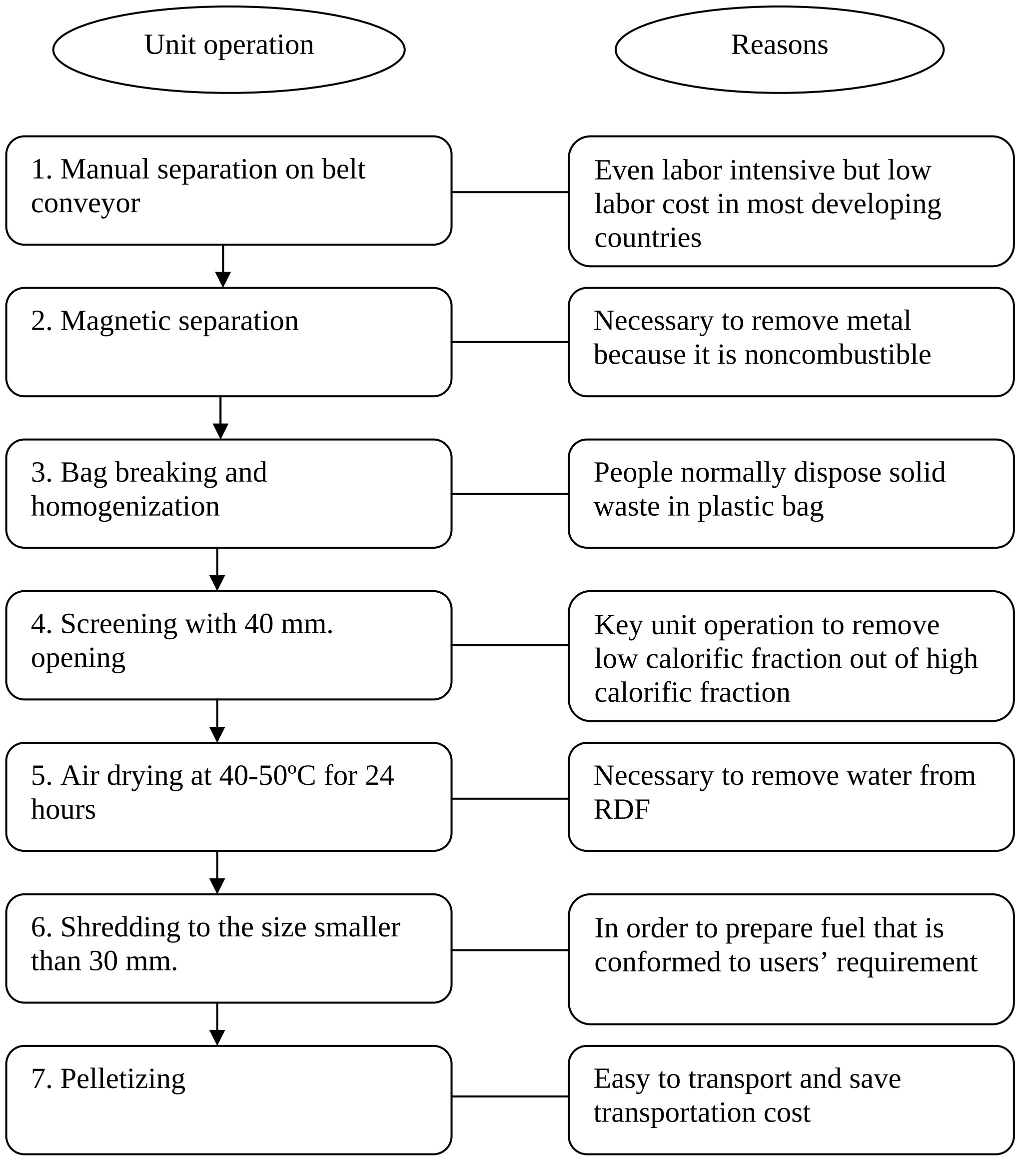


Figure 4.4 Appropriate RDF production process and reasons

4.3.3 Other influences on RDF characteristics

There are two main factors influencing on RDF characteristics in Thailand namely, role of Wongpanit Garbage Recycle Separation Company and project to make oil from plastic waste. Their influences on RDF characteristics are described below;

- **Role of Wongpanit Garbage Recycle Separation Company**

Wongpanit Garbage Recycle Separation Company is the biggest waste recycling company in Thailand. The company has several branches of waste recycling shops all over the country. Its business is buying recyclable wastes from community, intermediate treating and shipping to the recycling factories. Wongpanit Garbage Recycle Separation Company's role affects positively to RDF characteristic because it enhances waste separation at source. For example, noncombustible components such as glass, metal, aluminum can are removed at source, plastic bottles and caps which may contain PVC are removed from the waste stream. However, not all plastics are removed, plastic bags are not worth to recycle because they are normally contaminated and hence left over in the waste stream. In this regard, remaining waste containing plastic bags can be used as RDF feed stock.

- **Project to make oil from plastic waste**

Recently, Poland is introducing new technology to convert plastic waste into oil by using de-polymerization process. The Ministry of Energy plans to launch a pilot project in Samut Prakarn province (Praiwan, 2007). This project will affect negatively on RDF characteristics since plastic fraction will be diverted from RDF. The diversion of plastic waste from RDF will reduce calorific value of RDF.

4.4 Barriers and Possible Strategies of RDF Utilization in Thailand

According to information from potential RDF users, only cement industries are now ready to use RDF at 40% substitution. Although there are many barriers to the use of RDF as substituted or supplementary fuel in many industries, RDF utilization in Thailand will be possible if some policy and strategies are applied. Barriers and possible strategies are summarized and described one by one in this section as follows;

4.4.1 Technological Barriers

- **RDF production process**

Currently, there is no RDF production plant in Thailand. Although there are many research institutions studying the RDF production processes, none of them is formally proved to be suitable for Thai condition. Thailand still needs technology transfer from developed countries and adapts it to the local Thai conditions. Therefore, appropriate RDF production process in Thailand is recommended in this study.

Possible strategies for RDF production process are;

- Collaboration with developed countries for technology transfer, for example, MBT plant in Phitsanulok municipality (mentioned in chapter 2) is the collaboration between local government, institutional sector and the German company. It is generating high amount of high calorific fraction product and now under investigating the potential of minimizing the transportation cost to cement industries.

- Setting up pilot scale RDF production plants, which are potentially possible for Thai condition, to come up with the appropriate option(s). Based on these pilot studying, experiences, it could be further expanded later.

- **RDF combustion process and emission control**

Presently, only cement kilns can burn RDF and have capability to handle the air emissions. Other potentially possible RDF users such as power producers and industrial boilers still can not use their existing burners to burn RDF. They also do not have sufficient air pollution control equipment. In this regard, RDF combustion and emission control technologies are needed.

Possible strategy relating to RDF combustion process and emission control is;

- Technology transfer from developed countries in both installing new equipment and modifying or upgrading the existing equipment

- **Consistency in RDF quality and quantity**

RDF users are reluctant to use RDF because of they concern about consistency of RDF quality and quantity. Since RDF is made of MSW, its composition and amount may change from season to season.

Here are some possible strategies to overcome this barrier;

- Government has to set up RDF standard

- Company has to provide quality control measure for RDF production process

- Users should have dual-fuel or multi-fuel burners and use RDF as supplementary fuel to prevent seasonal effect from insufficient supply of RDF

4.4.2 Economical Barriers

- **Cost of RDF production process is higher than existing landfilling**

According to the cost data illustrated in Table 4.9, cost of RDF production is around 500 Baht/ton. This cost excludes plant construction, land, maintenance, overhead and transportation cost to users. Whereas landfill cost is now approximately 500 Baht/ton including everything. This issue makes RDF now is not attractive.

Possible strategies for this barrier are;

- Government has to promote the integrated solid waste management hierarchy and set up national policy regarding to minimization of waste to landfill

- Additional tax or fee for waste disposal in landfill has to be set up especially for new landfill site. This is to increase the cost of landfilling and make it is non-economical option.

- **High investment cost of RDF production plant**

Average unit capital cost of RDF production plant is around $98,000 per ton of MSW per day (3.43 million Baht/t/d) (Division of Pollution Prevention and Environmental Assistance, 1992a). This cost is relatively high compared to landfill cost which includes only land cost, lining and leachate collection and treatment system. In Thailand, there is no limitation of land available for landfill and hence land does not cost much. In addition to high investment cost, investors are reluctant to construct RDF production plant because there is no guarantee on price of RDF and RDF market.

Possible strategies to overcome this barrier are;

- Setting up suitable pattern of shareholders, for example public-private partnership and also type of business whether Built-Operate-Transfer (BOT) or Built-Own-Operate-Transfer (BOOT).

- Asking for financial aid or fund from both international organization such as Asian Development Bank (ADB), developed countries in CDM project and national organization such as The Board of Investment of Thailand (BOI), Ministry of Energy, for example, BOI has to offer tax-free for importing equipment relating to RDF production and Ministry of Energy has to provide soft loan for investment

.

- Government has to set up an incentive for RDF users such as lower the tax when using RDF. In addition, the government has to guarantee the minimum price of RDF.

- **RDF burner and additional air pollution control equipment are required**

As mentioned earlier, existing burners are not capable to burn RDF except cement kilns. In addition, existing air pollution control equipment in power producers and industrial boilers is insufficient to handle with emission from RDF combustion (dioxin, acid gas). Therefore, it needs to import special type of burner or modified the existing burner to burn RDF. According to information from Division of Pollution Prevention and Environmental Assistance (1992b), additional cost of modifying coal-fired power plant to co-combustion with RDF is ranging from $17 - $22 per kW (595 – 770 Baht/kW) depending on power production capacity. Furthermore, emission standard for combustion of RDF has not been set up. There are only emission standards for coal, fuel oil, natural gas, biomass and waste incineration. Possibly applicable emission standard for RDF combustion is that of incineration. But it is quite stringent and may lead to unnecessary high cost of air pollution control equipment.

Possible strategies for this issue are;

- Government has to offer tax-free and also provide soft loan for importing RDF burner and air pollution control equipment relating to RDF combustion.

- Government has to set up appropriate emission standards for co-combustion with RDF or pure RDF combustion to optimize cost of air pollution control equipment.

- **High transportation cost**

According to cost data mentioned in section 4.2.3, cost of RDF transportation from production plant (On-Nuch) to users (cement industries in Saraburi), which is around 300 km. away, is approximately 450 Baht/ton. This figure nearly equals to cost of RDF production (500 Baht/ton).

Possible strategy to solve this barrier is;

- Target RDF users have to be identified and arranged in zoning system. After that government together with investor has to find the appropriate RDF production plant's location which brings the shortest distance and covers zone's demand.

4.4.3 Health and Safety Barriers

- **RDF handling**

RDF is made from solid waste. Even the quality is improved but still some unpleasant smell, pathogen remained. In this regard, workers are reluctant to handle with RDF and special handling system is required.

Possible strategies for RDF handling barrier are;

- Company has to educate workers and people who are dealing with RDF about basic knowledge of RDF. When people know more about RDF, they will automatically have more positive opinion on RDF.

- Company has to train workers to wear glove and mask when handling with RDF for health and occupational safety

- **Public resistance on RDF combustion**

People who do not know about RDF may think that RDF combustion is the same as waste incineration and then automatically resist. The major concern is emission from RDF combustion especially dioxin and acid gas.

Possible strategies to solve public resistance are;

- Basic knowledge about RDF and benefits from RDF utilization have to be promoted in national and local levels.

- The companies those use RDF should have strong commitment to conserve environment, create the good image and contribute some social welfare.

4.5 Driving Mechanisms of RDF Utilization in Thailand

From barriers and possible strategies of RDF utilization in Thailand mentioned in section 4.4, driving mechanisms of RDF utilization in Thailand are summarized in Table 4.11 as follows;

Table 4.11 Driving mechanisms of RDF utilization in Thailand

Driving mechanisms	Level of importance	Time requirement
1. Concern of global warming and increasing in the price of fossil fuel	High	Short
2. Promotion of integrated solid waste management hierarchy which aims to minimize quantity of waste to landfill by government	High	Medium

Chapter 5

Conclusions and Recommendations

5.1 Conclusions

1) MSW generation in Thailand is approximately 14.3 Mt/y. In this figure, Bangkok contributes approximately 3 Mt/y (21%). Based on mass balance in Figure 4.1 and waste characteristics discussed in chapter 4, RDF contributes approximately 43% (Reject A + Reject B) of collected waste (wet basis). Average moisture content in Reject A and B is 60%. Therefore, potential RDF production in Thailand is approximately 2.46 Mt/y (dry basis).

2) Potential RDF composition from Bangkok MSW, which can produce RDF conformed to users' requirement, consists of 40% plastic, 30% yard waste, less than 10% paper, 10% food waste and 10% noncombustible fraction. It has LHV around 19.4 MJ/kg or 19.4 GJ/t. Chlorine content is around 0.6% and sulfur content is around 0.2%. Heavy metals such as Cd, Cr, Hg and Pb content do not exceed European RDF standard.

3) %C in produced RDF is approximately 57% which is relatively closed to %C in Lignite (60-75%). It means that produced RDF can be used as fuel, however, lower quality than Lignite.

4) Potential RDF market size from cement industries and industrial boiler is approximately 14.9 Mt/y of RDF, 2.7 Mt/y from cement industries and 12.2 Mt/y from industrial boilers. Majority of cement industries are ready to use RDF at 40% substitution (energy basis) without any plant modification. Whereas industrial boilers and power producers are not ready to use RDF because their existing incinerators can not burn RDF and they do not have sufficient air pollution control equipment especially for dioxin and acid gas

5) RDF receiving capacity of cement industries is around 2.7 Mt/y while potential RDF production in Thailand is around 2.46 Mt/y. It means that cement industry alone has sufficient capacity to burn RDF generated from the whole country.

6) The cost of RDF at cement plants including transportation cost, is around 63.8 Baht/GJ while the price of coal is 71.4 Baht/GJ. These figures show the margin between 63.8 Baht/GJ and 71.4 Baht/GJ. In this regard, it might be possible that production and distribution of RDF to cement plants will be financially viable.

7) Appropriate RDF production process for Bangkok MSW consists of manual sorting on belt conveyor, magnetic separation, bag breaking/homogenization, screening with the opening of 40mm, air drying, shredding and palletizing.

8) There are many barriers to the use of RDF in Thailand, namely technological barriers, economical barriers and health and safety barriers. To overcome these barriers, government has to set up the laws and regulations for MSWM followed the integrated solid waste management (ISWM) hierarchy. In addition, the concept of ISWM hierarchy together with basic knowledge of RDF has to be

promoted in national and local levels. Economical incentives have to be provided for both RDF production and utilization such as offering tax-free and soft loan for importing machine relating to production of RDF and lower the tax for the companies those use RDF. Finally, RDF standard and air emission standard for RDF combustion have to be set up to assure consistency of RDF quality and optimize air pollution control equipment cost.

9) Driving mechanisms of RDF utilization in Thailand are from concerns of global warming and increasing in the price of fossil fuel which is now Thailand is facing. Another driving mechanism is that the government started to promote integrated solid waste management hierarchy which is trying to minimize quantity of waste to landfill. However, this driving mechanism is just at the beginning, it still needs time to be effective.

5.2 Recommendations for Further Study

1) Pilot scale of RDF production processes based on this study's findings should be developed. This is to verify and validate produced RDF quality.

2) The optimum air emission standard for RDF combustion should be found out according to existing ambient air assimilation capacity.

3) Detailed study on existing types of burners and air pollution control equipments of potential RDF users who are not ready to use RDF should be investigated. This is to find appropriate technologies either adding new equipment or modifying existing equipment to be able to burn RDF.

4) RDF has also been used in brick industry in Europe. In this regard, it will be useful to investigate the potential of RDF utilization of brick making industry in Thailand in addition to the industries mentioned in this study.

5) In this study, chlorine was not removed from RDF production process. Therefore, chlorine content in produced RDF was still higher than European Standard. However, recently, dechlorination of RDF has been available. It is interesting to develop RDF production process that has dechlorination and see how much chlorine is reduced.

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Appendix A

Composition of Reject A

i) First sampling

Date: May 9, 2007

Weather condition: No rain

Table 1.i First sampling result

Type of Waste	Weight (kg)	Percent by Weight
Food waste	3	15.17
Wood and leave	5.5	27.82
Paper	1.5	7.59
Plastic	7.5	37.94
Leather and rubber	0.04	0.20
Cloth	0	0.00
Bone and Shell	0.03	0.15
Stone and Ceramic	1.6	8.09
Metal	0.4	2.02
Glass	0.2	1.01
Hazardous waste	0	0.00
Others	0	0.00
Total	19.77	100.00

ii) Second sampling

Date: July 6, 2007

Weather condition: No rain

Table 1.ii Second sampling result

Type of Waste	Weight (kg)	Percent by Weight
Food waste	1.3	3.78
Wood and leave	9.2	26.74
Paper	4	11.63
Plastic	15.2	44.19
Leather and rubber	0.2	0.58
Cloth	2.9	8.43
Bone and Shell	0	0.00
Stone and Ceramic	1.5	4.36
Metal	0	0.00
Glass	0.1	0.29
Hazardous waste	0	0.00
Others	0	0.00
Total	34.4	100.00

iii) Average composition

Table 1.iii Average composition of Reject A

Type of Waste	Percent by Weight (1)	Percent by Weight (2)	Average Percent by Weight [(1) + (2)] / 2
Food waste	15.17	3.78	9.48
Wood and leave	27.82	26.74	27.28
Paper	7.59	11.63	9.61
Plastic	37.94	44.19	41.06
Leather and rubber	0.20	0.58	0.39
Cloth	0.00	8.43	4.21
Bone and Shell	0.15	0.00	0.08
Stone and Ceramic	8.09	4.36	6.23
Metal	2.02	0.00	1.01
Glass	1.01	0.29	0.65
Hazardous waste	0.00	0.00	0.00
Others	0.00	0.00	0.00
Total	100.00	100.00	100.00

Appendix B

Detailed Calculation for Potential Energy Supply

The calculation was based on 1,100 ton/d of collected waste. Using the mass balance from Figure 4.1, waste composition in Table 4.1 and waste characteristics in Table 4.2, the calculation results are shown below;

i) Option 1: Using all Reject A as RDF

Waste 1,200 ton/d generates Reject A	=	420 ton/d
Waste 1,100 ton/d generates Reject A	=	420*1,100/1,200
	=	385 ton/d (wet basis)
Since, moisture content in Reject A	=	60%
Therefore, dry weight of Reject A	=	40% * 385 ton/d
	=	154 ton/d (dry basis)
Since, calorific value of option 1	=	21 MJ/kg (dry basis)
Then, Potential energy supply	=	21 * 1,000 MJ/ton * 154 ton/d
	=	$3.23 * 10^6$ MJ/d

ii) Option 2: Remove noncombustible parts from reject A and use as RDF

Since noncombustible fractions in Reject A	=	0.08 + 6.23 + 1.01 + 0.65
	=	7.97%
Therefore, combustible part of Reject A	=	(100-7.97)% * 385 ton/d
	=	354 ton/day (wet basis)
Since, moisture content in Reject A	=	60%
Therefore, dry weight of option 2	=	40% * 354 ton/d
	=	141.6 ton/d (dry basis)
Since, calorific value of option 2	=	21 MJ/kg (dry basis)
Then, Potential energy supply	=	21 * 1,000 MJ/ton * 141.6 ton/d
	=	$2.97 * 10^6$ MJ/d

iii) Option 3: Select only plastic and use as RDF

Since plastic fraction in Reject A	=	41.06%
Therefore, plastic fraction in Reject A	=	41.06% * 385
	=	158 ton/d (wet basis)
Since, moisture content in Reject A	=	60%
Therefore, dry weight of option 3	=	40% * 158 ton/d
	=	63.2 ton/d (dry basis)
Since, calorific value of option 3	=	33 MJ/kg (dry basis)
Then, Potential energy supply	=	33 * 1,000 MJ/ton * 63.2 ton/d
	=	$2.1 * 10^6$ MJ/d

Appendix C

Detailed Calculation for Ash and Residue to Landfill

The calculation was based on 1,100 ton/d of collected waste. Using waste quantity from Appendix 2 and waste characteristics in Table 4.2, the calculation results are shown below;

i) Option 1: Using all Reject A as RDF

Waste 1,100 ton/d generates Reject A	=	385 ton/d (wet basis)
Or	=	154 ton/d (dry basis)
Since, ash content in Reject A	=	11.8%
Therefore, ash generation from Reject A	=	11.8% * 385 ton/d
	=	45.43 ton/d

Since all Reject A is burnt, then the residue sent to landfill is only ash from combustion = 45.43 ton/d

ii) Option 2: Remove noncombustible parts from reject A and use as RDF

Combustible part of Reject A	=	354 ton/day (wet basis)
Or	=	141.6 ton/day (dry basis)
Since, ash content in option 2	=	8.7%
Therefore, ash generation from option 2	=	8.7% * 354 ton/d
	=	30.8 ton/d

However, not all Reject A is burnt, the remaining part (dry basis) is

	=	Reject A – Option 2
	=	154 – 141.6
	=	12.4 ton/d
Therefore, total ash and residue to landfill	=	Ash + remaining waste
	=	30.8 + 12.4
	=	43.2 ton/d

iii) Option 3: Select only plastic from Reject A and use as RDF

Plastic fraction in Reject A	=	158 ton/day (wet basis)
Or	=	63.2 ton/day (dry basis)
Since, ash content in option 3	=	8.8%
Therefore, ash generation from option 3	=	8.8% * 158 ton/d
	=	13.9 ton/d
Biodegradable fraction (dry basis)	=	(9.48+27.28)/100*385*40%
	=	56.6 ton/d

However, not all Reject A is burnt, the remaining part (dry basis) is

= Reject A – Option 3 – Biodegradable fraction

= 154 – 63.2 – 56.6

= 34.2 ton/d

Therefore, total ash and residue to landfill = Ash + remaining waste

= 13.9 + 34.2

= 48.1 ton/d

Appendix D

Users' Contact and Sources of Information

i) Power Producers

1. Gulf Electric Public Company Limited
   Tel. 0-2654-0155 Fax. 0-2654-0156
   Website: http://www.gulf.co.th

   Plant 1: Gulf Cogeneration Company Limited
   Address: Tandeow Subdistrict, Kaeng Khoi District, Saraburi Province
   Capacity: 107 MW
   Fuel: Natural gas
   Plant 2: Nong Khae Cogeneration Company Limited
   Address: Nongplamor Subdistrict, Nong Khae District, Saraburi Province
   Capacity: 126 MW
   Fuel: Natural gas and diesel oil
   Plant 3:Samutprakan Cogeneration Company Limited
   Address: Bang Pu Mai Subdistrict, Muang District, Samutprakarn Province
   Capacity: 121 MW
   Fuel: Natural gas and diesel oil
   Plant 4: Gulf Power Generation Company Limited
   Address: Moo 2, Ban Pa Subdistrict, Kaeng Khoi District, Saraburi Province
   Capacity: 1,468 MW
   Fuel: Natural gas
   Plant 5: Gulf Yala Green Company Limited
   Address: Moo 1, Pron Subdistrict, Muang District, Yala Province
   Capacity: 20.2 MW
   Fuel: Parawood residue

2. Glow Energy Public Company Limited
   Tel. 0-2670-1500 Fax. 0-2670-1548-9
   Website: http://www.glow.co.th

   Plant 1: Glow SPP 1 Company Limited
   Address: Eastern Industrial Estate, No.10, Soi G 2, Pakornsongkrawhrat Rd., Huaypong, Muang, Rayong 21150
   Capacity: 124 MW
   Fuel: Natural gas and diesel oil
   Plant 2: Glow IPP Company Limited
   Address: Chonburi Industrial Estate (Bowin) Highway # 331, K.M. 91-92, Bowin, Sriracha, Chonburi 20230
   Capacity: 713 MW
   Fuel: Natural gas and diesel oil
   Plant 3: Glow SPP Phase 1
   Address: 5, I - 4 Road, Map Ta Phut Industrial Estate, Muang District, Rayong 21150
   Fuel: Natural gas

Plant 4: Glow SPP phase 2
Address: 3, I - 4 Road, Map Ta Phut Industrial Estate, Muang District, Rayong 21150
Capacity: 281 MW
Fuel: Natural gas and diesel oil

Plant 5: Glow SPP Phase 3 and 4
Address: 11, I - 5 Road, Map Ta Phut Industrial Estate, Muang District, Rayong 21150
Capacity: 591 MW
Fuel: Natural gas and imported bituminous coal

3. Tri Energy Company Limited
   Address (Head office): 1550 Thanapoom Tower, 16th floor, New Petchaburi Rd., Makkasan, Ratchathewi, Bangkok 10400
   Tel. 0-2207-2700 Fax. 0-2207-0315
   Website: http://www.trienergy.co.th
   Capacity: 700 MW
   Fuel: Natural gas

4. Thai National Power Company Limited
   Address: 60/19 Moo 3, Mab Yang Porn, Pluak Daeng, Rayong, 21140
   Tel. 0-3889-1324-28 Fax. 0-3889-1330
   Contact person: Mr. Wasan Khangkhong
   Position: Operation Manager
   Fuel: Natural gas

5. Thai Oil Power Company Limited
   Address: Thai Oil Refinery Plant, Sriracha, Chonburi
   Tel. 0-3835-1555 Fax. 0-3835-1444
   Website: http://www.ptt-ep.com/en/operations/thaioil.asp
   Capacity: 817.5 MW
   Fuel: Natural gas

6. Bangkok Cogeneration Company Limited
   Address (Head office): 183 Rajanakarn Building, 16th Fl., South Sathorn, Yannawa, Sathorn, Bangkok 10120
   Tel. 0-2676-6262 Fax. 0-2676-6285
   Website: http://www.bkkcogen.com
   Capacity: 113 MW
   Fuel: Natural gas

7. BLCP Power Company Limited
   Address: No. 9, I-8 Rd., P.O Box 92, Map Ta Phut Industrial Estate, Amphur Muang, Rayong 21150
   Tel. 0-3892-5141 Fax. 0-3892-5199
   Website: http://www.blcp.co.th
   Capacity: 1,434 MW
   Fuel: Imported bituminous coal (from Australia and Indonesia)
   Contact person: Ms. Wimon Yongpanitkul
   Position: Senior Director of External Relations

8. Biomass Power Limited
   Address (Head office): 17th floor, SP Building, 388, Paholyothin Rd., Samsen Nai, Payathai, Bangkok 10400
   Tel. 0-2273-0037 Fax. 0-2273-0159
   Capacity: 6 MW
   Fuel: Rice husk
   Contact person: Mr. Montri Sriroon
   Position: Plant Manager
   Mobile: 08-1379-8837

9. Satuk Biomass Limited
   Address: 111 Moo 6, Burirum-Stuk Rd., Dornmon Sub-district, Satuk District, Burirum Province, 31150
   Tel. 0-4478-2372-9 Fax. O-4478-2376
   Capacity: 7.5 MW
   Fuel: Rice husk, Wood chip
   Contact person: Ms. Noppamas Wikaipat
   Position: Managing Director

10. Saha Cogen (Chonburi) Public Company Limited
    Address: 636 Moo 11, Sukaphiban 8 Rd., Nongkharm, Sriracha, Chonburi 20230
    Tel. 0-3848-1552-5 Fax. 0-3848-1551
    Website: http://www.sahacogen.com
    Capacity: 174 MW
    Fuel: Natural gas

11. Laem Chabang Power Company Limited
    Address: 205/7 Moo 3, Thung-Sukhla Sub-district, Sriracha District, Chonburi Province
    Tel. 0-3849-3470-4 Fax. 0-3849-3475
    Capacity: 70 MW
    Fuel: Natural gas

12. Eastern Power and Electric Company Limited
    Address: 999/12, Moo 11, Sukhumvit Rd., Km. 59, Klong-Daan, Bang-Bo, Samutprakarn 10550
    Tel. 0-2313-7530-7 Fax. 0-2313-7520
    Capacity: 350 MW
    Fuel: Natural gas
    Contact person: Mr. Noppadon Petprapan
    Position: Deputy Operation Manager

13. A T Biopower Company Limited
    Address: 96, Moo 2, Hor-Krai, Bangmoolnak, Phichit, 66120
    Tel. 0-5666-0378-83 Fax. 0-5666-0384
    Capacity: 22.5 MW
    Fuel: Rice husk
    Contact person: Mr. Nusapon Krachangphaew
    Position: Plant Manager

ii) Cement Industries

1. TPI Polene Public Co., Ltd.
   Address (Head office): 26/56 Chan Tat Mai Rd., Tungmahamek, Sathorn, Bangkok 10120
   Tel. 0-3622-2204
   Website: http://www.tpipolene.co.th
   Contact person: Mr. Karan Phiphitsombat
   Position: Plant Manager (Saraburi)

2. Jalaprathan Cement Public Co., Ltd.
3. Asia Cement Public Co., Ltd.
   Address (Head office):23/124-128, Soi Soonvijai, Rama 9 Rd., Huai Kwang, Bangkok 10320
   Tel. 0-2641-5600 Fax. 0-2641-5680
   Contact person: Mr. Apichit Akarapattangkul
   Position: Division Manager of Alternative Fuels & Materials
   Mobile: 0-81984-7412

4. Siam City Cement Public Co., Ltd
   Address (Head office): 7-12th floor, Column Tower, 199, Ratchada Phisek Rd., Klong Tei, Bangkok 10110
   Tel. 0-2797-7000 Fax. 0-2797-7001-2
   Website: http://www.siamcitycement.com
   Contact person: Mr. Vasin Taengkaew
   Position: External Relations Manager
   Mobile: 0-89920-1246

5. Siam Cement Public Co., Ltd.
   Address (Head office): 1 Siam Cement Road, Bangsue, Bangkok 10800
   Tel. 0-2586-5670
   Website: http://www.siamcement.com
   Contact person: Mr. Numpol Limprasert
   Position: Energy Management Manager

6. Cemex (Thailand), Co. Ltd.
   Address (Head office): 2034/88, 19th Floor, Ital-Thai Tower, New Petchburi Rd., Bangkapi, Huai Kwang, Bangkok 10320
   Tel. 0-3621-8054
   Website: http://www.cemexthailand.com
   Contact person: Dr. Vichit Prakaipan
   Position: Regional Research and Development Manager

Appendix E

Detailed Calculation for RDF Production Cost

The calculation was based on 1,000 ton/d of collected waste with the following assumptions;

- Operating 6 days/week, 14 h/d (2 Shifts)
- Life time of machine = 10 years
- Electricity cost = 0.0723 Euro/kWh (3.62 Baht/kWh)

Above assumptions are from Caputo and Pelagagge (2001) mentioned in section 2.2.4

- 200 baht/sorter, 4 sorters/shift
- Capacity of the plant = 1,100 tpd (14 h/d = 78.6 t/h)
- Bag breaking is equivalent to hammer mill

Using cost data from Table 2.8,

i) Belt conveyor cost = (0.35 + 0.43) Euro/d * 50 Baht/Euro / 1,100 ton/d
= 0.04 Baht/ton

ii) Manual sorting cost = 200 Baht/sorter * 4 sorters/shift * 2 shift/d / 1,100 ton/d
= 1.45 Baht/ton

iii) Magnetic separation cost = 0.03 Euro/ton * 50 Baht/Euro
= 1.50 Baht/ton

iv) Bag breaking and homogenization cost = 4.21 Euro/ton * 50 Baht/Euro
= 210.50 Baht/ton

v) Screening cost = 0.25 Euro/ton * 50 Baht/Euro
= 12.50 Baht/ton

vi) Drying cost = 2.87 Euro/ton * 50 Baht/Euro
= 143.50 Baht/ton

vii) Shredding cost = 0.44 Euro/ton * 50 Baht/Euro
= 22 Baht/ton

vii) Pelletizing cost = 2.09 Euro/ton * 50 Baht/Euro
= 104.50 Baht/ton

Total cost = 0.04 + 1.45 + 1.50 + 210.50 + 12.50 + 143.50 + 22 + 104.50
= 495.99 Baht/ton

Appendix F

Analytical Results

1. Moisture Content

1.1 First analyzing date: May 10, 2007
Place: EEM ambient laboratory, AIT

Air dried moisture at 40-50°C

	Tray weight (g)	Tray + Sample Weight (g)						
		day 1	day 2	day 3	day 4	day 5	day 6	day 7
Sample 1	170	630	425	no data	365	365	360	360
Sample 2	145	740	540	no data	445	430	415	410
Sample 3	155	895	705	no data	595	575	565	565

Sample 1, air dried moisture = (630 – 360)/(630-170) x 100
= 58.7%
Sample 2. air dried moisture = (740 – 410)/(740 – 145) x 100
= 55.46%
Sample 3, air dried moisture = (895 – 565)/(895 – 155) x100
= 45.27%

Average air dried moisture = (58.7 + 55.46)/2
= 57.08%

Remarks: sample 3 was rejected because its value deviated from sample 1 and 2

Residual moisture after air dry 105°C for 1 hour

	Container Weight (g)	Before 105 (g)	After 105 (g)
Sample 1	20.00	21.06	20.96
Sample 2	19.76	20.78	20.70
Sample 3	18.98	20.10	20.01

Sample 1, residual moisture = (21.06 – 20.96)/(21.06 – 20.00) x 100
= 9.43 %
Sample 2, residual moisture = (20.78 – 20.70)/(20.78 – 19.76) x 100
= 7.84%
Sample 3, residual moisture = (20.10 – 20.01)/(20.10 – 18.98) x 100
= 8.04%

Average residual moisture = (9.43 + 7.84 + 8.04)/3
= 8.44%

Total moisture content $= 57.08 + \frac{(100-57.08) \times 8.44}{100}$
= 60.7%

1.2 Second analyzing date: July 6, 2007
Place: EEM ambient laboratory, AIT

Air dried moisture at 40-50°C

	Tray weight (g)	Tray + Sample Weight (g)						
		day 1	day 2	day 3	day 4	day 5	day 7	day 11
Sample 1	145	1090	850	715	625	580	550	535

Sample 1, air dried moisture = (1090 – 535)/(1090 -145) x 100
= 58.73%

Residual moisture after air dry at 105°C for 1 hour

	Container Weight (g)	Before 105 (g)	After 105 (g)
Sample 1	145	535	530

Sample 1, residual moisture = (535 – 530)/(535 – 145) x 100
= 1.28 %

Total moisture content = $58.73 + \frac{(100-58.73) \times 1.28}{100}$
= 59.26%

Average total moisture content = (60.7 + 59.26)/2
= 59.98%
~ 60%

2. Ash Content

Option 1: Use all reject A as RDF
Date of analysis: June 10, 2007
Place: EEM laboratory, AIT

Put in the furnace at 750°C for 30 minutes

	Container Weight (g)	Before 750 (g)	After 750 (g)
Sample 1	19.883	20.887	19.992
Sample 2	19.837	20.845	19.964

Sample 1, Ash content = (19.992 – 19.883)/(20.887 – 19.883)x100
= 10.9 %
Sample 2, Ash content = (19.964 – 19.837)/(20.845 – 19.837)x100
= 12.6%

Average ash content = (10.9 + 12.6)/2
= 11.8 %

Option 2: Remove noncombustible fraction
Date of analysis: June 29, 2007
Place: EEM laboratory, AIT

	Container Weight (g)	Before 750 (g)	After 750 (g)
Sample 1	19.662	20.706	19.753
Sample 2	19.898	20.898	19.985

Sample 1, Ash content = (19.753-19.662)/(20.706-19.662)x100
= 8.7%
Sample 2, Ash content = (19.985-19.898)/(20.898-19.898)x100
= 8.7%

Average ash content = 8.7%

Option 3: Select only plastic
Date of analysis: June 29, 2007
Place: EEM laboratory, AIT

	Container Weight (g)	Before 750 (g)	After 750 (g)
Sample 1	18.930	19.931	19.010
Sample 2	19.859	20.863	19.956

Sample 1, Ash content = (19.010-18.930)/(19.931-18.930)x100
= 8%
Sample 2, Ash content = (19.956-19.859)/(20.863-19.859)x100
= 9.7%

Average ash content = (8+9.7)/2
= 8.8%

3. Calorific Value

Option 1: Use all Reject A as RDF
Date of analysis: June 9, 2007
Place: EEM laboratory, AIT
Using bomb calorimeter

Sample 1, reading value = 19.19 MJ/kg
Sample 2, reading value = 21.42 MJ/kg
Sample 3, reading value = 21.77 MJ/kg

Average calorific value = 20.8 MJ/kg
Standard Deviation = 1.14

Option 2: Remove noncombustible fraction
Date of analysis: July 20, 2007
Place: EEM laboratory, AIT
Using bomb calorimeter

Sample 1, Reading value = 19.43 MJ/kg
Sample 2, Reading value = 22.68 MJ/kg
Sample 3, Reading value = 21.82 MJ/kg

Average calorific value = 21.31 MJ/kg
Standard Deviation = 1.37

Option 3: Select only plastic

Sample 1, Reading value = 33.25 MJ/kg
Sample 2, Reading value = 32.90 MJ/kg
Sample 3, Reading value = 33.35 MJ/kg

Average calorific value = 33.17 MJ/kg
Standard Deviation = 0.19

4. Sulfur content

Faculty of Science, Silpakorn University Sanamchan Palace Campus
Nakorn Pathom 73000 Thailand Tel : International 66 34 255093 Fax : 66 34 255820

หมายเลขวิเคราะห์ที่ no.00080/50 **ทำการวิเคราะห์ขึ้นเพื่อ** วิเคราะห์ตัวอย่างเพื่อหาค่า Sulfur

Customer: ชื่อลูกค้า นางสาวจิดาภา นิธิกุล

Address : ที่อยู่ 24/4 ถนนประชาราษฎร์ ตำบลตลาดขวัญ อำเภอเมือง จังหวัดนนทบุรี

วัน/เดือน/ปี/รับตัวอย่าง ก.ย.50 **Sample: ตัวอย่าง** ขยะ

RESULTS/รายงานผลการวิเคราะห์

Sample	Sulfur (s) (w/w)
Option 1	0.20
Option 2	0.18

หมายเหตุ : รายงานผลการวิเคราะห์นี้ใช้รับรองเฉพาะตัวอย่างที่ได้รับการวิเคราะห์เท่านั้น

ลงชื่อ

(ผศ.ดร.คลฤดี ฉิมพาลี)

ผู้ทำการวิเคราะห์

วัน 18 เดือน ก.ย. ปี 50

ลงชื่อ

(ผศ.ดร.ธงชัย เตโชวิศาล)

หัวหน้าศูนย์เครื่องมือฯ

วัน 18 เดือน ก.ย. ปี 50

ลงชื่อ

(ผศ.ดร.จรุงแสง ลักษณบุญส่ง)

คณบดีคณะวิทยาศาสตร์

วัน 19 เดือน ก.ย. ปี 50

Faculty of Science, Silpakorn University Sanamchan Palace Campus
Nakorn Pathom 73000 Thailand Tel : International 66 34 255093 Fax : 66 34 255820

หมายเลขวิเคราะห์ที่ no.00068/50 **ทำการวิเคราะห์ขึ้นเพื่อ** วิเคราะห์ตัวอย่างเพื่อหาค่า Sulfer

Customer: ชื่อลูกค้า นางสาวจิดาภา นิธิกุล

Address : ที่อยู่ 24/4 ถนนประชาราษฎร์ ตำบลตลาดขวัญ อำเภอเมือง จังหวัดนนทบุรี

วัน/เดือน/ปี/รับตัวอย่าง 9 ส.ค. 50 **Sample: ตัวอย่าง ขยะ**

RESULTS/รายงานผลการวิเคราะห์

Sample	Sulfur (s) (w/w)
Option 1	0.20
Option 3	0.13

หมายเหตุ : รายงานผลการวิเคราะห์นี้ใช้รับรองเฉพาะตัวอย่างที่ได้รับการวิเคราะห์เท่านั้น

ลงชื่อ
(ผศ.ดร.ดลฤดี ฉิมพาลี)
ผู้ทำการวิเคราะห์
วัน 28 เดือน ส.ค. ปี 50

ลงชื่อ
(ผศ.ดร.ธงชัย เตโชวิศาล)
หัวหน้าศูนย์เครื่องมือฯ
วัน 28 เดือน ส.ค. ปี 50

ลงชื่อ
(ผศ.ดร.จรุงแสง ลักษณบุญส่ง)
คณบดีคณะวิทยาศาสตร์
วัน.........เดือน.................ปี.........

5. Chlorine content

Faculty of Science, Silpakorn University Sanamchan Palace Campus

Nakorn Pathom 73000 Thailand Tel : International 66 34 255093 Fax : 66 34 255820

Results/รายงานผลการวิเคราะห์

หมายเลขวิเคราะห์ที่ 068/50

Customer: ชื่อลูกค้า คุณจิดาภา นิธิกุล

วัน/เดือน/ปี/รับตัวอย่าง 11 กันยายน 2550

Sample: ตัวอย่าง มูลฝอยชุมชน

พารามิเตอร์	หน่วย	ผลการวิเคราะห์	
		Option 1	Option 2
Chlorine content	%	0.58	0.66

หมายเหตุ : รายงานผลการวิเคราะห์นี้ใช้รับรองเฉพาะตัวอย่างที่ได้รับการวิเคราะห์เท่านั้น

ลงชื่อ..............................

(นายนที ส่งบุญ)

ผู้ทำการวิเคราะห์

วันที่ 14 กันยายน พ.ศ. 2550

ลงชื่อ..............................

(อาจารย์ ดร. นภวรรณ รัตสุข)

หัวหน้าภาควิชาวิทยาศาสตร์สิ่งแวดล้อม

วันที่ 14 กันยายน พ.ศ. 2550

ลงชื่อ..............................

(ผู้ช่วยศาสตราจารย์ ดร.จรุงแสง ลักษณบุญส่ง)

คณบดีคณะวิทยาศาสตร์

วันที่ 17 กันยายน พ.ศ. 2550

Faculty of Science, Silpakorn University Sanamchan Palace Campus
Nakorn Pathom 73000 Thailand Tel : International 66 34 255093 Fax : 66 34 255820

Results/รายงานผลการวิเคราะห์

หมายเลขวิเคราะห์ที่ 056/50

Customer: ชื่อลูกค้า คุณจิดาภา

วัน/เดือน/ปี/รับตัวอย่าง 9 สิงหาคม 2550 Sample: ตัวอย่าง มูลฝอยชุมชน

พารามิเตอร์	หน่วย	ผลการวิเคราะห์	
		Option 3, sample 1	Option 3, sample 2
Chorine content	%	0.68	3.92

หมายเหตุ : รายงานผลการวิเคราะห์นี้ใช้รับรองเฉพาะตัวอย่างที่ได้รับการวิเคราะห์เท่านั้น

ลงชื่อ..

(นายนที ส่งบุญ)

ผู้ทำการวิเคราะห์

วันที่ 16 สิงหาคม พ.ศ. 2550

ลงชื่อ..

(อาจารย์ ดร. นภวรรณ รัตสุข)

หัวหน้าภาควิชาวิทยาศาสตร์สิ่งแวดล้อม

วันที่ 16 สิงหาคม พ.ศ. 2550

ลงชื่อ..

(ผู้ช่วยศาสตราจารย์ ดร.จรุงแสง ลักษณบุญส่ง)

คณบดีคณะวิทยาศาสตร์

วันที่ 17 สิงหาคม พ.ศ. 2550

6. %CHONS

JGSEE

A graduate education and research consortium of five institutions

Report code. JGSEE Laboratory 007-2007
Ref. code. LAB_QT 020-2007

July 6, 2007

LABORATORY REPORT

Customer: Asian Institute of Technology

The result of samples analyses are shown in the table bellows.

Sample name	% Calculated				Elemental (mg/kg)	
	Nitrogen	Carbon	Hydrogen	Sulfur	Chlorine	Mercury
Solid waste	0.02	56.61	2.33	0.01	<0.0	72

The result is valid only for the sample tested under the analytical method specified herein. This document shall not be reproduced.

Signed:

U. Chaiyo
(Ms. Ubonwan Chaiyo)
Analyst

(Assoc. Prof. Dr. Sirintornthep Towprayoon)
Acting Chairperson of Environment Division

KMUTT SIIT-TU KMITNB CMU PSU JGSEE

The Joint Graduate School of Energy and Environment
King Mongkut's University of Technology Thonburi, 91 Prachauthit Rd, Bangmod, Tungkru, Bangkok, Thailand 10140
Tel. (662) 4708309-10, 8729014-5 Fax. (662) 4279634 www.jgsee.kmutt.ac.th E-mail : jgsee@jgsee.kmutt.ac.th

Analytical conditions

Sample preparation

Sample weight	0.5 g	
Reagent	65%HNO_3 (suprapure)	3.0 mL
	37%HCl (suprapure)	9.0 mL

Digestion Program

Power	Ramp	Hold	Fan
800	5:00		1
800	5:00	20:00	1
		20:00	2

Inductively Coupled Plasma Mass Spectrophotometer (ICP-MS)

Instrument	ICP-MS 7500a series
Brand	Agilent Technology
Analysis	Mercury and Chlorine
Method	PM

Tuning Parameters

Plasma Condition		Ion Lenses		Q-Pole Parameters	
RF Power:	1500 W	Extract 1:	0 V	AMU Gain :	127
RF Matching:	1.68 V	Extract 2:	-65 V	AMU Offset :	123
Smpl Depth:	8 mm	Einzel 1,3:	-123 V	Axis Gain :	.09995
Torch-H:	0.8 mm	Einzel 2:	-80 V	Axis Offset :	-0.06
Torch-V	0.1 mm	Omega Bias:	-28 V	QP Bias :	-3 V
Carrier Gas:	0.9 L/min	Omega (+) :	4 V		
Makeup Gas:	0.3 L/min	Omega (-) :	0.9 V	Detector Parameters	
Optional Gas:	0%	QP Focus :	3.3 V	Discriminator :	8 mV
Nebulizer Pump:	0.1 rps	Plate Bias :	-25 V	Analog HV :	1720 V
Sample Pump:	--- rps			Pulse HV :	1180 V
S/C Temp:	2 degC				

KMUTT SIIT-TU KMITNB CMU PSU JGSEE

The Joint Graduate School of Energy and Environment
King Mongkut's University of Technology Thonburi, 91 Prachauthit Rd, Bangmod, Tungkru, Bangkok, Thailand 10140
Tel. (662) 4708309-10, 8729014-5 Fax. (662) 4279634 www.jgsee.kmutt.ac.th E-mail : jgsee@jgsee.kmutt.ac.th