AGRICULTURAL WASTE TO ENERGY:

STRATEGY FOR SMOG REDUCTION IN CHIANG MAI

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List of Acronyms and Abbreviations

%	percent
AD	Anno Domini
BC	Before Christ
Btu	British thermal unit
C_2H_2	Acetylene
C_2H_4	Ethylene
$C_6H_{12}O_6$	Glucose
CH_4	Methane
CHP	Combined Hat and Pwer
CO	Carbon Mnoxide
CO_2	Carbon Doxide
CO_{2e}	Carbon Doxide Euivalent
COPD	Chronic Obstructive Pulmonary Disease
Ca.	aproximately (*lat.* Circa)
DNA	Deoxyribonucleic Acid
EGG	Renewable Energy Sources Act
EJ	Exajoule
EPA	Environmental Protection Agency
ESMAP	Energy Sector Management Assistance Program
FAME	Fatty-acid Methyl Esters
GDP	Gross Domestic Product
GWh	Gigawatt-hour
GWP	Global Warming Potential

H_2	Hydrogen
IEA	International Energy Agency
IRR	Internal Rate of Return
kg	Kilogram
km	Kilometer
kW	Kilowatt
kWh	Kilowatt-hour
lb	Pound
MFA	Material Flow Analysis
MFM	Material Flow Management
MJ	Megajoule
MSW	Municipal Solid Waste
MW	Megawatt
N_2O	Nitrous Oxide
NIMBY	Not In My Backyard
NGO	Non-governmental Organization
NO_X	Nitrogen Oxide
NPV	Net Present Value
O_2	Oxygen
O_3	Ozone
PAH	Polycyclic Aromatic Hydrocarbon
PM	Particulate Matter
R&D	Research and Development
RDF	Refuse Derived Fuel
SI	International System of Units

SO_X	Sulfur Oxide
USA	United States of America
USD	United States Dollar
VSPP	Very Small Power Provider
WACC	Weighted average of cost of Capital
WHO	World Health Organization
WRI	World Resources Institute
WVO	Waste Vegetable Oil
μg	Microgram
$\mu g/m^3$	Microgram per cubic meter

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1. Executive Summary

The aim of this research is to analyze how biomass-to-energy technology, more specifically, the biomass gasification technology which produces electricity from syngas generated from biomass feedstock, can contribute to the reduction of smog in northern Thailand, which has been a major problem to Chiang Mai and surrounding provinces since 2007. The cause of the smog is mainly due to the open burning of agricultural wastes, most significantly corn. Each year, over 213,624.82 tons of unwanted parts of corn are left and burned openly in Chiang Mai alone and generate theoretically 7.28 tons of particulate matter. Significant impacts on human health were instant, as well as the economy of the province due to the decreasing number of tourists

However, these unwanted parts of corn produced in Chiang Mai actually have a theoretical energy potential of producing electricity up to 200.48 GWh or 8.5 percent of total electricity consumption in the province. This potential can be made available through the establishment of biomass gasification plants. Two types of gasification plants are suggested; a 21 MW gasification plant which uses corn stalks and leaves as the main feedstock and an 8 MW gasification plant which uses corn husks and cobs.

As a result of a pre-feasibility study conducted in this research, both cases provide positive NPVs along with economically attractive mean payback periods of 7.75 and 8.1 years for the 21 MW and 8 MW gasification plants respectively. The mean IRRs for the 21 MW and 8 MW gasification plants are 11.5 and 10.5 percent respectively, which are higher than the average WACC of 8.5 percent. Therefore, both scenarios are financially feasible.

In conclusion, establishing biomass gasification plants in Chiang Mai would lead to the avoidance of open burning which is the major cause of smog. It would help reduce risks related to energy security of the province and also enhance the biomass market through revalorizing wastes from corn cultivation.

2. Introduction

2.1 Problem Description

The problem of heavy smog due to the practice of open burning in northern Thailand has become significant to public arena in March 2007 when the Pollution Control Department first reported that the amount of particulate matter with aerodynamic diameter of less than 10 micrometers (PM_{10}) measured at the ambient air quality monitoring station at Yupparaj Wittayalai School, locating in the heart of Chiang Mai city, has reached 383 μg/m3, exceeding the safety level of 120 μg/m3 (Rayanakorn, 2010). The number was by far the highest that has ever been recorded in the country since the official ambient air quality monitoring has been conducted (Rayanakorn, 2010). According to Dontree (2012), seven other provinces in northern Thailand also shared similar situation. These provinces are Lamphun, Lampang, Mae Hong Son, Chiang Rai, Phayao, Phrae and Nan. The amount of PM_{10} measured in Mae Hong Son peaked at 340 μg/m3, being the second highest after Chiang Mai, followed by Lampang (259 μg/m3) and Chiang Rai (212 μg/m3) (Jaikhamsueb, 2007). Total number of patients with health problems relating to air pollution reported within these eight provinces almost reached 60,000 people just within the period of 15-23 March 2007 (Rayanakorn, 2010). Despite the effort of the government in trying to reduce the amount of open burning within these provinces, the problem continued to occur each year during the dry season starting from December and lasting until April. By mid March 2010, the amount of PM_{10} measured in Mae Hong Son soared up to 518 μg/m3, four times higher than the safety level and was regarded as dangerous for human (Dontree, 2012).

According to the research on ambient air quality analysis done by Kreasuwan et al. (2008), 50-70% of the airborne particles measured in Chiang Mai were generated from open burning of forested and cultivated areas, 10% from diesel combustion and the rest from external sources outside the province. The research conducted by Dontree et al. (2011) further suggested that open burning of forested area in Chiang Mai is almost entirely caused by human activities such as forest clearing for cultivation, collection of mushrooms and vegetables which grow well after the fire and hunting. Due to the nature of landscape combining with air pressure cycle, the smoke generated from open burning could not be blown up into the atmosphere creating severe smog condition which lasted throughout the dry season, most severe in March when the number of open burning normally peaks.

The reason why smog that contains PM_{10} is harmful to human's health is basically because it contains different types of organic compound called Polycyclic Aromatic Hydrocarbons (PAH), with over 10 types of PAH being considered as carcinogens (Dontree, 2012). Because of their small size, once they enter the lungs, they can never be removed. Researches had been carried out extensively to study the effects of smog on human's health. It was found that the development of asthma correlates to the amount of daily airborne particles (Wiwattanadate et al., 2007). Toxic substances including heavy metals and PAH were found in airborne particles sampled in Chiang Mai (Rayanakorn et al., 2007). These toxic substances also have the ability of destroying DNAs of lung cells (Vinitketkamnuen et al., 2007). The proportion of patients with lung cancer has increased to 40: 100,000 people in Chiang Mai, two times higher than the average of 20: 100,000 people in the national level (Rayanakorn, 2010). Not only that this problem has a strong impact on human's health, the region's economy was also heavily affected. Because northern Thailand, especially Chiang Mai, is one of the most popular tourist destinations, tourism sector suffered a huge loss during the smog period due to the loss of tourists. Local people are also forced to spend more money on health care, creating even more financial problems. In the social aspect, the problem of smog has led to a certain level of social discordant as to whom it should be responsible for causing the smog and how the problem should be sorted out (Dontree, 2012).

The significant aspect which is needed to be examined when analyzing the problem of smog in northern Thailand is the growth of contract farming, especially corn plantation. In recent years, there have been companies which encourage local farmers living on highlands to produce more corn as a source of food supply for animal husbandry sector. These companies provide support for the entire production chain including seeds distribution, know-how on planting conditions and provide the markets for the products (Dontree, 2012). This led to the rapid increase of corn plantation since 2005, most notably in Mae Chaem district in Chiang Mai. In 2011, approximately 288 km^2 of corn plantation (Arjharn, 2012) produced more than 213,624 tons of corn stalks and other unwanted parts which were mostly disposed by open burning. Some of the unwanted parts were used as soil conditioner in tangerine plantations and food for animals, but the percentage is lower than one percent (Arjharn, 2012). Efforts were made by the government every year aiming to solve the problem, yet the smog still continues to occur and even proved to be worsened. Many suggestions were raised by researchers in order to improve the current approach towards solving the problem which proves to be ineffective. Dontree (2012) suggested that decentralization of the management and cross-sector cooperation need to be promoted. Contract farming contractors are also encouraged to provide alternatives to local farmers to substitute their financial loss for not burning the agricultural waste.

One of the possible alternatives is the introduction of gasification technology. With a local gasification plant constructed within the region, agricultural wastes such as corn stalks and leaves, can be used to generate syngas for electricity production. Strong cooperation between each regional stakeholder is needed in order to successfully implement the concept. Applying regional material flow management approach, sustainable farming and community can be achieved as every stakeholder can benefit from the system and contribute to less environmental impacts; farmers can benefit from income through their agricultural products and revalorized agricultural wastes, contractors from raw material supply and positive reputation, and the region as a whole from energy and materials supply.

2.2 Research Question

This research will analyze how gasification technology can help reduce the problem of smog in northern Thailand. Furthermore, it will determine what social, political and economical factors are needed to be taken place, in order to successfully establish the gasification plant.

2.3 Methodology

This is a descriptive qualitative research using a case study approach. Data and information will be gathered from reliable secondary sources including books, scientific journals, and other forms of publication as well as internet sources. Specific information about Chiang Mai and the smog problem will derive from published scientific researches, newspapers and conference presentations and publications. Data regarding the existing agricultural area and the amount of agricultural products and residues currently produced will also be based on published literatures.

2.4 Structure of the thesis

The structure of the thesis is as follow. Chapter 2, the introductory chapter introduces the problem of smog which has occurred in northern Thailand since 2007. Research question and methodology are also covered within this chapter. Chapter 3 is the literature review. Available knowledge regarding energy security, material flow management, biomass energy, biorefinery, gasification process and air pollution are covered. In Chapter 4, general information about Chiang Mai is analyzed and introduced. The following chapter, Chapter 5, further describes the problem of open burning and current measure taken in Chiang Mai. Chapter 6 then introduces the massive practice of corn cultivation in Chiang Mai which is one of the main causes of the smog. The energy potential and smog reduction potential of switching from open burning to gasification process are described in Chapter 7. In Chapter 8, current situation of biomass gasification plants in Thailand is introduced, as well as the fundamental requirements for establishing a biomass gasification plant. Chapter 9 then analyzes the pre-feasibility study of establishing a biomass gasification plant in Chiang Mai with financial feasibility study for different scenarios. Before the concluding chapter, suggestions for further steps of the establishment of a biomass gasification plant are suggested in Chapter 10.

3. Literature Review

In this part of the thesis, available knowledge regarding Energy Security, Material Flow Management, Biomass Energy, Biorefinery and Air Pollution will be covered respectively. The purpose is to provide basic knowledge which leads to a better understanding of the proposed solution to the smog problem; i.e. biomass-to-energy technology. The interrelation of these aforementioned topics is the key to achieve such purpose.

Because energy security is one of the most important aspects in modern societies, the topic is selected and further realizes in the Market Analysis in Chapter 9 which points out the risk of energy security in Chiang Mai. In order to achieve a better energy security, a planned material flow management strategy is needed because utilizing local renewable resources can greatly reduce the energy security risks.

The topics of Biomass Energy and Biorefinery provide insight into the background and technical knowledge regarding biomass technology. They offer a sound understanding of the fundamental knowledge which is crucial to the Technology Analysis described in Chapter 9. The last topic, Air Pollution, is included to signify the magnitude of the smog crisis, particularly relating to human health effects.

3.1 Energy Security

3.1.1 Overview

Recently, the concept of energy security has become one of the major topics to be discussed among the global arena, resulting from the constantly increasing oil price, as well as the increasing demand on energy. According to the European Commission (2000), the term energy security means the “uninterrupted physical availability of energy products on the market, at a price which is affordable for all consumers (private and industrial)”. In other words, it refers to the "secure" state of energy supply where it is adequate, affordable and reliable to all consumers with minimum risks of energy incapacity caused by various factors such as growing demand, attack on centralized power production, transmission losses, or political actions (IEA, 2007).

3.1.2 Risks to Energy Security

According to International Energy Agency (2007), risks to energy security can be categorized into three different categories as follows

1) **Energy market instabilities**: refers to changes caused by political unrest, conflict, trade embargoes, and other unforeseen changes caused by external factors; even though they normally don't affect the physical supply of energy, it can heavily affect the pricing of energy in the market
2) **Technical failures**: refers to failures in energy supply systems caused by accidents or human error; has sharp and wide-ranging effects such as power outages especially in large interconnected systems
3) **Physical security threats**: refers to actions such as terrorism, sabotage or piracy, and natural disasters; can affect any part in the energy supply chain such as power stations, oil and gas exploration, extraction and refinery, and logistics

These risks can be especially high in developing countries where there are low-income economies and strong dependence on oil importing because the energy price can be easily affected and result in negative balance of payments (ESMAP, 2005). Decentralizing domestic energy supply and reducing energy demand can help reduce the risks to energy security (IEA, 2007).

3.1.3 Challenges to Energy Security

Eight major challenges to energy security are described according to Vivoda (2011) as follows: (1) Environment, (2) Technology, (3) Demand-side Management, (4) Domestic Socio-cultural and Political Factors, (5) Human Security, (6) International, (7) Public Relations, and (8) Policy.

(1) **Environment:** perhaps the most serious challenge for traditional energy security thinking; strongly connected to the supply of energy

(2) **Technology:** the development of technology that provides alternatives to the traditional fossil fuel-based operation is needed

(3) **Demand-side Management:** traditional energy security thinking focuses mainly on the supply-side management, but risks from the demand side cannot be underestimated due to its uncertain nature; it is also the key component of the new energy security concept

(4) **Domestic Socio-cultural and Political Factors:** establishing large power plants, waste disposal facilities, etc. has become increasingly difficult due to the opposition from the locales which makes it important to consider local politics in the energy security planning

(5) **Human Security:** not only the country that needs to be energy "secured" but the entire population has to be able to access to the energy as well

(6) **International:** international implications of energy security challenges need to be addressed in the country's energy security policies

(7) **Public Relations:** policies regarding energy security should allow public participation, as well as public education campaigns regarding energy security

(8) **Policy:** to establish the policy regarding energy security itself is also a major challenge; by having or not having the energy security policy, the capacity and/or commitment of the country to ensure energy security can be analyzed

3.1.4 Renewables and Energy Security

According to IEA (2007), risks to energy security can be reduced by using domestically supplied renewable energy sources. The dependence on energy imports which has high risks can be reduced when using locally available renewable energy sources. Transmission costs and losses can also be minimized when the power generation is located close to the end-users (IEA, 2007). However, sustainable strategy towards domestic renewable energy sources and modern energy services are strongly needed to be implemented in order to prevent environmental degradation and resource scarcity caused by extensive use of indigenous energy sources, which will eventually stress the total energy supply and increase risks to energy security (Saghir, 2006; Bugaje, 2006; Plas & Abdel-Hamid, 2005).

In 2011, over 47 percent of total energy demand in Thailand was still supplied by oil and almost 38 percent by natural gas (Haema, 2012). With the current capability, the country can only produce 15 percent of crude oil and as less as one percent of petroleum, meaning that 85 percent of crude oil and 99 percent of petroleum need to be imported (Haema, 2012). Even though domestically produced natural gas accounted for as much as 74 percent of the total natural gas used, it is still a non-renewable source of energy which will soon be depleted. Domestic energy supply needs to be strongly supported by alternative sources of renewable energy, such as biomass and solar energy, in order to ensure the country's energy security in the near future.

3.2 Material Flow Management

Material Flow Management (MFM), as described by Wagner and Enzler (2006), refers to the "objective-oriented, responsible, integrated and efficient controlling of material systems, with the objective arising from both the economic and ecological sector and with the inclusion of social aspects. The objectives are determined on a company level, within the scope of the chain in which stakeholders are involved or on a national level."

The Ministry of the Environment, Forest and Consumer Protection & Ministry for the Economy, Commerce, Agriculture and Viticulture (2008) of Germany described the aspects of MFM as follows:

- Integrated consideration of the entire social system (consumption, supply and waste disposal, infrastructure, commerce and agriculture, etc.) and its industrial activities
- Linking of material and energy flows intrinsic to the system and networking of the corresponding players
- Utilization of potentials intrinsic to the system (raw materials, waste materials, processes)
- Increased implementation of renewable energies and secondary fuels
- Increase of energy efficiency in the private and industrial area
- Decentralization of the energy supply

In short, MFM is the optimization of resources which takes into account the economic, ecological and social aspects. It is the opposite managerial approach to the end-of-pipe approach which favors implementation of add-on measures to curb emission reductions aside as Frondel, Horback & Rennings (2006) described. Especially, in the situation where natural resources that we need are exhausting, MFM can offer a much more efficient, effective and sustainable solution than the traditional end-of-pipe approach.

3.3 Biomass Energy

3.3.1 Background

Biomass is the oldest form of energy used by humans (Balat, 2011). It refers to various kinds of material with recent biological origin and is generally divided into three main groups: (1) energy crops grown specifically to be used as fuel (2) agricultural residues and byproducts, and (3) residues from forestry, construction, and other wood-processing industries (National Renewable Energy Laboratory, 2003). In developing countries, it accounts for 35% of total primary energy consumption and 14% in the global level (Demirbas, 2006). Indeed, biomass is often the only available and affordable source of energy for many rural populations in developing countries (Demirbas, 2006). A study carried out by Hoogwijk *et al*. (2005) further reveals that in East Sahelian Africa, biomass serves as much as 81% of the main energy source. Similarly in Bhutan and Nepal, it accounts for 86% and 97% respectively (Hoogwijk *et al*., 2005). However, despite the current contribution of only 14%, it has the theoretical potential to supply 100% of the world's total energy demand (Speight, 2011).

Different forms of products can be generated from biomass including heat, gaseous fuels, liquid and electricity (Karekezi *et al.*, 2004). Traditional utilizations of biomass in many parts of the world include direct combustion for heating and anaerobic digestion for biogas, which can be dated back to as early as the 10^{th} century BC where biogas was used for heating bath water in Assyria (Shapland, n.d.). Major development of biogas technology later include the establishment of the first digestion plant in Bombay, India in 1859 AD (Meynell, 1976) followed by the use of biogas as a fuel for street lamps in Exeter, England in 1895 (McCabe and Eckenfelder, 1957).

Balat (2011) claims that among the various types of energy source, "biomass can be considered as the best option and has the largest potential" for future energy supply, especially in developing countries where Chopra and Jain (2007) expected 90% of the world's population to reside by 2050. Large biomass potential found in many parts of the world has been assessed in order to show the estimated amount of energy that can be produced. These areas include South America and the Caribbean (47-221 EJ/year), sub-Saharan Africa (31-317 EJ/year), the Commonwealth of Independent States (C.I.S.) and Baltic States (45-199 EJ/year), Oceania (20-174 EJ/year) and North America (38-102 EJ/year) (Smeets *et al*., 2007).

Five reasons to support the use of biomass as the main energy source are described by Karekezi *et al*. (2004) as follows

(1) It contributes to poverty reduction in developing countries.

(2) It meets energy needs at all time, without expensive conversion devices.

(3) It can deliver energy in all forms that people need.

(4) It is carbon dioxide (CO_2)-neutral and can even act as carbon sinks.

(5) It helps to restore unproductive and degraded lands, increasing biodiversity, soil fertility and water retention.

The use of biomass is considered to be CO_2-neutral because the CO_2 released during the burning of biogas was previously removed from the atmosphere by plants through the process of photosynthesis in order to produce biomass (Federal Ministry of Food, Agriculture and Consumer Protection, 2009). Not only that it doesn't release additional CO_2 to the atmosphere, through the process of fermentation, additional methane (CH_4) as well as laughing gas or nitrous oxide (N_2O) can also be avoided (Federal Ministry of Food, Agriculture and Consumer Protection, 2009). Both CH_4 and N_2O are greenhouse gases with large global warming potential (GWP) of 21 and 310 respectively (time horizon of 100 years), while CO_2 has the GWP of only 1 (United Nations Framework Convention on Climate Change, 2012).

Modern utilization of biomass is characterized by the use of combined heat and power (CHP) technology widely adopted in Scandinavian countries, the production of ethanol from sugarcane and the co-combustion of biomass in conventional coal-based power plants (Hoogwijk *et al.*, 2005). Three main utilization processes of biomass, i.e. direct combustion of wastes for electricity generation, bioethanol and biodiesel as liquid fuels, and combined heat and power production are expected to be widely used among industrialized countries in the future (Balat, 2011).

3.3.2 Types of Biomass

Six specific types of biomass can be further divided according to Balat (2011) as follows

1) Wood and wood wastes
2) Agricultural crops and their waste byproducts
3) Municipal solid waste (MSW)
4) Animal wastes
5) Waste from food processing
6) Aquatic plants and algae

Wood and wood wastes contribute to more than half (64%) of the total average energy produced from biomass, followed by municipal solid waste (24%), agricultural waste (5%) and landfill gases (5%) (Demirbas, 2001).

As described by Gnansounou *et al*. (2005), 15 issues are needed to be considered when comparing and selecting types of biomass for energy production. These issues are;

1) Chemical composition of the biomass
2) Cultivation practices
3) Availability of land and land-use practices
4) Use of resources
5) Energy balance
6) Emission of greenhouse gases, acidifying gases and ozone depletion gases
7) Absorption of minerals to water and soil
8) Injection of pesticides
9) Soil erosion
10) Contribution to biodiversity and landscape value losses
11) Farm-gate price of the biomass
12) Logistic cost (transport and storage of the biomass)
13) Direct economic value of the feedstock taking into account the coproducts
14) Creation or maintenance of employment
15) Water requirements and water availability

3.4 Biorefinery

3.4.1 Overview

Biorefinery refers to a facility that integrates biomass-conversion processes and equipment to produce other products including fuels, electrical/heat energy and chemicals from biomass (Balat, 2011). These products can be generated either through thermal or biological processes. It uses the same concept of producing multiple products from a single source as the petroleum refineries (Gravitis, 2007). As concluded by Balat (2011), biorefinery can "take advantage of the differences in biomass components and intermediates and maximize the value derived from the biomass feedstock". Because it intends to produce multiple products, a biorefinery needs to integrate various conversion processes within the system. For example, an intensified integrated biorefinery with the integration of various conversion processes including fermentation, gasification, hydrolysis, catalytic conversion, and gas-to-liquid conversion, can be created to produce a wide range of products as shown in Figure 3. 1.

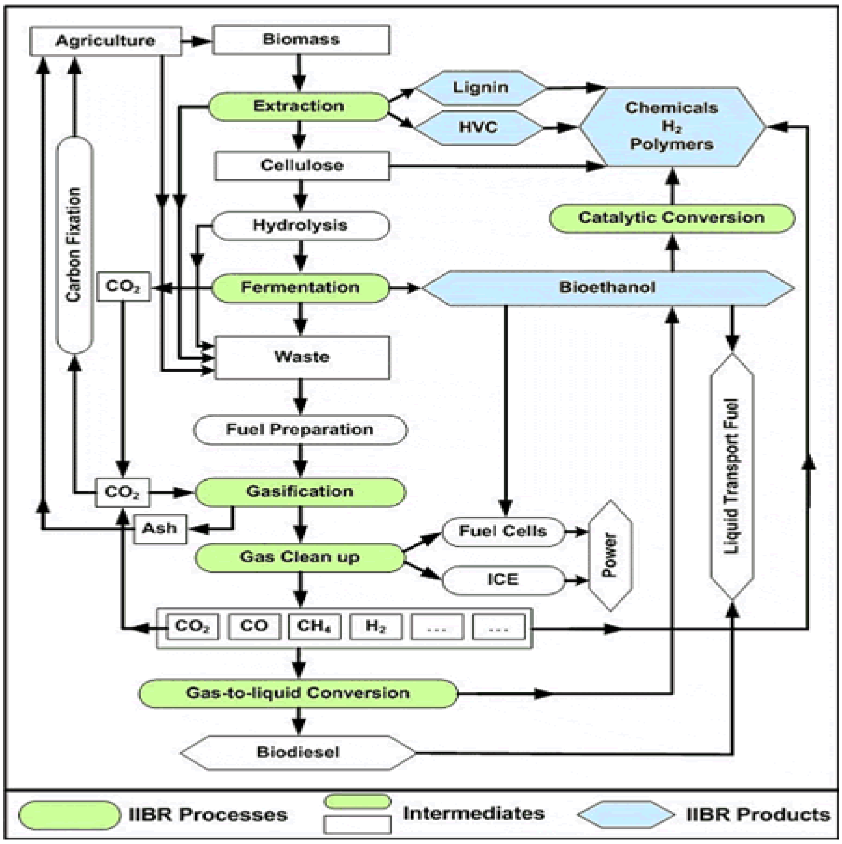


Figure 3.1 Intensified Integrated Biorefinery

Source: Newcastle University's Process Intensification and Miniaturisation. (2001). Biomass and gasification. Retrieved from http://research.ncl.ac.uk/pim/biomass.htm on December 16, 2012.

The concept of biorefinery is built upon two platforms as shown in Figure 3. 2: (1) sugar platform, (2) syngas platform.

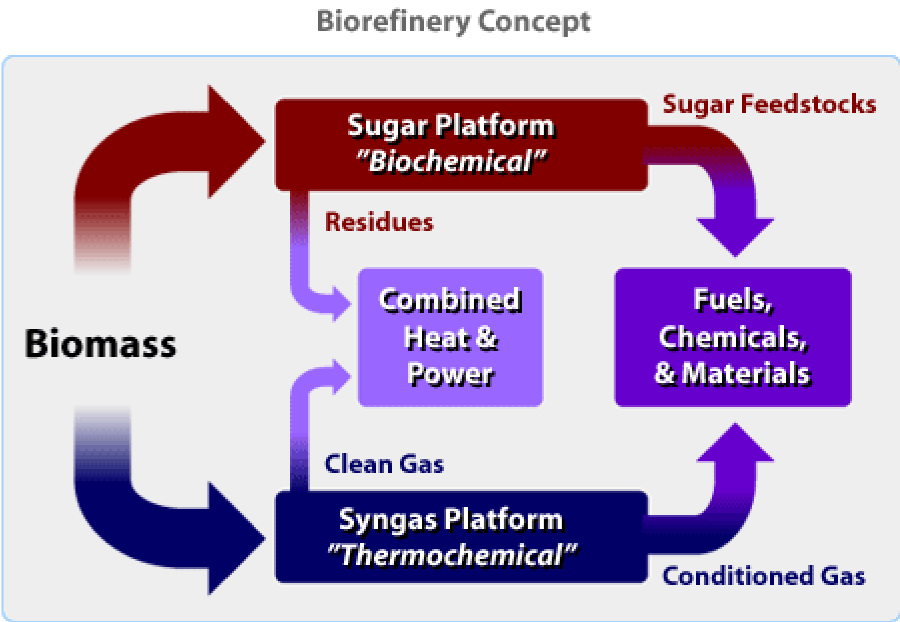


Figure 3.2 Biorefinery Concept

Source: National Renewable Energy Laboratory. (2009). What is a biorefinery?. Retrieved from http://www.nrel.gov/biomass/biorefinery.html on December 16, 2012.

The sugar platform is based on the biochemical conversion processes of biomass into raw component sugars and focuses on developing "the capability of biomass to produce inexpensive sugar streams that can be used to make fuels, chemicals, and other materials" (Balat, 2011). The syngas platform is based on thermochemical conversion processes of biomass or biorefinery residues to intermediates such as pyrolysis oil and syn gas (Balat, 2011). These intermediates can either be used as raw fuels or to be purified and produce transportation fuels, oils and hydrogen (Crocker and Crofcheck, 2006). Theoretically, all kinds of biomass can be used for biorefinery, but the construction and operation of the processes depend on the basis of the chemical composition of each biomass feedstock (Speight, 2011).

3.4.2 Composition of Biomass Feedstocks

When designing a refinery, it is important to understand the composition of the biomass feedstocks since there is a wide range of biomass sources, their composition is greatly variable (Speight, 2011). Calorific value (heat value, heat content) is the main component that reflects the composition of the feedstocks. It refers to the energy released per unit mass or per unit volume of the fuel when it is completely burned (ASABE, 2011). It is normally expressed in the units of MJ/kg in International System (SI) of Units and Btu/lb in English units (U.S. Department of Energy, 2011). Higher calorific value means that the fuel can be used to produce energy more efficiently. Biomass as a whole generally has a calorific value between the range of 6,000 to 8,500 Btu/lb (Speight, 2011), which is slightly lower than those of coals and much lower than petroleum. Table 3.1 shows the different calorific values of biomass sources and fossil fuels.

Table 3.1 Calorific value of selected fuels

Fuel	*Btu/lb*
Natural gas	23,000
Gasoline	20,000
Crude oil	18,000
Heavy oil	16,000
Coal (anthracite)	14,000
Coal (bituminous)	11,000
Wood (farmed trees, dry)	8,400

Coal (lignite)	8,000
Biomass (herbaceous, dry)	7,400
Biomass (corn stover, dry)	7,000
Wood (forest residue, dry)	6,600
Bagasse (sugar cane)	6,500
Wood	6,000

Source: Speight, J. (2011). Biorefinery. In J. Speight (Ed.), *The Biofuels Handbook* (pp. 120). Cambridge: The Royal Society of Chemistry.

In order to determine the calorific value, moisture content or the condition of water molecules in the final combustion products needs to be measured (U.S. Department of Energy, 2011). Oven-dried biomass has the moisture content of 0%, while air-dried biomass normally has about 15 to 20% of moisture (Speight, 2011). Higher moisture content reduces the calorific value of the feedstocks, thus reducing the efficiency of energy production.

3.5 Gasification Process

3.5.1 Description

Gasification is a process that produces gas for internal combustion engine or fuel cell from biomass by using gasifiers. Synthesis gas, simply called *syngas*, is a product of biomass gasification which can be used for electricity production. It is primarily composed of hydrogen and carbon monoxide unlike *biogas*, which is composed mainly of methane and carbon dioxide (Speight, 2011). The chemical reaction of biomass gasification can be expressed as follows:

$$\mathbf{C_6H_{12}O_6 + O_2 + H_2O \longrightarrow CO + CO_2 + H_2 + other\ products}$$

According to Bocci et al. (2014), the oxidants used in the thermo-chemical process which converts biomass to syngas include air, pure O_2, steam and CO_2 or their mixture. Currently, air is the most used oxidant because of its great availability and zero cost. However, large amount of nitrogen in the air requires higher power on blowers and bigger equipment, as well as reduces the heating value of the syngas produced (Bocci et al., 2014). Using pure O_2 as oxidant helps increase the heating value of the syngas produced but also increases the operational cost due to the O_2 production (Bocci et al., 2014). Using steam or CO_2 as oxidant requires heat supply for the endothermic gasification reactions, which can be supplied indirectly through heat exchangers or directly via air or O_2 to partially burn the biomass (Bocci et al., 2014).

Typically, gasifiers can be classified into two main families; i.e. fixed bed and fluidized bed. Three types of fixed bed gasifiers can be further categorized; i.e. updraft (UD) configuration, downdraft (DD) configuration and crosscurrent.

1) Updraft Gasifier

In UD gasifier, biomass moves from the top, while gasifying agent move from the bottom. The system can be alternatively called *Counter Current Gasifier*. The energy efficiency is generally high because the heat generated from the combustion zone flows through the pyrolysis zone and reduction zone. However, the product gas contains higher tar content than from DD gasifier because the tar is produced and carried out of the reactor with the upward flowing product gas unlike in DD where tar cracking is aided due to the intimately mixed reaction product in the turbulent high-temperature region around the throat (Bocci et al., 2014). Figure 3.3 illustrates the operating principle of an updraft gasifier.

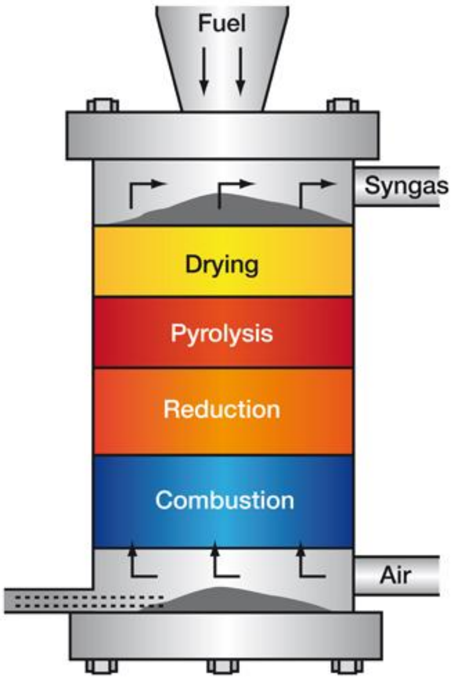


Figure 3.3 Updraft Gasifier

Source: GB Gasifired (2012). Biomass gasifier model. Retrieved from http://www.gbgasifired.com/model.html on May 15, 2014.

2) Downdraft Gasifier

In DD gasifier, both biomass and gasifying agent move in the same direction from the top to the bottom of the reactor. It can be alternatively called *Cocurrent Gasifier*. The product gas contains less tar than from UD gasifier because the product from the pyrolysis zone flows through the combustion zone and breaks down into gas before leaving the gasifier as shown in Figure 3.4. However, overall energy efficiency of the DD is relatively low, thus it is more suitable for small-scale electricity generation with an internal combustion engine. According to

Bocci et al. (2014), “downdraft gasifiers are not suitable for scale-up to larger size (> 1 MW) because they do not allow for uniform distribution of flow and temperature in the constricted area (throat)”.

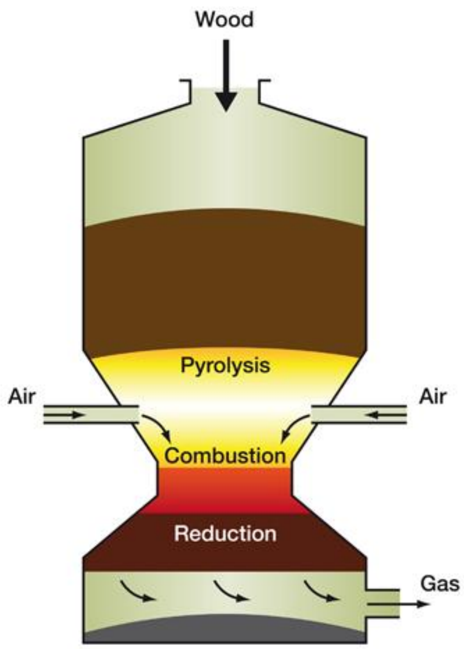


Figure 3.4 Downdraft Gasifier

Source: GB Gasifired (2012). Biomass gasifier model. Retrieved from http://www.gbgasified.com/model.html on May 15, 2014.

3) Crossdraft Gasifier

In Crossdaft or *Crosscurrent Gasifier*, the biomass moves down from the top and the gasifying agent is fed at right angles. Product gas from the crossdraft gasifier is relatively clean due to the low tar production (0.01-0.1 g/Nm^3) because of its small reaction zone with low thermal capacity which allows a faster response than other fixed-bed types, thus the crossdraft gasifier requires a relatively simple gas-cleaning system unlike the UD and DD gasifier (Bocci et al., 2014).

On the other hand, fluidized bed gasifier mixes the biomass feedstock with hot bed material, such as inert sand and catalyst, and keeps them in a semi-suspended condition (fluidized state) “by means of the gasifying medium through them at the appropriate velocities” as described by Bocci et al. (2014). Due to the intense gas-solid mixing, the process of drying, pyrolysis, oxidation and reduction in fluidized bed system cannot be distinguished. Because of the excellent mixing of gas and solid, the temperature and concentration of gas and solid mixture are uniform in the entire bed, thus the biomass conversion is close to 100 percent (Bocci et al., 2014). Feedstock for the fluidized bed gasifiers can also be less specific thus making the system more appropriate for large installations than fixed bed gasifiers. However, the system is more complicated, the product gas has higher particulates (from 10 to 100 g/Nm3) and the tar production lies between that for updraft and downdraft gasifiers. Higher abrasive action is also one of the effects of the fluidized bed gasifiers due to the fast movement of the bed material. Figure 3.5 illustrates how a fluidized bed gasifier operates.

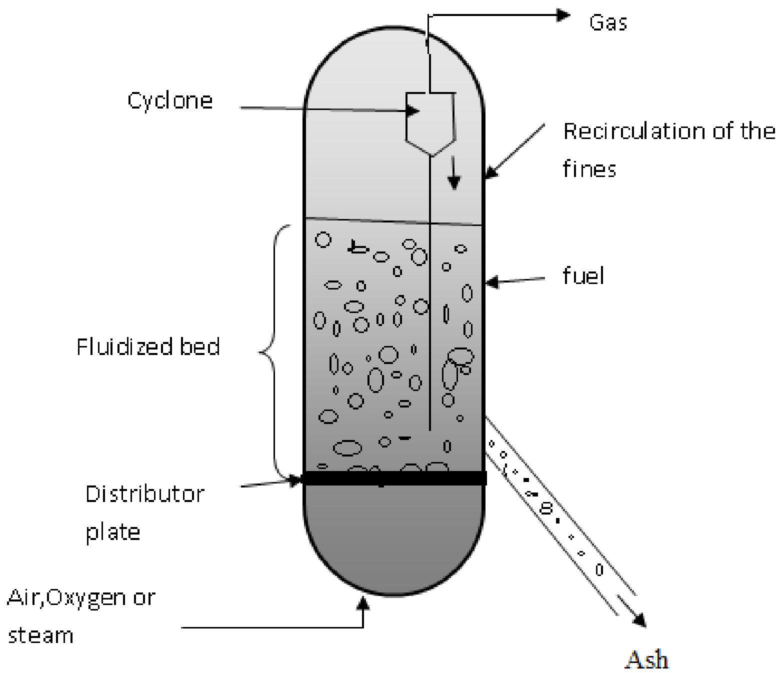


Figure 3.5 Fluidized bed gasifier

Source: Sivakumar, L. & Anithamary, X. (2012). Lower order modeling and control of

Alstom fluidized bed gasifier. Retrieved from http://www.intechopen.com/books/gasification-for-practical-applications/lower-order-modeling-and-control-of-alstom-fluidized-bed-gasifier on May 15, 2014.

It is suggested that instead of using bioenergy crops to produce energy, biomass residues can offer a cheaper source of energy with less environmental impacts (Speight, 2011). With the use of co-gasification of biomass and various types of low-cost waste such as waste from animal farms, the system can be much more economical.

3.5.2 Gas Treatment

As the product gas from gasification process contains high amount of particulate matters, it is needed to be treated before delivering to the electricity generator. Thailand's Department of Alternative Energy Development and Efficiency[2] (2011) describes various technologies for pollution filtering which are widely used among gasification plants including electrostatic precipitator, cyclone, bag filter and wet scrubber.

- **Electrostatic Precipitator** removes fine particles from the gas by inducing minimal electrostatic charge which makes the particles attract to the collector plates as shown in Figure 3.6. It has relatively high filtration efficiency, but is not suitable for biomass feedstock which produces silica in the ash such as rice husk.

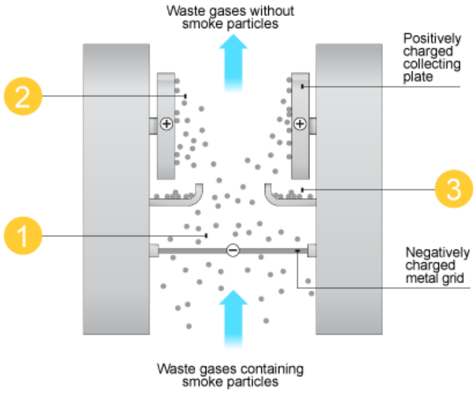


Figure 3.6 Electrostatic Precipitator

Source: BBC (n.d.). Using static electricity. Retrieved from www.bbc.co.uk/schools/gcsebitesize/science/add_aqa_pre_2011/electricity/staticelectrev2.shtml on May 15, 2014.

- **Cyclonic Separator** removes fine particles by using rotational effect and gravity. The particles are separated from the gas and moved towards the wall and down to the hopper as shown in Figure 3.7.

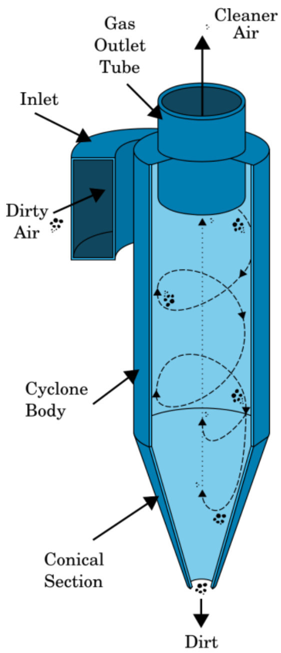


Figure 3.7 Cyclone Separator

Source: Wikipedia (2007). Cyclonic separation. Retrieved from http://en.wikipedia.org/wiki/File:Cyclone_separator.svg on May 15, 2014.

- **Bag Filter** or **Baghouse** uses fabric collectors (filter bags) to filter the particles from flowing gas. It requires regular cleaning of the collectors and does not work well in an environment or with feedstock with high humidity.

Figure 3.8 Bag Filter

Source: Gromicko, N. (n.d.). Baghouse inspection. Retrieved from http://www.nachi.org/baghouse-inspection.htm on May 15, 2014.

- **Wet Scrubber** or **Wet Collector** uses liquid to remove particles from the gas. It does so by spraying water droplets which then capture and incorporate the particles. These water droplets are then separated from the product gas. According to Arjharn (2012), this process can be used to separate tar from the product gas from the gasification process. Figure 3.9 illustrates the operating principle of a wet scrubber.

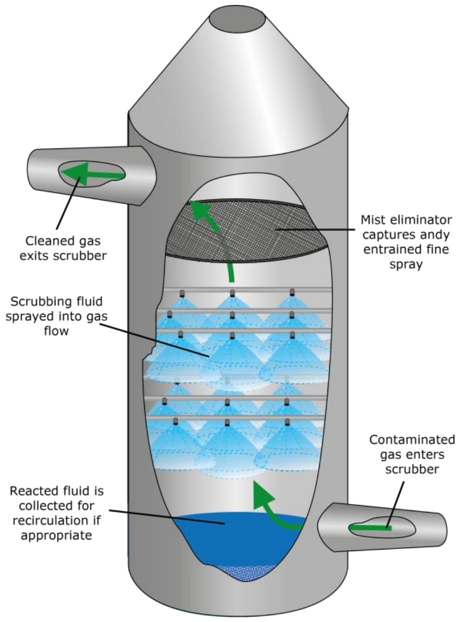


Figure 3.9 Wet Scrubber

Source: BETE (n.d.). Gas scrubbing. Retrieved from http://www.bete.co.uk/spray-nozzle-applications/gas-scrubbing on May 15, 2014.

3.6 Air Pollution

3.6.1 Particulate Matter

As described by World Health Organization (2000), airborne particulate matter (PM) refers to a complex mixture of organic and inorganic substances in the atmosphere. They can be generally categorized by their size and the way they behave in the atmosphere. PM_{10} and $PM_{2.5}$ are the types of particulate matter that are mainly focused throughout this research. According to Tiwary & Colls (2010), PM_{10} refers to the mass concentration of particulate matter due to particles that pass through a size-selective inlet that has 50% efficiency at an aerodynamic diameter of 10 µm, while $PM_{2.5}$ refers to the corresponding concentration for a cut diameter of 2.5µm. In other words, they are particles with less than 10 µm and 2.5 µm in diameter respectively. These types of particulate matter can especially create serious adverse effects because they have very low sedimentation speeds under gravity, meaning that they can stay remaining in the atmosphere for days (Tiwary & Colls, 2010). Effects of having high concentration of these particulate matters include human health effects, loss of visual range and also soiling of surfaces.

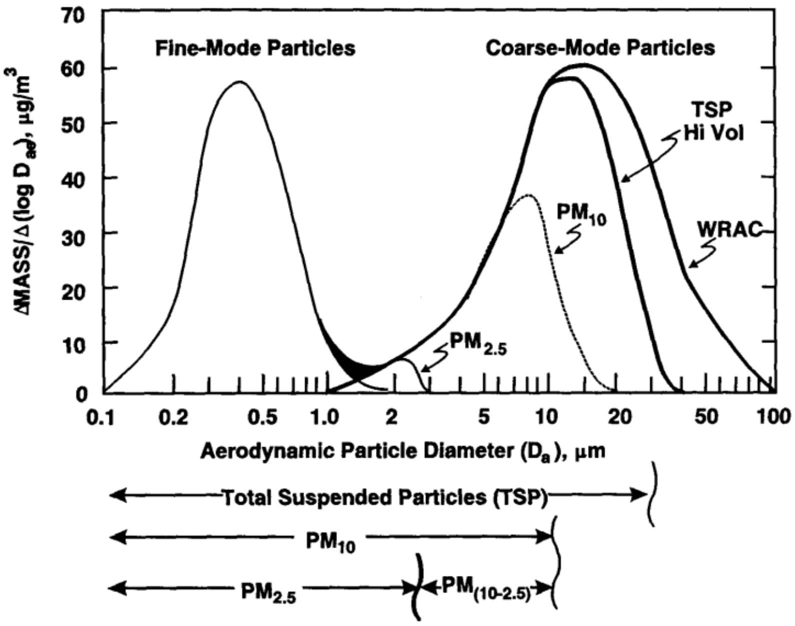


Figure 3.10 Schematic representation of the size distribution of particulate matter in ambient air **Source:** WHO. (2001). Air quality guidelines. Retrieved from http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf on January 28, 2013.

In many countries, legislations have taken place in order to secure the air quality by limiting the amount of particulate matter either PM_{10} or $PM_{2.5}$ or both. In the European Union (EU), the limit value for annual average of PM_{10} is 40 μg/m^3. In the United States, the limit value for annual average is 50 μg/m^3. Even though the air quality standards for PM_{10} are stricter in the European Union than in the United States, the standards for $PM_{2.5}$ are, however, stricter in the United States. The annual average of $PM_{2.5}$ in the United States has the limit of 15 μg/m^3, in the European Union; the limit value is 25 μg/m^3 (Palmgren, 2004 and European Commission, 2012).

Sources of particulate matter can be various. Generally, two different categories of particle sources can be recognized; natural sources and anthropogenic sources. Examples of natural sources include wind erosion, sea salt, volcanoes, forest fires and pollen. Examples of anthropogenic sources include combustion, crushing or spraying. According to Tiwary & Colls (2010), it is forecasted that within the next 25 years the anthropogenic aerosols, or airborne particles generated from anthropogenic sources, released from the Asian region will dominate the global anthropogenic aerosols component. The Asian Brown Cloud, a phenomenon described in the South Asian region is one of the major phenomenons that strongly support this argument. Studies conducted by the Indian Ocean Experiment (INDOEX) between 1995 and 1999 revealed that this phenomenon has negative environmental impacts that go beyond the confines of local scale (Tiwary & Colls, 2010).

3.6.2 Human Health Effects

Air pollution can have various effects on human health. A 1997 joint study conducted by the World Health Organization (WHO), the World Resources Institute (WRI) and the US Environmental Protection Agency (EPA) estimated that around 700,000 people worldwide have died from diseases related to air pollution. The number is estimated to rise up to 8 million by the year 2020 (Tiwary & Colls, 2010).

Tiwary & Colls (2010) have classified typical health effects caused by air pollutants as follows;

- Reduced lung functioning
- Irritation of the eyes, nose, mouth and throat
- Asthma attacks
- Respiratory symptoms such as coughing and wheezing
- Restricted activity or reduced energy level
- Increased use of medication

- Increased hospital admission
- Increased respiratory disease such as bronchitis
- Premature (‘brought forward’) death

As shown above, the respiratory system is the most heavily affected system in human body because it is the main route for air pollutants to enter into the body. Particles entering through the respiratory system can deposit within the lungs and respiratory tract, and create various health effects depending on their aerodynamic diameter, as well as local airspeed and residence time (Tiwary & Colls, 2010). Particles less than 100 μm can be inhaled and enter into the respiratory system. However, typically only particles less than 50 μm can pass through the nose and mouth, and particles less than 10 μm can penetrate to the bronchi or may even penetrate into lower respiratory tract (Tiwary & Colls, 2010). Figure 3.6 shows the total and regional deposition of particles according to their aerodynamic diameters. This type of particle is regarded as respirable fraction. The deposition of particles in the respiratory tract can be the cause of diseases ranging from asthma, bronchitis, chronic obstructive pulmonary diseases (COPD) and even secondary organismic disease (Hussain, Madl & Khan, 2011).

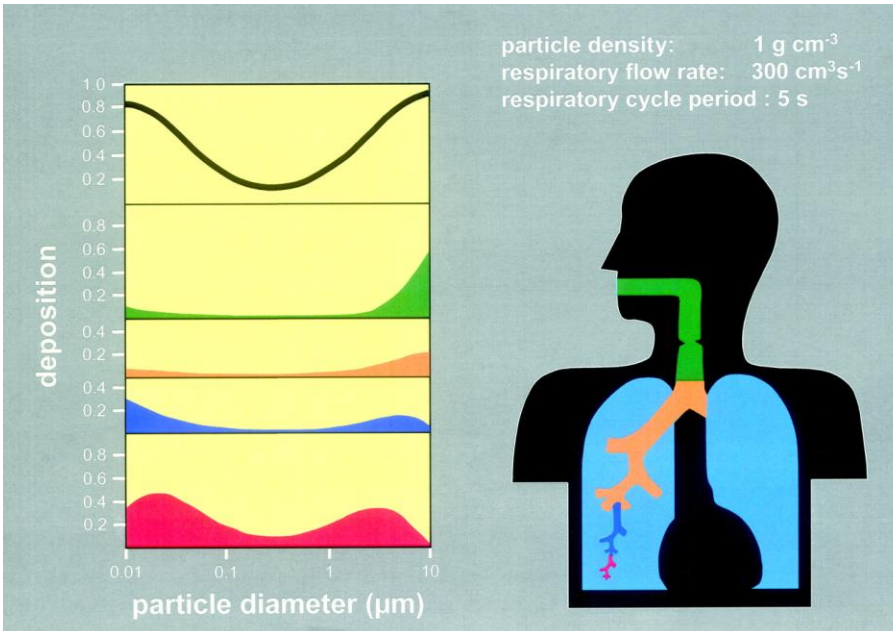


Figure 3.11 Total and regional deposition of unit-density spheres in the human respiratory tract predicted by the ICRP deposition model for oral inhalation at rest

Source: Heyder, J. (2004). Deposition of inhaled particles in the human respiratory tract and consequences. Retrieved from http://pats.atsjournals.org/content/1/4/315.full on January 30, 2013.

4. General Information about Chiang Mai

This chapter provides general information about Chiang Mai including its geography, administration system, climate, land use, communication and transportation, and the existing ambient air quality monitoring stations. The purpose of this chapter is not only to introduce Chiang Mai, but also to show the relation between the smog problem and the characteristics of the province because the smog problem is amplified particularly in this region due to its geography, climate, land use and road accessibility.

4.1 Geography

Chiang Mai is the largest province in northern Thailand, covering the total area of approximately 22,042 km^2. It extends 317 km N – S and 138 km E – W. Most of the areas are valleys surrounded by mountainous terrains stretching in a north-south direction with three major ranges being Thanon Thong Chai Range and Phi Pan Nam Range in the east, and Daen Lao Range in the north. Five major valleys are located among these mountain ranges; i.e. Chiang Mai – Lamphun Valley, Fang Valley, Phrao Valley, Chiang Dao Valley and Mae Chaem Valley (Dontree et al., 2011). Due to this geographical characteristic, Chiang Mai has a very broad range of altitude starting from 200 – 2,585 meters above sea level (Chulalongkorn University, 1991) creating a diverse nature of climate and land use (Dontree et al., 2011). Because of this geographical characteristic, the smog can be easily accumulated within the valleys.

4.2 Administration

Chiang Mai is subdivided into 25 districts (Amphoe) with 200 subdistricts (Tambon) subdivided within the districts.

List of Districts in Chiang Mai

(1) Mueng Chiang Mai
(2) Chom Thong
(3) Mae Chaem
(4) Chiang Dao
(5) Doi Saket
(6) Mae Taeng
(7) Mae Rim
(8) Samoeng
(9) Fang
(10) Mae Ai
(11) Phrao
(12) San Pa Tong
(13) San Kamphaeng
(14) San Sai
(15) Hang Dong
(16) Hot
(17) Doi Tao
(18) Omkoi
(19) Saraphi
(20) Wiang Haeng
(21) Chai Prakan
(22) Mae Wang
(23) Mae On
(24) Doi Lo
(25) Galayani Vadhana

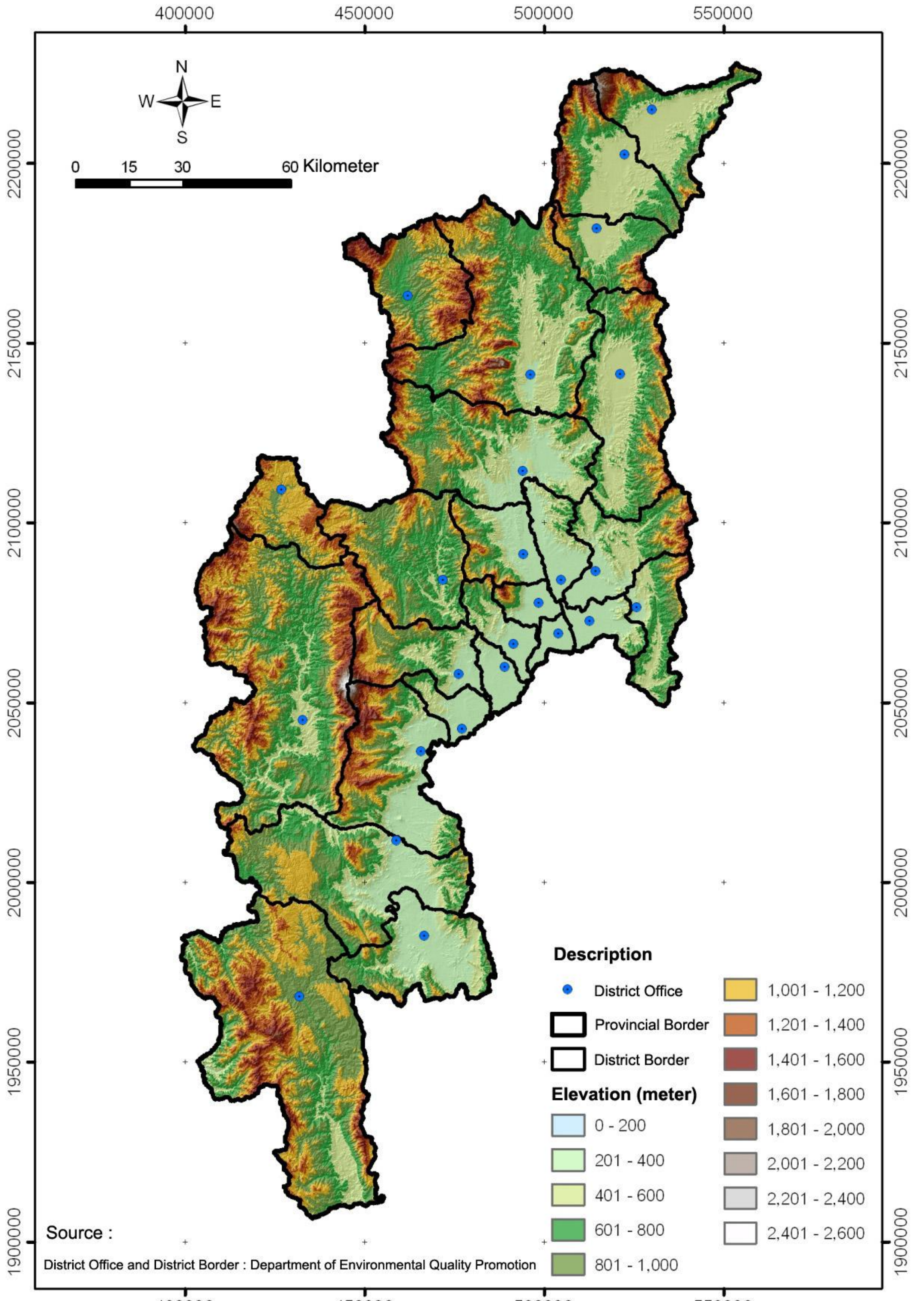


Figure 4.1 Map of Chiang Mai

Source: Dontree et al. (2011). Prioritizing of burned areas using multi-source spatial

data for open field burning surveillance and prevention in Chiang Mai province. Chiang Mai: Department of Geography, Faculty of Social Science, Chiang Mai University.

4.3 Climate

Chiang Mai has a tropical savanna climate with remarkable difference between rainy and dry season (Dontree et al., 2011). Heavy rainfall occurs during the rainy season (May – mid October) due to the influence of the south-west monsoon winds from Indian Ocean. From mid October until mid February, with the influence of cold north-east winds from China, the temperature drops and the climate becomes less humid. There is little or no rainfall from mid February until April, as well as very little or no movement of wind. Average annual temperature of Chiang Mai measuring from the year 1971 to 2000 is 26°C with the period between December and April, which is also the period of smog, having the widest range between the lowest and highest temperature (Dontree et al., 2011). Relative humidity is lowest in March and April, while, on the other hand, evaporation rate is highest. Direction of wind during the smog period is coming from the south with very low speed of 3-4 knots per hour, making it impossible for the particles to be blown up into the atmosphere (Dontree et al., 2011).

4.4 Land Use

Various types of land use are categorized into nine categories; i.e. deciduous forest, evergreen forest, agroforestry, forest park, rotational farming, plant farm, paddy field, orchard and tree plantation and others including rural and urban residential area, industry, grassland and wetland (Dontree et al., 2011). Approximately 71% of the total area of Chiang Mai is covered by forest. The study done by Dontree et al. (2011) shows that the number of forested area in 2010 has slightly decreased from the year 2008, when the problem of smog first received public attention, from 71.4% to 71.1%. Within the total forested area, approximately 70% are deciduous forest, followed by evergreen forest and forest park, mostly in mountainous area. Orchard and tree plantation has the highest proportion of agricultural land use, being 7.3% of total agricultural area, followed by paddy field, rotational farming and plant farm, mostly corn which has increased more than any other types of farm plants (Dontree et al., 2011).

Table 4.1 Total Land Use of the year 2008 and 2010

Types of Land Use	**2008**		**2010**	
	Area (km^2)	**Percentage (%)**	**Area (km^2)**	**Percentage (%)**
Deciduous Forest	11,203.94	50.8	11,109.39	50.4

Evergreen Forest	4,532.40	20.6	4,414.45	20.0
Paddy Field	1,064.27	4.8	1,013.28	4.6
Plant Farm	496.10	2.3	650.90	3.0
Orchard/Tree Plantation	1,605.53	7.3	1,605.74	7.3
Rotational farming	1,538.31	7.0	1,460.27	6.6
Agroforestry	24.29	0.1	24.29	0.1
Forest Park	129.37	0.6	147.10	0.7
Others	1,446.91	6.6	1,615.70	7.3
Total	**22,041.12**	**100.0**	**22,041.12**	**100.0**

Source: Dontree et al. (2011). Prioritizing of burned areas using multi-source spatial data for open field burning surveillance and prevention in Chiang Mai province. Chiang Mai: Department of Geography, Faculty of Social Science, Chiang Mai University.

4.5 Communication and Transportation

Roads are the basic means of transportation in Chiang Mai of which every district has substantially good accessibility (Dontree et al., 2011). Complex road system can be found in plains and low lying areas where there is higher population. Fewer roads are paved on highlands.

Major routes include Highway No. 11 (Lamphang – Lamphun – Chiang Mai), Highway No. 106 (Chiang Mai – Lam Phun), Highway No. 107 (Chiang Mai - Fang), Highway No. 108 (Chiang Mai – Mae Hong Son) and Highway No. 118 (Chiang Mai – Doi Saket). Total length of all major routes is 3,640.5 km.

Minor routes include Highway No. 1001 (Chiang Mai – Phrao), Highway No. 1004 (Chiang Mai – Doi Suthep), Highway No. 1006 (Chiang Mai – San Kamphaeng), Highway No. 1013 (San Pa Tong – Mae Wang), Highway No. 1095 (Mae Ma Lai - Pai), Highway No. 1096 (Mae Rin – Sa Moeng), Highway No. 1099 (Hot – Om Koi), Highway No. 1103 (Hot – Doi Tao), Highway No. 1230 (Mae On – Mae Ta), Highway No. 1269 (Hang Dong – Sa Moeng) and Highway No. 1317 (San Kamphaeng – Mae On – Doi Saket). Total length of all minor routes is 12,136.6 km.

Apart from major and minor routes which are national highways, local roads can be found throughout the province with the total length of 14,937.1 km.

4.6 Ambient Air Quality Monitoring Station

According to the Pollution Control Department, the ambient air monitoring station is established to determine the general levels of pollutants in the atmosphere, evaluate the magnitude of air pollution problems and long term air pollution trends, assess the effectiveness of air pollution control programs, provide information and serve as a source of data. There are currently ten ambient air monitoring stations in northern region of Thailand, of which two stations are located in Chiang Mai. One of the stations is located at Yupparaj Wittayalai School and another at Chiang Mai Government Center. Pollutants that are monitored include CO, SO_2, NO, NO_2, NO_x, O_3, PM_{10} and $PM_{2.5}$ (Pollution Control Department, n.d.). Other stations are located Lam Pang, Mae Hong Son, Chiang Rai, Nan and Lam Phun.

5. Open Burning Analysis

Purpose of the open burning analysis is to provide an insight into the causes of smog problem. It locates the areas where particulate matter is generated and provides information about the nature of the area. The analysis also shows the trend of the open burning which correlates to the fluctuating amount of particulate matter in each year. Various measures currently taken in order to cope up with the open burning crisis are also introduced. They show the efforts and the direction of the problem solving process that is currently being taken.

5.1 Open Burning Data

Dontree et al. (2011) collected open burning data by monitoring number of hotspots, which are the areas with extremely high temperature and can be monitored and recorded via MODIS satellite. Hotspot data can be accessed through different websites including http://www.dnp.go.th/forestfire, http://maps.geog.umd.edu and http://geoinfo.ait.ac.th/mod14/mod14_db/search_db_mod14b.php. Even though the satellite data has the advantage of providing a near-real-time data, it has a fixed updating schedule of four to five times per day, i.e. 1.30-2.00, 10.00-11.30, 13.00-14.30 and 21.30-22.00.

According to Dontree et al. (2011), in the year 2007, 2008, 2009, 2010 and 2011, total numbers of hotspots monitored in Chiang Mai province were 2,380, 1,034, 847, 2,434 and 684 respectively. The dramatic decrease of hotspots in the year 2011 was due to the La Niña phenomenon which caused heavy and more frequent rainfalls in northern Thailand than usual, thus leading to the low number of hotspots (Dontree et al., 2011). From the collected data, it is obvious that the areas with high density of hotspots are mostly the same areas in every data collected year, which are mainly highlands and forested areas. The districts with three highest numbers of hotspots in Chiang Mai province are Mae Chaem, Omkoi and Chiang Dao as seen in Table 5.1. Other districts with significant numbers of hotspots include Samoeng, Wiang Haeng, Hot and Mae Taeng.

Table 5.1 Number of Hotspot in each district in the year 2007, 2010 and 2011

District	Number of Hotspots					
	2007		2010		2011	
	Number	%	Number	%	Number	%
Mueng Chiang Mai	7	0.29	8	0.34	0	0.00
Chom Thong	76	3.12	88	3.70	26	3.80
Mae	528	21.69	504	21.18	166	24.27

Chaem						
Chiang Dao	254	10.44	267	11.22	75	10.96
Doi Saket	62	2.55	21	0.88	5	0.73
Mae Taeng	112	4.60	125	5.25	38	5.56
Mae Rim	25	1.03	48	2.02	18	2.63
Samoeng	115	4.72	126	5.29	23	3.36
Fang	61	2.52	72	3.03	12	1.75
Mae Ai	93	3.82	106	4.45	27	5.41
Phrao	81	3.33	120	5.04	21	3.07
San Pa Tong	2	0.08	7	0.29	3	0.44
San Kamphaeng	5	0.21	11	0.46	1	0.15
San Sai	25	1.03	17	0.71	2	0.29
Hang Dong	12	0.49	16	0.67	2	0.29
Hot	102	4.19	115	4.83	43	6.29
Doi Tao	37	1.52	30	1.26	12	1.75
Omkoi	460	18.90	446	18.74	121	17.69
Saraphi	9	0.37	1	0.04	0	0.00
Wiang Haeng	130	5.34	102	4.29	16	2.34
Chai Prakan	72	2.96	61	2.56	31	4.53
Mae Wang	47	1.93	67	2.82	19	2.78

Mae On	16	0.66	13	0.55	0	0.00
Doi Lo	10	0.41	9	0.38	9	1.32
Galayani Vadhana	93	3.82	0	0.00	4	0.58
Total	2,434	100.00	2,380	100.00	684	100.00

Source: Dontree et al. (2011). Prioritizing of burned areas using multi-source spatial data for open field burning surveillance and prevention in Chiang Mai province. Chiang Mai: Department of Geography, Faculty of Social Science, Chiang Mai University.

From the field observation by Dontree et al. (2011) in two different districts, Chiang Dao and Wiang Haeng, during 13-14 March 2011, it was found that the areas which were openly burned were located in deciduous forests with tall dry grass covering the forest floor ranging from the altitude 640 to 740 meters from sea level. This type of area can produce high temperature once burned. The purpose of open burning was most likely to increase cultivated area according to the corn plantations which were observed nearby (Dontree et al., 2011).

From the data from the year 2007, 2009 and 2010, it is shown that the numbers of hotspots are highest in March followed by February, January and December (Dontree et al., 2011). However, in the year 2011, the La Niña phenomenon had delayed the open burning peak for about one month, thus the highest number of hotspots was recorded in April, followed by March, February, January, December and May respectively as shown in Table 5.2.

Table 5.2 Monthly Hotspots in the year 2007, 2009, 2010 and 2011

Year	December		January		February		March		April		**Total**	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
2007	NA		94	3.86	465	19.10	1,664	68.36	211	8.67	2,434	100
2009	32	2.01	25	1.57	401	25.22	866	54.47	266	16.73	1,590	100
2010	58	2.44	24	1.01	460	19.33	1.254	52.69	584	24.54	2,380	100
2011	23	3.39	14	2.06	119	17.53	232	34.17	291	42.86	679	100

Source: Dontree et al. (2011). Prioritizing of burned areas using multi-source spatial data for open field burning surveillance and prevention in Chiang Mai province. Chiang Mai: Department of Geography, Faculty of Social Science, Chiang Mai University.

Note: Insufficient data for the year 2008 thus not included in the table

According to Dontree et al. (2011), the collected and combined satellite data shows that the total open burning area in Chiang Mai province in the year 2007, 2010 and 2011 are 4,243.66 km^2, 4,739.73 km^2 and 1.16 km^2 respectively. These equal to approximately 19 percent, 22 percent and five percent of the total area of Chiang Mai province. Districts with large open burning areas are generally similar in all three years with Mae Chaem being the district with the largest area of open burning in all years (Dontree et al., 2011). Other districts with large open burning areas in all three years include Hot, Doi Tao, Chiang Dao, Chom Thong, Om Koi, Mae Ai, Mae Taeng and Fang.

Dontree et al. (2011) concludes that all sets of data collected from satellite hotspot data, forest fire reports and Landsat 5 TM satellite point out in the same direction that the main open burning areas are located in the southern part of the province including Mae Chaem, Hot, Om Koi and Chom Thong. Several districts in the northern part of the province including Chiang Dao, Chai Prakan, Mae Ai and Fang, also have large areas of open burning. Another conclusion is that open burnings happen most frequently in March. Combining with the weak southern wind and the geographical factor, the problem of smog is accelerated during that period.

5.2 Impacts of Open Burning

Open burning can strongly affect air quality, which is monitored and shown in Air Quality Index (AQI) and the amount of PM^{10}. Table 5.3 shows the AQI standard for Thailand.

Table 5.3 AQI Values for Thailand

AQI Values	Levels of Health Concern	Suggestions for Health Prevention
0-50	Good	No health effect
0-100	Moderate	No health effect
101-200	Unhealthy	People, especially children and elderly people, should avoid long outdoor activities Patients with respiratory system problems should avoid outdoor exercises
201-300	Very Unhealthy	People, especially children and elderly people, should avoid outdoor exercises Patients with respiratory system problems should avoid any outdoor activities
Over 300	Hazardous	People should avoid outdoor exercises Patients with respiratory system problems should stay inside the buildings

Source: Pollution Control Department (2012). Air Quality Index: AQI.

Retrieved from http://www.pcd.go.th/info_serv/air_aqi.htm on March 16, 2014.

As shown in Table 5.3, the density of air pollution is high enough to affect human health when the monitored AQI is higher than 100. As for the amount of PM^{10}, it is set as a national safety level at 120 mg/m^3.

According to the findings by Dontree et al. (2011), the AQI values and the amounts of PM10 in the year 2007, 2010 and 2011 are shown to correspond to the number of hotspots. In general, the AQI values and amount of PM^{10} usually do not exceed the national safety level during January and the first half of February when there are few hotspots. However, both the AQI values and amount of PM^{10} dramatically increase and exceed the national safety level during the second half of February to mid March when the number of hotspots is at its peak as shown in Table 5.4.

Table 5.4 Dates with peak AQI value and PM^{10} for the year 2007- 2011

Dates	Monitoring Station	PM^{10}	AQI Values	Numbers of Hotspots
14 March 2007	Yupparaj Wittayalai	382.7	247	35
24 March 2008	Yupparaj Wittayalai	206.2	137	28
14 March 2009	Yupparaj Wittayalai	238.3	151	22
17 March 2010	Yupparaj Wittayalai	279.9	170	26
8 March 2011	City Hall	92.0	107	89

Source: Dontree et al. (2011). Prioritizing of burned areas using multi-source spatial data for open field burning surveillance and prevention in Chiang Mai province. Chiang

Mai: Department of Geography, Faculty of Social Science, Chiang Mai University.

Despite the correlation between AQI value, amount of PM^{10} and number of hotspots, it is found that dates with the highest number of hotspots do not have to be the dates with the highest amount of PM^{10} and AQI value (Dontree et al., 2011). This is because the number of hotspots only tells the number of areas with high temperature but does not tell the size of the burning area.

5.3 Current Measures

5.3.1 Open Burning Prevention

The Department of Local Administration has the tasks of forest fire and open burning control, as well as environment and natural resource management. According to Dontree et al. (2011), some Department of Local Administrations has a more advanced legal framework for open burning control. An example includes the Department of Local Administration of Tumbon San Tia in Chom Thong district, which has passed the regulation on smoke and dust control from open burning on July 4, 2007. The regulation describes the control of open burning of municipal waste, dry grass, trees and other materials that would produce smoke, heat, dust, soot, ash and other toxic substances.

Person who 1) owns the land and doesn't take care of trees and grass, letting dry leaves in the open risking for natural or man-made fire or leaves dry municipal solid waste in the open, 2) burns waste, dry grass, trees or other materials either in his/her own land or public space including forest, 3) cooking or selling food which produces smoke or dust along the streets or public space, and 4) leaving or dumping solid waste in public or private space allowing open burning, would be found guilty and will need to pay the fine of no more than 500 to 1,000 Baht or approximately 15.5 to 31 US Dollars (Dontree et al., 2011).

An action plan suggested by Dontree et al. (2011) after a series of dialogues between local authorities and local residents of Tumbon Sob Tia, Chom Thong district, concludes that the management should be classified according to the land use; fire prevention for watershed area, and controlled burning for cultivated areas and other types of forest, which are mostly deciduous and mixed deciduous forest with high amount of dry biomass, except the ones close to residential area or small dams. Firebreaks and fire monitoring routes are also planned. Total cost for the making of firebreaks and controlled burning for the three months with heavy smog problem (February - April) would be 249,584 Baht or approximately 7,747.45 US Dollars. According to Dontree et al. (2011), the Bureau of the Budget sets the cost of firebreak making at 3,400 Baht (approximately 105.54 US Dollars) per kilometer. Tumbon San

Kia has come up with a firebreak plan with the length of 50.21 kilometers, summing the cost up to 170,714 Baht or approximately 5,299.21 US Dollars. As for the cost of controlled burning, Ping River Basin Forest Fire Control Station offers the price at 5,000 Baht (approximately 155.21 US Dollars) per 500 Rai (approximately 0.8 km^2) per day. Tumbon San Kia has concluded that the total area for controlled burning would be 12.62 km^2 making the total cost for controlled burning 78,870 Baht or approximately 2,448.24 US Dollars per year (Dontree et al., 2011).

5.3.2 Alternative Use of Biomass Waste

Several projects have been initiated in Mae Khai village, Mae Chaem district, to tackle the problem of open burning. These projects include alternative usage of corn stalks and leaves, such as material for growing mushroom, producing paper and total mixed ration (TMR) for dairy cattle and also for energy production through producing household-scale gasifiers which help produce a sufficient amount of energy just for a household level and has low production and operation costs.

According to Tangtaweepat (2011), the household-scale gasifier is locally made from materials which can be domestically supplied. The investment cost is only 149.71 Baht (approximately 5 USD) as shown in Table 5.5. It is calculated that the average amount of feedstock (mainly stalks, cobs and husks) needed is 2 kilograms per household per day (Tangtaweepat, 2011).

Figure 5.1 Household-scale Gasifier

Source: Tangtaweepat, S. (2011).

Reducing smog from corn cultivation project. Retrieved from

http://www.clinictech.most.go.th/online/UserManage/FinalReport/2014361227111.pdf on June 2, 2014.

Table 5.5 Investment Cost of a Household-scale Gasifier

Materials	Amount	Price per unit (Baht)	Costs (Baht)
Clay soil (m^3)	0.009	42.85	0.40
Sand (m^3)	0.019	900.00	16.65
Cement (kg)	0.167	125.00	19.16
Rice husk (kg)	0.500	1.00	0.50
Galvanized iron 4x8 ft. (sheet)	0.250	400.00	100.00

Nail (nail)	6.000	0.50	3.00
Asbestos cement pipe (diameter: 2 inch; length: 2 m)	0.100	100.00	10.00
Total			149.71

Source: Tangtaweepat, S. (2011). Reducing smog from corn cultivation project. Retrieved from http://www.clinictech.most.go.th/online/UserManage/FinalReport/2014361227111.pdf on June 2, 2014.

Twenty households out of 120 households in Mae Khai village installed the gasifiers in 2011 (Tangtaweepat, 2011). This led to the avoidance of open burning of approximately 14.6 tons of corn wastes (Tangtaweepat, 2011). The project was forecasted to gain more popularity as the numbers of users are expected to be 60 and 120 households in the following years (Tangtaweepat, 2011). However, no quantitative data was provided in the updated reports regarding the number of users.

6. Corn Cultivation

The purpose of this chapter is to introduce the significance of corn cultivation in the region. It provides data regarding the area of corn cultivation, corn yields and corn wastes. The structure of the current corn cultivation management is also introduced in order to show the ineffectiveness of the system.

6.1 Global and Domestic Situations

Corn is one of Thailand's most important crops. Corn products are sold domestically as well as exported. Most of the corns are used to produce animal feeds, as well as ethanol which has a growing demand in many countries, such as the United States, raising the incentive for corn plantation among Thai farmers. According to Achavanuntakul et al. (2013), the global corn yield in the year 2011 is 883.460 million tons, increasing from the previous year by 33 tons or 3.9 percent. The United States is currently the world's largest producer of corn with 313.918 million tons of corn, or 35.53 percent of global production, produced in the year 2011 (Achavanuntakul et al., 2013). China is the second largest producer followed by Brazil and Argentina, while Thailand currently ranks at number 22 (Achavanuntakul et al., 2013).

Table 6.1 shows the corn plantation area and yield of Thailand comparing to ten other major corn producing countries in the year 2009, 2010 and 2011.

Table 6.1 Corn: plantation area, yield, and yield per km2 of the world's top ten producers in the year 2009-2011

Country	Plantation Area (km^2)			Yield (million tons)			Yield/km^2 (kg)		
	2009	2010	2011	2009	2010	2011	2009	2010	2011
Global	1,588,747	1,640,697.6	1,703,980.8	820.539	850.445	883.460	826	829	830
United States	321,688	329,604.8	339,862.4	332.549	316.165	313.918	1,654	1,535	1,478
China	312,036.8	325,179.2	335,606.4	164.108	177.541	192.904	841	874	920
Brazil	136,547.2	126,788.8	132,188.8	50.720	55.364	55.660	594	699	674
Argentina	23,531.2	29,027.2	37,478.4	13.121	22.677	23.800	892	1,250	1,016
Ukraine	20,891.2	26,476.8	35,436.8	10.486	11.953	22.838	892	1,250	1,016
India	82,616.0	85,532.8	72,700.8	16.720	21.726	21.570	324	406	475
Mexico	62,230.4	71,480.0	60,691.2	20.143	23.902	17.635	518	522	465
Indonesia	41,606.4	41,316.8	38,614.4	17.630	18.328	17.629	578	710	730
France	16,798.4	15,710.4	15,409.6	15.288	13.975	15.709	1,456	1,423	1,630
Romania	23,334.4	20,942.4	25,870.4	7.973	9.042	11.718	547	691	725
Thailand	11,048.0	11,628.8	11,531.2	4.616	4.861	5.022	668	669	697
Others	536,419.2	557,009.6	598,590.4	167.185	175.511	185.063	499	504	496

Source: Achavanuntakul et al. (2013). Maize supply chain management analysis to support sustainable watershed management in Nan Province. Sal Forest.

According to the Department of Agriculture (2009), over 94 percent of the total corn yield is used for animal feed production. Phetchabun Province has the largest area of corn plantation, which is 1720.858 km^2 in 2012, followed by Nakhon Ratchasima, Loei, Nan and Tak, while Chiang Mai ranks at number thirteen (Office of Agricultural Economics, 2012).

6.2 Corn Cultivation in Chiang Mai

According to Arjharn (2012), the total area of corn plantation in Chiang Mai in the harvesting year 2010/2011 is 287.77 km^2. Table 6.2 shows the amount of corn products generated. Most of the unwanted parts that are left after harvesting are stalks and leaves which were generated as many as 159,855.30 tons. In Mae Chaem district alone, approximately 22,400 tons of stalks and leaves are generated annually (Tangtaweepat, 2011). The second most generated unwanted parts are corncobs and husks which were generated approximately 53,769.51 tons. According to Arjharn (2012), very fractional amount of these unwanted parts were reused as soil protection materials in tangerine plantation and animal feed but the total amount was too small to be considered, so the percentage of unused unwanted parts is 100 percent.

Table 6.2 Biomass Potential from corn cultivation in Chiang Mai in the harvesting year 2010/2011

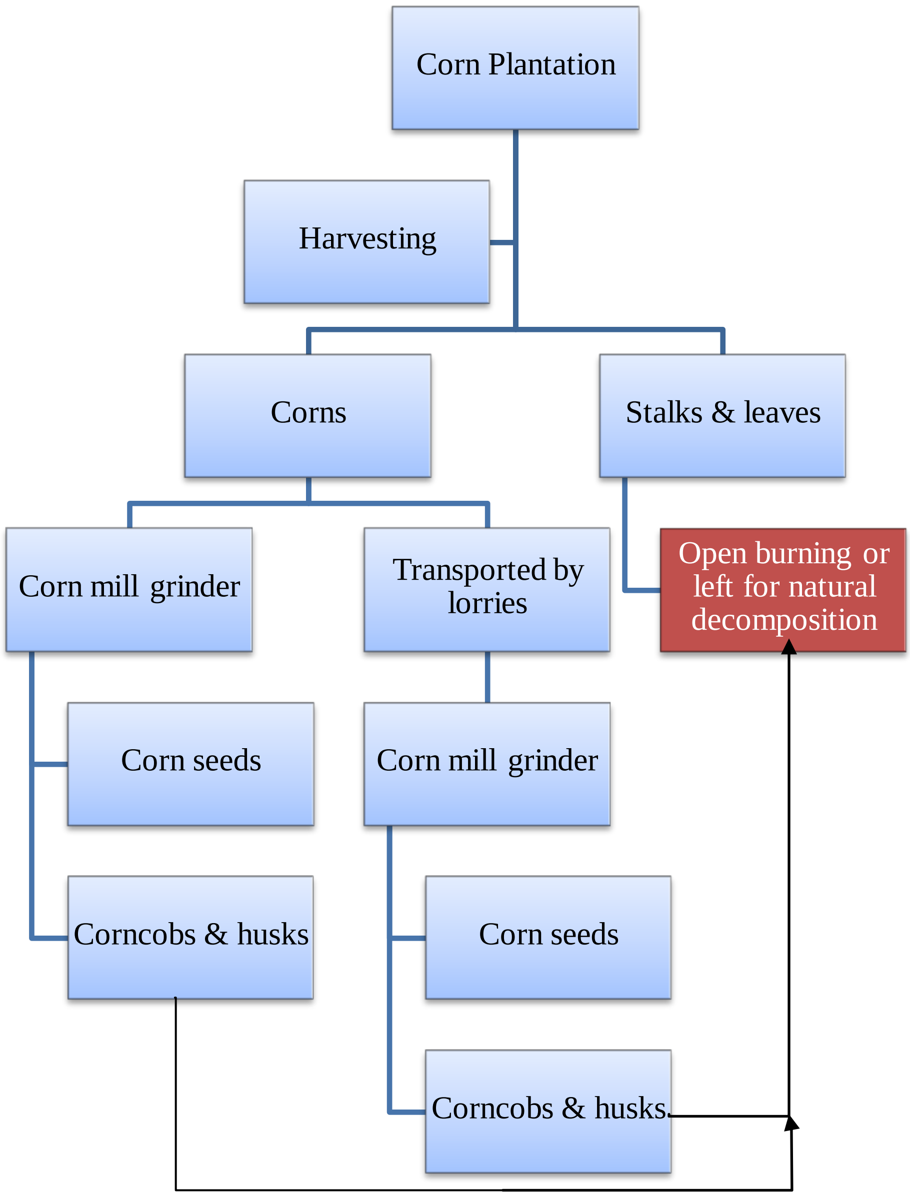
Plantation Area (km^2)	Yield (ton)	Types of unwanted parts/wastes	Ratio between yield and wastes	Amount of unwanted parts (ton)
287.77	145,323	Stalks/leaves	1.10	159,855.30
		Cobs/husks	0.37	53,769.51
Total				**213,624.81**

Source: Arjharn, W. (2012). Agricultural waste management for fuels and smog reduction. National Research Council of Thailand.

6.3 Current Management

In general, waste from corn cultivation can be generated in two different stages. The first stage is after harvesting. Corn stalks and leaves are left in the plantations and seen as waste. Current management in most corn cultivation on highlands in Chiang Mai is to burn these stalks and leaves (Arjharn, 2012). The second stage where corn waste is generated is after collected corns are transported to the millhouse where corncobs and husks are separated. These unwanted corncobs and husks are then burned later on as well. Figure 6.1 shows the current management of corn cultivation in Chiang Mai.

Figure 6.1 Current Corn Management on highlands



Source: Arjharn, W. (2012). Agricultural waste management for fuels and smog reduction. National Research Council of Thailand.

Open burning of corn plantation and forest fire is closely linked because most of the cultivated areas are located within or near forested areas, which are mainly deciduous or mixed deciduous forest. These types of forests have high amount of biomass during the dry season because the trees shred their leaves to reduce transpiration rate. According to Dontree et al. (2011), open burnings of corn plantation are uncontrolled and unmonitored, thus the fire often spreads into the nearby forest and leads to forest fire. Local residents also benefit from forest fire because they can collect mushrooms and local plants, mainly Katuk (*Sauropus androgynus*) and Barometer Earthstars (*Astraeus hygrometricus*), which can only grow well after the fire and are difficult to cultivate, thus they are not fully motivated to prevent the spread of fire from cultivated area

7. Energy and Smog Reduction Potentials

This chapter further builds up on the previous chapter and provides information regarding energy potential from corn waste in order to point out the significant energy potential that is currently unused. This chapter also provides information regarding smog reduction potential by switching from open burning to biomass-to-energy technology.

7.1 Energy Potential from Corn Waste

The unused unwanted parts from corn cultivation have high potentials ready to be recovered including both energy potential and material recovery potential. The energy potential is expressed in calorific value which refers to the energy contained within the material. For unwanted stalks, the calorific value ranges from 18,300 kJ/kg to 19,836 kJ/kg depending on the percentage of humidity in the stalks (Arjharn, 2012). The higher the humidity there is within the stalk, the lower the calorific value it has. The lowest percentage of humidity which allows the highest calorific value of the stalk is at 5.37 percent (Arjharn, 2012). A combination of stalks and leaves with very little humidity (about 4.70 percent) also offers a similarly high calorific value, which is approximately 19,611 kJ/kg. Table 7.1 shows the energy potential of different unwanted corn parts.

As shown in Table 7.1, the annual agricultural waste from corn cultivation in Chiang Mai province alone has a theoretical potential of producing electricity as much as 200.48 GWh. This equals to as much as 86.71 kiloton of oil equivalent. According to the Department of Alternative Energy Development and Efficiency[1] (2011), total electricity consumption in Chiang Mai in 2011 was 2,358 GWh, thus the energy potential from corn wastes can account up to 8.5 percent of total electricity consumption. Arjharn (2012) also suggests that the installed capacity for a centralized power plant which generates electricity from corn stalks and leaves is 21 MW. As for a centralized power plant which uses corn cobs and husks as feedstock, the installed capacity of 8MW is suggested according to the annual amount of biomass. A gasification plant is needed to be established in order to enable the production of electricity from corn waste.

Table 7.1 Energy potential of unwanted parts

Types	Amount (ton/year)	Humidity (%wb)	Calorific Value (MJ/kg)	Total energy (MJ/kg)	Oil equivalent (ktoe)	Electricity production (GWh)/capacity (MW)
Stalks/ leaves	159,855.30	10.65	16.361	2,608,199,075	61.75	144.90/21

Cobs/ husks	53,769.51	12.30	19.611	1,054,473,861	24.96	58.58/8
Total	213,624.82	22.95	35.972	3,662,672,936	86.71	200.48

Source: Arjharn, W. (2012). Agricultural waste management for fuels and smog reduction. National Research Council of Thailand.

7.3 Energy Production and Smog Reduction

Arjharn (2012) conducted a study which determines the amount of particulate matter generated from open burning of various parts of corn. The study was conducted according to the EPA Method 5 standard. The United States Environmental Protection Agency (EPA) is a governmental agency of the United States which aims to protect human health and the environment. The EPA Method 5 standard is a standard created for the determination of particulate matter emissions from stationary source. The result of this study conducted by Arjharn (2012) is then used to determine the approximate amount of particulate matter generated from open burning of corn cultivation in Chiang Mai.

Table 7.2 shows the result of the study. Five different products were detected and measured; i.e. dust, carbon monoxide (CO), nitrogen-oxides (NO_x), sulfur dioxide (SO_2), and carbon dioxide (CO_2).

Table 7.2 Total amount of greenhouse gases and dust produced from open burning of corns

Type	Amount (µg/kg of dry biomass)	
	Corn cob/husk	**Corn stalk/leave**
Dust	101.68	11.33
CO	335.52	185.73
NO_x	10.01	6.21
SO_2	2.58	1.43
CO_2	0.57	0.31

Source: Arjharn, W. (2012). Agricultural waste management for fuels and smog reduction. National Research Council of Thailand.

Table 7.3 further shows the amount of total dust and different types of gas generated from open burning of various parts of corn in Chiang Mae Province. As can be seen, despite the larger amount, corn stalks and leaves produce less total dust than corn cobs and husks, but the amount is still relatively large. On the other hand, corn cobs and husks produce lower amount of greenhouse gases.

Table 7.3 Amount of greenhouse gases and dust produced from open burning of corn in Chiang Mai Province

Corn Parts	**Amount (ton/year)**	**CO (ton/year)**	**NO_x (ton/year)**	**SO_2 (ton/year)**	**CO_2 (ton/year)**	**Dust (ton/year)**
Stalk/leave	159,855.30	29.69	0.99	0.23	0.05	1.81
Cob/husk	53,769.51	18.04	0.54	0.14	0.03	5.47
Total	213,624.81	47.73	1.53	0.37	0.08	**7.28**

Source: Arjharn, W. (2012). Agricultural waste management for fuels and smog reduction. National Research Council of Thailand.

According to Table 7.3, the open burning of corn by-products in Chiang Mai alone can cause average total dust as much as 7.28 ton/year. However, this does not represent the total amount of atmospheric dust in Chiang Mai Province because airborne particulate matters are free to move without boundaries. The exact amount of airborne particulate matters per year over Chiang Mai Province can be much higher than the amount produced because particulate matters from the surrounding provinces and neighboring countries can also be transported to and stay within Chiang Mai as well. However, if open burning of corn by-products in Chiang Mai can be avoided, hypothetically 7.28 ton/year can be alleviated, thus greatly reducing the magnitude of the smog problem within the region.

8. Biomass Gasification Plant

The purpose of this chapter is to introduce to the current state and requirements for the preparation of establishing a biomass gasification plant in Thailand.

8.1 Overview

According to Thailand's Department of Alternative Energy Development and Efficiency[2] (2011), eastern part of Thailand has the highest capacity of electricity production from biomass. The region requires feedstock of approximately 3,000 tons per day, which is much higher than the production capacity of the feedstock within the region, thus it needs to import feedstock from surrounding regions such as upper and lower north-east, central and western region. Over 90 percent of electricity produced within this region comes from sugar factories. In upper southern Thailand, biomass wastes from oil palms and rubber trees are abundant. However, only one electricity generating facility exists due to the competing demand of rubber tree waste, which can also be used to make furniture. In lower southern Thailand, there is only one facility existing as well. The main feedstock for this facility is biomass waste from rubber production.

In northern Thailand, most of the biomass plants are located in the southern area. In upper northern Thailand, where Chiang Mai is located, very few biomass plants exist despite the relatively low prices for biomass. According to Department of Alternative Energy Development and Efficiency[2] (2011), it is because there are few consumers within the region and the region itself is also far away from larger consumers in the central and eastern parts making it not feasible to transport electricity.

8.2 Requirements

In order to establish a biomass gasification plant, these requirements provided by the Department of Alternative Energy Development and Efficiency[2] (2011) should be carefully considered.

8.2.1 Feedstock Properties

1) **Availability of feedstock**

Because corn can be cultivated only once a year, the feedstock is needed to be stored for continuous availability for electricity generation. Table 8.1 shows the calendar for corn production in northern Thailand.

Table 8.1 Biomass Calendar

	Sep	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**
Cobs												
Stalks												

Source: Energy for Environment Foundation (2011). Biomass calendar. Retrived from http://www.efe.or.th/efe-book.php?task=26 on June 4, 2014.

As shown in Table 8.1, the availability of feedstock covers approximately five months, thus it is important to plan for an effective storage system which will enable the gasification plant to produce electricity continuously throughout the year. According to Tangtaweepat (2013), farmers in Mae Khai village in Mae Chaem district have already been introduced to a compressing technology which helps compress the corn waste making it easier to store and transport.

Alternative source of feedstock should also be considered in order to reduce the risk of feedstock shortage. Most of the biomass gasification plant in Thailand operates with at least one kind of alternative feedstock which can substitute the loss of another when in shortage.

2) Biological properties

Because corn stalks are consisted of potassium dioxide (KO_2) which has a strong eroding property, materials used to build a power plant thus need to have a strong resistance to erosion. The stalks are also considered to be light comparing to other types of feedstock, thus it requires a more effective machinery to cut the stalks making corn stalks have relatively high investment compared to other types of biomass.

8.2.2 Balancing Supply and Demand

The problem of unequal supply and demand for biomass feedstock and/or electricity generated from biomass can be a very discouraging challenge to the endorsement of biomass energy. There has been a problem with rice husks in Thailand, where it is the most popular source of feedstock. Because of the high demand for rice husks, not only among the energy sector but also among agricultural sector, the price of husks dramatically increased and remains at a high level, thus it is suggested that a power plant should allow the use of two or more types of feedstock to reduce the risks of feedstock availability (Department of Alternative Energy Development and Efficiency[2], 2011).

8.2.3 Public Participation

It is essential to note that communities surrounding power plants, including biomass power plants, in Thailand have always been skeptical, if not, against the business (Department of Alternative Energy Development and Efficiency[2], 2011). It is because they have been negatively affected by these power plants through various means, particularly from exhausted dust from biomass power plant. In order to avoid public resistance, a carefully planned dust filtering process along with other measures to manage environmental impacts should be at the heart of the managerial scheme and fully disclosed to the public.

Several steps regarding public communication have been suggested by the Department of Alternative Energy Development and Efficiency[2] (2011) for investors to try to fulfill before taking on the project.

- Hold public hearings which corporate local citizens from the surrounding communities to gather information regarding impacts from the power plant which might cause damages to the communities.
- Provide information regarding filtering process which can be effectively installed to the biomass power plant in order to avoid dust emission which the public is most concerned. The investor should be able to assure the community that it will manage the power plant in a manner that will not cause any harmful effect on the environment in order to be accepted by the community before starting the construction of the power plant.

- During the construction of the power plant, the investor should provide means of help to the communities in order to create and strengthen a good relationship between the investor and the community. For example, the investor might provide the community with playgrounds or stationery, or participate in community events such as religious ceremonies.
- Representative of the power plant should participate in public meetings of the Subdistrict Administrative Organization (SAO) every once in a while to be involved in the discussions among local citizens and community leaders. The participation will provide useful information and insights for the company to further develop better relationship with the community.
- Allow the community to invest in projects developed by the company in order to create a sense of ownership.

9. Case Study: Pre-feasibility study for biomass gasification plant in Chiang Mai

This chapter looks into the possibility of establishing biomass gasification plants in Chiang Mai which utilize corn waste as its main feedstock for electricity generation in order to help reduce the smog generated from open burning. It aims to realize whether the establishment of biomass gasification plants in Chiang Mai can be financially feasible or not. A pre-feasibility study is conducted containing three main components; 1) market analysis, 2) technology analysis, and 3) financial analysis.

9.1 Market Analysis

Electricity is one of the major sources of final energy consumptions in Thailand. The demand for electricity is growing in the recent year. The peak electricity demand in Thailand in 2014 was 26,942.10 MW, slightly exceeding the previous year (Electricity Generating Authority of Thailand[2], 2014). Similar growing trend can be observed in Chiang Mai as well as shown in Table 9.1.

Table 9.1 Electricity Consumption in Chiang Mai

Year	Electricity Consumption (GWh)
2006	1,776
2007	1,902

2008	2,007
2009	2,103
2010	2,300
2011	2,358

Source: Chiang Mai Provincial Government (n.d.). Electricity consumption in Chiang Mai by district within 5 years (2006-2010). Retrieved from http://www.chiangmai.go.th/docmeet/1330325534.pdf on June 23, 2014 & Department of Alternative Energy Development and Efficiency[1] (2011). Annual report: electric power in Thailand 2011. Ministry of Energy; Thailand.

Currently, however, Chiang Mai has only two major commercial electric power plants. First, Mae Ngat Dam in Mae Taeng district with the installed capacity of 9 MW can generate electricity from hydropower approximately 19 GWh per year (Electricity Generating Authority of Thailand[3], n.d.). Second, a geothermal power plant located in Mon Pin, Fang district, with the installed capacity of 300 KW and generates electricity approximately 1.2 GWh per year (Thailand Energy and Environmental Network, n.d.).

Therefore, total electricity generation within the province is extremely low, roughly 20.2 GWh per year or 0.86 percent of total electricity consumption in Chiang Mai. This leads to the import of electricity from other electric power plants in nearby provinces including Mae Moh Power Plant in Lampang Province which produces electricity from lignite, Lan Krabue Power Plant in Kamphaeng Phet Province which produces electricity from natural gas, Bhumibol Dam in Tak Province and Sirikit Dam in Uttaradit Pronvince which produce electricity from hydropower.

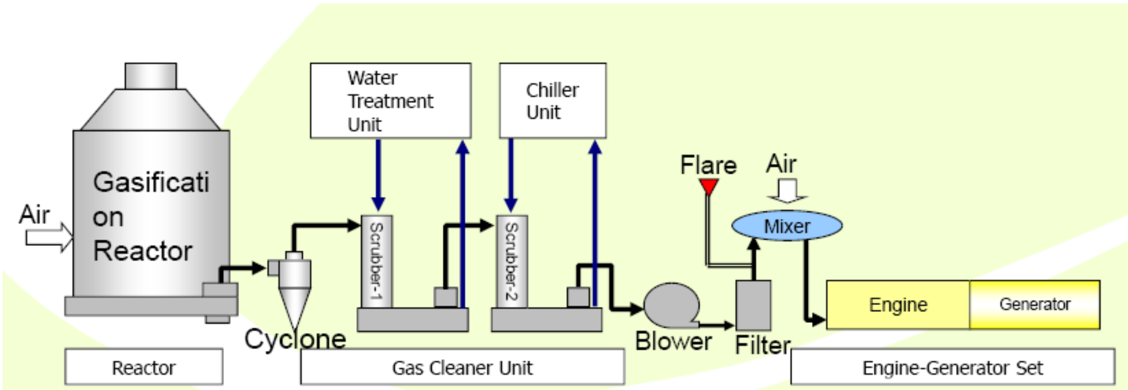
The import of electricity from other provinces implies a set of costs that consumers in Chiang Mai need to bear inevitably. These costs include the cost of electricity lost due to transmission losses and the cost of transmission facilities from the electricity providers to the consumers. It also reflects the energy security of the province. Because Chiang Mai is the largest city in northern Thailand, the strong dependence of electricity on external sources can pose as a risk to the energy security within the province. If any issue arises at the major sources of electricity providers such as the Mae Moh Power Plant, Sirikit Dam and Bhumobol Dam, which produces over 15,450 GWh, 1,245 GWh and 1,062 GWh per year respectively (Electricity Generating Authority of Thailand[2], Electricity Generating Authority of Thailand[4] & Electricity Generating Authority of Thailand[1], n.d.), the availability and accessibility to electrical power in Chiang Mai would be significantly restricted.

Because of the growing demand for electricity and the lack of sufficient capacity for electricity generation within the province, there is a large market potential for the development of electricity power plants in Chiang Mai. The situation can be seen as an opportunity for the introduction of a biomass gasification plants. Not only would it supply for the growing demand of electricity and enhance the energy security of the province, it would also create and enhance a new market for agricultural waste from corn cultivation through revalorizing unwanted corn parts which are traditionally neglected.

9.2 Technology Analysis

There are five main components for a gasification plant; i.e. pellet mill, gasification reactor, gas cleaning unit, water treatment unit and engine-generator set, as shown in Figure 9.1. The technologies are available through domestic agencies and have proved to be operating in biomass gasification plants throughout Thailand.

Figure 9.1 Gasification Process



Source: Arjharn, W. (2012). Agricultural waste management for fuels and smog reduction. National Research Council of Thailand.

Before feeding the feedstock into the gasification reactor, it needs to be cut and pelletized. The pellet mill can either be installed within the same area as the gasification plant or located in a different place depending on the financial viability. Arjharn (2012) suggests the use of downdraft fixed-bed gasifier for the gasification reactor because the system produces cleaner product gas with less tar content than the updraft gasifier. However, the product also has higher temperature, thus a chiller unit is required to cool down the gas after being filtered in the gas cleaning stage.

Several gas filtration technologies are commercially available as described in Chapter 3. Each has different advantages and disadvantages regarding to the efficiency, investment and operational costs. Henchobdee (2009) and Arjharn (2012) suggest that cyclone separator is the most appropriate technology for treating the product gas from a gasification plant due to the high filtration efficiency of 96 to 99 percent. The system can also operate in the environment with high temperature (Henchobdee, 2009). Table 9.2 compares the advantages and disadvantages of different filtration technology.

Table 9.2 Comparison of various filtration technologies

Type	**Size of particulate matter (μm)**	**Advantage**	**Disadvantage**

Cyclone Separator	>10	Low investment and operational costs; works well at high temperature	High pressure drop; cannot filter particulate matter smaller than 5 μm
Baghouse Filter	0.1	High filtration efficiency; filters dry particulate matter	Large size, thus requires large area for installation; requires constant maintenance; does not work well at high temperature and high humidity
Electrostatic Precipitator	<1	High filtration efficiency; low pressure drop	High operational costs due to the use of electricity; prohibited from inflammable and explosive

			particulate matter; produces ozone (O_3) which is highly corrosive
Wet Collector	<1	High filtration efficiency	Highly corrosive; requires waste water treatment unit

Source: Henchobdee, O. (2009). Life cycle assessment of IGCC (Integrated Gasification Combined Cycle) from agricultural residues. Chulalongkorn University.

As shown in Table 9.2, the cyclone separator is the most appropriate technology to treat the product gas from the downdraft gasification reactor due to the high temperature of the gas. However, it cannot filter particulate matter that is smaller than 10 μm, thus other gas cleaning technologies are required afterwards. Wet scrubber (or wet collector) and bag filter are suggested by Arjharn (2012) for cleaning the product gas after the cyclone separator. However, as shown in Table 9.2, a water treatment unit is thus required for the wet scrubber due to the use of water in the system. The waste water from the wet scrubber contains high amount of tar and particulate matter which are important to be treated before discharging into water sources. The bag filter is required to filter as much particulate matter from the product gas as possible, but due to the disadvantage in high temperature environment, it is set to be the last gas cleaning process after the cyclone separator and wet scrubber.

Figure 9.2 Gas Cleaning System

Source: Arjharn, W. (2012). Agricultural waste management for fuels and smog reduction. National Research Council of Thailand.

Figure 9.2 shows the gas cleaning unit as suggested by Arjharn (2012). The hot product gas from the gasification reactor enters through the cyclone separator (1), the particulate matter larger than 10 μm is filtered out. The gas is then passed on to the wet scrubber (2) which filters tar and particulate matter smaller than 1 μm out from the gas and results in the production of waste water. The process also reduce the temperature of the gas. The cooled gas is then passed on to the bag filter (3) which can filter particulate matter as small as 0.1 μm before flowing into the electricity generator.

Figure 9.3 Waste Water Treatment (Close System)

Source: Arjharn, W. (2012). Agricultural waste management for fuels and smog reduction. National Research Council of Thailand.

The proposed waste water treatment system is as shown as in Figure 9.3. It is a close system with three different tanks. Water from the wet scrubber flows into tank number (1), and then fills the tank until it overflows into tank number (2) which transports the water to the flocculation tank to be treated through flocculation process which separates solid substances from the water. The treated water then enters into tank number (3) ready to be discharged.

9.3 Financial Analysis

In this section, the analysis is divided into three different parts as follow;

1) Cost analysis
2) Benefit analysis
3) Financial feasibility analysis

1) Cost analysis

The cost of establishing a biomass gasification plant can be categorized into two main categories; i.e. fixed costs and variable costs.

a) Fixed costs

Fixed costs are the costs that doesn't change or vary according to the productivity of the power plant. Examples of these costs include construction cost and interest rate. According to a study by Klomjit & Kveeyarn (2011), total investment cost for the establishment of a large-scale biomass gasification plant (capacity >5,000 KW) is 45,000 - 55,000 Baht/kWh. This is calculated according to the following assumptions;

- Biomass feedstock price is 1,000 Baht/ton
- Plant factor 85 percent
- Discount rate 9 percent
- Operational lifespan of 25 years
- Fixed electricity prices

These assumptions are used as a basis for the calculation for the feasibility analysis in this case study as well, although the price of the feedstock is a bit positive. Therefore, in able to establish a centralized biomass gasification plant which uses corn stalks and leaves as feedstock with the capacity of 21 MW, the total investment cost is 945,000,000 - 1,365,000,000 Baht or approximately 29,103,787 - 42,038,803 USD. Total investment cost for a centralized biomass gasification plant which uses corn husks and cobs as feedstock with the capacity of 8 MW is 360,000,000 - 520,000,000 Baht or approximately 11,087,157 - 16,014,782 USD.

b) Variable cost

Variable costs are the costs that vary according to the productivity of the power plant. They are the costs that enable the operation of the plant throughout its life span. These costs can be summed up as O&M cost which accounts for 2.50 percent of the total investment cost for a large-scale biomass gasification plant (Klomjit & Kveeyarn, 2011). Therefore, the O&M cost for a 21 MW power plant is 23,625,000 – 34,125,000 Baht (728,043 – 1,051,618 USD) and 9,000,000 - 13,000,000 Baht (277,179 - 400,370 USD) for an 8 MW power plant.

2) Benefit analysis

Financial benefit of a biomass gasification plant comes from the income from selling electricity to the Electricity Generating Authority of Thailand (EGAT). The calculation of financial benefit from electricity production is shown in the following section.

Assumptions for the calculation of the projected income are as follow;

- Working days: 335 days (30 days for maintenance)
- Operating hours: 8,040 hours
- On peak operating hours: 13 hours/day
- Off peak operating hours: 11 hours/day
- Own electricity consumption: 10% of total electricity generation
- Electricity consumption price: 1.6660 Baht/kWh

The selling price for electricity specified by EGAT is as follow;

- Peak period (09.00-22.00) = 2.9278 Baht/kWh
- Off peak period (22.00-09.00) = 1.1154 Baht/kWh

According to Electricity Generating Authority of Thailand [1] (2014), the fuel adjustment charge (F_t) is 0.69 Baht/kWh. The current adder for electricity generated from a biomass power plant is 0.30 Baht/kWh.

Projected income for a 21 MW biomass gasification plant from selling electricity to EGAT

Operating hours	8,040 hours/year
Net Output	21 MW/hour = 21,000 kW/hour
Peak operating hours	4,355 hours/year
Electricity generation (peak)	4,355 hours/year x 21,000 kW = 91,455,000 kWh/year
Plant factor 85%	77,736,750 kWh/year
Income (plus F_t and Adder price)	(2.9278 + 0.69 + 0.3) Baht/kWh x (77,736,750 kWh/yr) = 304,557,039.15 Baht/year
Off peak operating hours	3,685 hours/year

Electricity generation (off peak)	3,685 hours/year x 21,000 kW
	= 77,385,000 kWh/year
Plant factor 85%	66,777,250 kWh/year
Income (plus F_t and Adder price)	(1.1154 + 0.69 + 0.3) Baht/kWh x (66,777,250 kWh/yr) = 140,592,822.15 Baht/year
Total income	304,557,039.15 + 140,592,822.15
	= 445,149,861.30 Baht/year

However, the gasification plant uses approximately 10 percent of its total electricity generated for its own operation (Klomjit & Kveeyarn, 2011). The use of self-generated electricity can be translated into savings from not buying electricity from EGAT. The savings are calculated and included as part of the financial benefit.

Therefore, income from electricity generation after own consumption is as follow;

Income after own consumption	= Total income – 10% of total income
	445,149,861.30 – (445,149,861.30 x 0.1)
	= 400,634,875.17 Baht/year

To calculate the total financial benefit of the gasification plant, income from electricity generation after own consumption is combined with the savings from not buying electricity from EGAT for the operation of the plant.

To find the amount of savings from not buying electricity from EGAT, the amount of self generated electricity consumption is multiplied with the price of electricity provided by EGAT, which is 1.6660 Baht/kWh.

Total electricity generation	144,514,000 kWh/year
Own elec. consumption (10%)	14,451,400 kWh/year
Savings	14,451,400 kWh/year x 1.6660 Baht/kWh
	= 24,076,032.40 Baht/year

Therefore;

Total benefit	400,634,875.17 + 24,076,032.40
	= **427,710,907.57 Baht/year**

Projected income for an 8 MW biomass gasification plant from selling electricity to EGAT

Operating hours	8,040 hours/year
Net Output	8 MW/hour = 8,000 kW/hour
Peak operating hours	4,355 hours/year
Electricity generation (peak)	4,355 hours/year x 8,000 kW
	= 34,840,000 kWh/year
Plant factor 85%	29,614,000 kWh/year
Income (plus F_t and Adder price)	(2.9278 + 0.69 + 0.3) Baht/kWh x (29,614,000 kWh/yr) = 116,021,729.20 Baht/year
Off peak operating hours	3,685 hours/year
Electricity generation (off peak)	3,685 hours/year x 8,000 kW
	= 29,480,000 kWh/year
Plant factor 85%	25,058,000 kWh/year
Income (plus F_t and Adder price)	(1.1154 + 0.69 + 0.3) Baht/kWh x (25,058,000 kWh/year) = 52,757,113.20 Baht/year
Total income	116,021,729.20 + 52,757,113.20
	= 168,778,842.40 Baht/year

Income after own consumption	168,778,842.40 – (168,778,842.40 x 0.1)
	= 151,900,958.16 Baht/year

To find the savings;

Total electricity generation	54,672,000 kWh/year
Own elec. consumption 10%	5,467,200 kWh/year
Savings	5,467,200 kWh/year x 1.6660 Baht/kWh
	= 9,108,355.20 Baht/year

Therefore;

Total benefit	151,900,958.16 + 9,108,355.20
	= **161,009,313.36 Baht/year**

According to the calculations, the total financial benefit for a 21 MW biomass gasification plant is 427,710,907.57 Baht/year or approximately 13,213,189 USD/year. The total income for an 8 MW biomass gasification plant is 161,009,313.36 Baht/year or approximately 4,974,029 USD/year.

3) Financial feasibility analysis

The financial feasibility can analyzed through the following measures

1. Net Present Value (NPV) which reflects the profitability of the project at the specified discount rate. The project is profitable when NPV is greater than 0.
2. Internal Rate of Return (IRR) which is the rate of interest of the project. The project is deemed feasible when IRR > weighted average of cost of Capital (WACC) which is approximately 7.7 – 9.2 % (Deloitte, 2013).
3. Payback Period which is length of time required to recover the initial amount of capital investment (Kato, 2011).

Methodology

The methodology for NPV calculation is based on a study by Klomjit & Kveeyarn (2011), where the NPV is reflected in the difference between Present Value (PV) of Benefit and PV of Cost. The PV of benefit and cost for each year is calculated according to the discount factor at 9 percent.

Result

The Present Value (PV) of a 21 MW biomass gasification plant with initial capital investment of 945,000,000 Baht is shown as in Table 9.3.

Table 9.3 Marginal Cost of 21 MW biomass gasification plant with initial capital investment of 945,000,000 Baht

Notes: O&M cost = 2.50% Fuel and O&M increase = 0.00%

Year	Discount Factor 9%	Direct Benefit			Total Cost			Present Value	
		Annual Gen. (kWh)	Electricity Income	Total Benefit	Investment & Fuel	O&M	Total Cost	PV Benefit	PV Cost
0	1.0000	0	0	0	945000000	0	945000000	0	945000000
1	0.9174	91455000	400634875.17	427710907.57	134001000	23625000	157626000	392381987	144606092
2	0.8417	91455000	400634875.17	427710907.57	134001000	23625000	157626000	360004271	132673804
3	0.7722	91455000	400634875.17	427710907.57	134001000	23625000	157626000	330278363	121718797
4	0.7084	91455000	400634875.17	427710907.57	134001000	23625000	157626000	302990407	111662258
5	0.6499	91455000	400634875.17	427710907.57	134001000	23625000	157626000	277969319	102441137
6	0.5963	91455000	400634875.17	427710907.57	134001000	23625000	157626000	255044014	93992384
7	0.5470	91455000	400634875.17	427710907.57	134001000	23625000	157626000	233957866	86221422
8	0.5019	91455000	400634875.17	427710907.57	134001000	23625000	157626000	214668105	79112489
9	0.4604	91455000	400634875.17	427710907.57	134001000	23625000	157626000	196918102	72571010
10	0.4224	91455000	400634875.17	427710907.57	134001000	23625000	157626000	180665087	66581222
11	0.3875	91455000	400634875.17	427710907.57	134001000	23625000	157626000	165737977	61080075
12	0.3555	91455000	400634875.17	427710907.57	134001000	23625000	157626000	152051228	56036043
13	0.3262	91455000	400634875.17	427710907.57	134001000	23625000	157626000	139519298	51417601
14	0.2992	91455000	400634875.17	427710907.57	134001000	23625000	157626000	127971104	47161699
15	0.2745	91455000	400634875.17	427710907.57	134001000	23625000	157626000	117406644	43268337
16	0.2519	91455000	400634875.17	427710907.57	134001000	23625000	157626000	107740378	39705989
17	0.2311	91455000	400634875.17	427710907.57	134001000	23625000	157626000	98843991	36427369
18	0.2120	91455000	400634875.17	427710907.57	134001000	23625000	157626000	90674712	33416712
19	0.1945	91455000	400634875.17	427710907.57	134001000	23625000	157626000	83189772	30658257
20	0.1784	91455000	400634875.17	427710907.57	134001000	23625000	157626000	76303626	28120478
21	0.1637	91455000	400634875.17	427710907.57	134001000	23625000	157626000	70016276	25803376
22	0.1502	91455000	400634875.17	427710907.57	134001000	23625000	157626000	64242178	23675425
23	0.1378	91455000	400634875.17	427710907.57	134001000	23625000	157626000	58938563	21720863
24	0.1264	91455000	400634875.17	427710907.57	134001000	23625000	157626000	54062659	19923926
25	0.1160	91455000	400634875.17	427710907.57	134001000	23625000	157626000	49614465	18284616
Total				**10692772689.25**			**4885650000**	**4201190390**	**1548281385**

Table 9.4 shows the NPV and IRR of the 21 MW biomass gasification plant with initial capital investment of 945,000,000 Baht.

Table 9.4 NPV and IRR of 21 MW biomass gasification plant with initial capital investment of 945,000,000 Baht

Year	PV of Benefit	PV of Cost	PV Benefit - PV Cost	NPV
0	0	945000000.00	-945000000.00	-945000000.00
1	392381986.60	144606092.40	247775894.20	-697224105.80
2	360004270.90	132673804.20	227330466.70	-469893639.09
3	330278362.83	121718797.20	208559565.63	-261334073.47
4	302990406.92	111662258.40	191328148.52	-70005924.95
5	277969318.83	102441137.40	175528181.43	105522256.48
6	255044014.18	93992383.80	161051630.38	266573886.87
7	233957866.44	86221422.00	147736444.44	414310331.31
8	214668104.51	79112489.40	135555615.11	549865946.42
9	196918101.85	72571010.40	124347091.45	674213037.86
10	180665087.36	66581222.40	114083864.96	788296902.82
11	165737976.68	61080075.00	104657901.68	892954804.50
12	152051227.64	56036043.00	96015184.64	988969989.15
13	139519298.05	51417601.20	88101696.85	1077071686.00
14	127971103.54	47161699.20	80809404.34	1157881090.34
15	117406644.13	43268337.00	74138307.13	1232019397.47
16	107740377.62	39705989.40	68034388.22	1300053785.68
17	98843990.74	36427368.60	62416622.14	1362470407.82
18	90674712.40	33416712.00	57258000.40	1419728408.23
19	83189771.52	30658257.00	52531514.52	1472259922.75
20	76303625.91	28120478.40	48183147.51	1520443070.26
21	70016275.57	25803376.20	44212899.37	1564655969.63
22	64242178.32	23675425.20	40566753.12	1605222722.75
23	58938563.06	21720862.80	37217700.26	1642440423.01
24	54062658.72	19923926.40	34138732.32	1676579155.33
25	49614465.28	18284616.00	31329849.28	1707909004.61
IRR			18%	

The Present Value (PV) of a 21 MW biomass gasification plant with initial capital investment of 1,365,000,000 Baht is shown as in Table 9.5.

Table 9.5 Marginal Cost of 21 MW biomass gasification plant with initial capital investment of 1,365,000,000 Baht

Notes: O&M cost = 2.50%		Fuel and O&M increase = 0.00%

Year	Discount Factor 9%	Direct Benefit			Total Cost			Present Value	
		Annual Gen. (kWh)	Electricity Income	Total Benefit	Investment & Fuel	O&M	Total Cost	PV Benefit	PV Cost
0	1.0000	0	0	0	1365000000	0	1365000000	0	1365000000
1	0.9174	91455000	400634875.17	427710907.57	193557000	34125000	227682000	392381987	208875467
2	0.8417	91455000	400634875.17	427710907.57	193557000	34125000	227682000	360004271	191639939
3	0.7722	91455000	400634875.17	427710907.57	193557000	34125000	227682000	330278363	175816040
4	0.7084	91455000	400634875.17	427710907.57	193557000	34125000	227682000	302990407	161289929
5	0.6499	91455000	400634875.17	427710907.57	193557000	34125000	227682000	277969319	147970532
6	0.5963	91455000	400634875.17	427710907.57	193557000	34125000	227682000	255044014	135766777
7	0.5470	91455000	400634875.17	427710907.57	193557000	34125000	227682000	233957866	124542054
8	0.5019	91455000	400634875.17	427710907.57	193557000	34125000	227682000	214668105	114273596
9	0.4604	91455000	400634875.17	427710907.57	193557000	34125000	227682000	196918102	104824793
10	0.4224	91455000	400634875.17	427710907.57	193557000	34125000	227682000	180665087	96172877
11	0.3875	91455000	400634875.17	427710907.57	193557000	34125000	227682000	165737977	88226775
12	0.3555	91455000	400634875.17	427710907.57	193557000	34125000	227682000	152051228	80940951
13	0.3262	91455000	400634875.17	427710907.57	193557000	34125000	227682000	139519298	74269868
14	0.2992	91455000	400634875.17	427710907.57	193557000	34125000	227682000	127971104	68122454
15	0.2745	91455000	400634875.17	427710907.57	193557000	34125000	227682000	117406644	62498709
16	0.2519	91455000	400634875.17	427710907.57	193557000	34125000	227682000	107740378	57353096
17	0.2311	91455000	400634875.17	427710907.57	193557000	34125000	227682000	98843991	52617310
18	0.2120	91455000	400634875.17	427710907.57	193557000	34125000	227682000	90674712	48268584
19	0.1945	91455000	400634875.17	427710907.57	193557000	34125000	227682000	83189772	44284149
20	0.1784	91455000	400634875.17	427710907.57	193557000	34125000	227682000	76303626	40618469
21	0.1637	91455000	400634875.17	427710907.57	193557000	34125000	227682000	70016276	37271543
22	0.1502	91455000	400634875.17	427710907.57	193557000	34125000	227682000	64242178	34197836
23	0.1378	91455000	400634875.17	427710907.57	193557000	34125000	227682000	58938563	31374580
24	0.1264	91455000	400634875.17	427710907.57	193557000	34125000	227682000	54062659	28779005
25	0.1160	91455000	400634875.17	427710907.57	193557000	34125000	227682000	49614465	26411112
Total				**10692772689.25**			7057050000	4372484513	2236406445

Table 9.6 shows the NPV and IRR of the 21 MW biomass gasification plant with initial capital investment of 1,365,000,000 Baht.

Table 9.6 NPV and IRR of 21 MW biomass gasification plant with initial capital investment of 1,365,000,000 Baht

Year	PV of Benefit	PV of Cost	PV Benefit - PV Cost	NPV
0	0	1365000000.00	-1365000000.00	-1365000000.00
1	392381986.60	208875466.80	183506519.80	-1181493480.20
2	360004270.90	191639939.40	168364331.50	-1013129148.69
3	330278362.83	175816040.40	154462322.43	-858666826.27
4	302990406.92	161289928.80	141700478.12	-716966348.15
5	277969318.83	147970531.80	129998787.03	-586967561.12
6	255044014.18	135766776.60	119277237.58	-467690323.53
7	233957866.44	124542054.00	109415812.44	-358274511.09
8	214668104.51	114273595.80	100394508.71	-257880002.38
9	196918101.85	104824792.80	92093309.05	-165786693.34
10	180665087.36	96172876.80	84492210.56	-81294482.78
11	165737976.68	88226775.00	77511201.68	-3783281.10
12	152051227.64	80940951.00	71110276.64	67326995.55
13	139519298.05	74269868.40	65249429.65	132576425.20
14	127971103.54	68122454.40	59848649.14	192425074.34
15	117406644.13	62498709.00	54907935.13	247333009.47
16	107740377.62	57353095.80	50387281.82	297720291.28
17	98843990.74	52617310.20	46226680.54	343946971.82
18	90674712.40	48268584.00	42406128.40	386353100.23
19	83189771.52	44284149.00	38905622.52	425258722.75
20	76303625.91	40618468.80	35685157.11	460943879.86
21	70016275.57	37271543.40	32744732.17	493688612.03
22	64242178.32	34197836.40	30044341.92	523732953.95
23	58938563.06	31374579.60	27563983.46	551296937.41
24	54062658.72	28779004.80	25283653.92	576580591.33
25	49614465.28	26411112.00	23203353.28	599783944.61
IRR	5%			

The Present Value (PV) of an 8 MW biomass gasification plant with initial capital investment of 360,000,000 Baht is shown as in Table 9.7.

Table 9.7 Marginal Cost of 8 MW biomass gasification plant with initial capital investment of 360,000,000 Baht

Notes: O&M cost = 2.50% Fuel and O&M increase = 0.00%

Year	Discount Factor 9%	Direct Benefit			Total Cost			Present Value	
		Annual Gen. (kWh)	Electricity Income	Total Benefit	Investment & Fuel	O&M	Total Cost	PV Benefit	PV Cost
0	1.0000	0	0	0	360000000	0	360000000	0	360000000
1	0.9174	29614000	151900958.16	161009313.36	51048000	9000000	60048000	147709944	55088035
2	0.8417	29614000	151900958.16	161009313.36	51048000	9000000	60048000	135521539	50542402
3	0.7722	29614000	151900958.16	161009313.36	51048000	9000000	60048000	124331392	46369066
4	0.7084	29614000	151900958.16	161009313.36	51048000	9000000	60048000	114058998	42538003
5	0.6499	29614000	151900958.16	161009313.36	51048000	9000000	60048000	104639953	39025195
6	0.5963	29614000	151900958.16	161009313.36	51048000	9000000	60048000	96009854	35806622
7	0.5470	29614000	151900958.16	161009313.36	51048000	9000000	60048000	88072094	32846256
8	0.5019	29614000	151900958.16	161009313.36	51048000	9000000	60048000	80810574	30138091
9	0.4604	29614000	151900958.16	161009313.36	51048000	9000000	60048000	74128688	27646099
10	0.4224	29614000	151900958.16	161009313.36	51048000	9000000	60048000	68010334	25364275
11	0.3875	29614000	151900958.16	161009313.36	51048000	9000000	60048000	62391109	23268600
12	0.3555	29614000	151900958.16	161009313.36	51048000	9000000	60048000	57238811	21347064
13	0.3262	29614000	151900958.16	161009313.36	51048000	9000000	60048000	52521238	19587658
14	0.2992	29614000	151900958.16	161009313.36	51048000	9000000	60048000	48173987	17966362
15	0.2745	29614000	151900958.16	161009313.36	51048000	9000000	60048000	44197057	16483176
16	0.2519	29614000	151900958.16	161009313.36	51048000	9000000	60048000	40558246	15126091
17	0.2311	29614000	151900958.16	161009313.36	51048000	9000000	60048000	37209252	13877093
18	0.2120	29614000	151900958.16	161009313.36	51048000	9000000	60048000	34133974	12730176
19	0.1945	29614000	151900958.16	161009313.36	51048000	9000000	60048000	31316311	11679336
20	0.1784	29614000	151900958.16	161009313.36	51048000	9000000	60048000	28724062	10712563
21	0.1637	29614000	151900958.16	161009313.36	51048000	9000000	60048000	26357225	9829858
22	0.1502	29614000	151900958.16	161009313.36	51048000	9000000	60048000	24183599	9019210
23	0.1378	29614000	151900958.16	161009313.36	51048000	9000000	60048000	22187083	8274614
24	0.1264	29614000	151900958.16	161009313.36	51048000	9000000	60048000	20351577	7590067
25	0.1160	29614000	151900958.16	161009313.36	51048000	9000000	60048000	18677080	6965568
Total				**4025232834.00**			1861200000	1657830179	589821480

Table 9.8 shows the NPV and IRR of the 8 MW biomass gasification plant with initial capital investment of 360,000,000 Baht.

Table 9.8 NPV and IRR of 8 MW biomass gasification plant with initial capital investment of 360,000,000 Baht

Year	PV of Benefit	PV of Cost	PV Benefit - PV Cost	NPV
0	0	360000000.00	-360000000.00	-360000000.00
1	147709944.08	55088035.20	92621908.88	-267378091.12
2	135521539.06	50542401.60	84979137.46	-182398953.67
3	124331391.78	46369065.60	77962326.18	-104436627.49
4	114058997.58	42538003.20	71520994.38	-32915633.11
5	104639952.75	39025195.20	65614757.55	32699124.45
6	96009853.56	35806622.40	60203231.16	92902355.60
7	88072094.41	32846256.00	55225838.41	148128194.01
8	80810574.38	30138091.20	50672483.18	198800677.18
9	74128687.87	27646099.20	46482588.67	245283265.86
10	68010333.96	25364275.20	42646058.76	287929324.62
11	62391108.93	23268600.00	39122508.93	327051833.55
12	57238810.90	21347064.00	35891746.90	362943580.45
13	52521238.02	19587657.60	32933580.42	395877160.86
14	48173986.56	17966361.60	30207624.96	426084785.82
15	44197056.52	16483176.00	27713880.52	453798666.34
16	40558246.04	15126091.20	25432154.84	479230821.17
17	37209252.32	13877092.80	23332159.52	502562980.69
18	34133974.43	12730176.00	21403798.43	523966779.12
19	31316311.45	11679336.00	19636975.45	543603754.57
20	28724061.50	10712563.20	18011498.30	561615252.88
21	26357224.60	9829857.60	16527367.00	578142619.87
22	24183598.87	9019209.60	15164389.27	593307009.14
23	22187083.38	8274614.40	13912468.98	607219478.12
24	20351577.21	7590067.20	12761510.01	619980988.13
25	18677080.35	6965568.00	11711512.35	631692500.48
IRR			17%	

The Present Value (PV) of an 8 MW biomass gasification plant with initial capital investment of 520,000,000 Baht is shown as in Table 9.9.

Table 9.9 Marginal Cost of 8 MW biomass gasification plant with initial capital investment of 520,000,000 Baht

Notes: O&M cost = 2.50% Fuel and O&M increase = 0.00%

Year	Discount Factor 9%	Direct Benefit			Total Cost			Present Value	
		Annual Gen. (kWh)	Electricity Income	Total Benefit	Investment & Fuel	O&M	Total Cost	PV Benefit	PV Cost
0	1.0000	0	0	0	520000000	0	520000000	0	520000000
1	0.9174	29614000	151900958.16	161009313.36	73736000	13000000	86736000	147709944	79571606
2	0.8417	29614000	151900958.16	161009313.36	73736000	13000000	86736000	135521539	73005691
3	0.7722	29614000	151900958.16	161009313.36	73736000	13000000	86736000	124331392	66977539
4	0.7084	29614000	151900958.16	161009313.36	73736000	13000000	86736000	114058998	61443782
5	0.6499	29614000	151900958.16	161009313.36	73736000	13000000	86736000	104639953	56369726
6	0.5963	29614000	151900958.16	161009313.36	73736000	13000000	86736000	96009854	51720677
7	0.5470	29614000	151900958.16	161009313.36	73736000	13000000	86736000	88072094	47444592
8	0.5019	29614000	151900958.16	161009313.36	73736000	13000000	86736000	80810574	43532798
9	0.4604	29614000	151900958.16	161009313.36	73736000	13000000	86736000	74128688	39933254
10	0.4224	29614000	151900958.16	161009313.36	73736000	13000000	86736000	68010334	36637286
11	0.3875	29614000	151900958.16	161009313.36	73736000	13000000	86736000	62391109	33610200
12	0.3555	29614000	151900958.16	161009313.36	73736000	13000000	86736000	57238811	30834648
13	0.3262	29614000	151900958.16	161009313.36	73736000	13000000	86736000	52521238	28293283
14	0.2992	29614000	151900958.16	161009313.36	73736000	13000000	86736000	48173987	25951411
15	0.2745	29614000	151900958.16	161009313.36	73736000	13000000	86736000	44197057	23809032
16	0.2519	29614000	151900958.16	161009313.36	73736000	13000000	86736000	40558246	21848798
17	0.2311	29614000	151900958.16	161009313.36	73736000	13000000	86736000	37209252	20044690
18	0.2120	29614000	151900958.16	161009313.36	73736000	13000000	86736000	34133974	18388032
19	0.1945	29614000	151900958.16	161009313.36	73736000	13000000	86736000	31316311	16870152
20	0.1784	29614000	151900958.16	161009313.36	73736000	13000000	86736000	28724062	15473702
21	0.1637	29614000	151900958.16	161009313.36	73736000	13000000	86736000	26357225	14198683
22	0.1502	29614000	151900958.16	161009313.36	73736000	13000000	86736000	24183599	13027747
23	0.1378	29614000	151900958.16	161009313.36	73736000	13000000	86736000	22187083	11952221
24	0.1264	29614000	151900958.16	161009313.36	73736000	13000000	86736000	20351577	10963430
25	0.1160	29614000	151900958.16	161009313.36	73736000	13000000	86736000	18677080	10061376
Total				**4025232834.00**			2688400000	1657830179	851964360

Table 9.10 shows the NPV and IRR of the 8 MW biomass gasification plant with initial capital investment of 520,000,000 Baht.

Table 9.10 NPV and IRR of 8 MW biomass gasification plant with initial capital investment of 520,000,000 Baht

Year	PV of Benefit	PV of Cost	PV Benefit - PV Cost	NPV
0	0	520000000.00	-520000000.00	-520000000.00
1	147709944.08	79571606.40	68138337.68	-451861662.32
2	135521539.06	73005691.20	62515847.86	-389345814.47
3	124331391.78	66977539.20	57353852.58	-331991961.89
4	114058997.58	61443782.40	52615215.18	-279376746.71
5	104639952.75	56369726.40	48270226.35	-231106520.35
6	96009853.56	51720676.80	44289176.76	-186817343.60
7	88072094.41	47444592.00	40627502.41	-146189841.19
8	80810574.38	43532798.40	37277775.98	-108912065.22
9	74128687.87	39933254.40	34195433.47	-74716631.74
10	68010333.96	36637286.40	31373047.56	-43343584.18
11	62391108.93	33610200.00	28780908.93	-14562675.25
12	57238810.90	30834648.00	26404162.90	11841487.65
13	52521238.02	28293283.20	24227954.82	36069442.46
14	48173986.56	25951411.20	22222575.36	58292017.82
15	44197056.52	23809032.00	20388024.52	78680042.34
16	40558246.04	21848798.40	18709447.64	97389489.97
17	37209252.32	20044689.60	17164562.72	114554052.69
18	34133974.43	18388032.00	15745942.43	130299995.12
19	31316311.45	16870152.00	14446159.45	144746154.57
20	28724061.50	15473702.40	13250359.10	157996513.68
21	26357224.60	14198683.20	12158541.40	170155055.07
22	24183598.87	13027747.20	11155851.67	181310906.74
23	22187083.38	11952220.80	10234862.58	191545769.32
24	20351577.21	10963430.40	9388146.81	200933916.13
25	18677080.35	10061376.00	8615704.35	209549620.48
IRR			4%	

The payback period of the project can be calculated by the following formula;

$$\{(\text{Year } n \text{ when NPV}>0) - 1\} + \frac{(\text{PV Benefit} - \text{PV Cost}) - \text{NPV}}{(\text{PV Benefit} - \text{PV Cost})}$$

Therefore, the payback period for each scenario is as follow;

21 MW (Investment 945,000,000 Baht)	4.4 years
21 MW (Investment 1,365,000,000 Baht)	11.1 years
8 MW (Investment 360,000,000 Baht)	4.5 years
8 MW (Investment 520,000,000 Baht)	11.6 years

In conclusion, for a 21 MW biomass gasification plant, the NPV ranges from 599,783,944.61 - 1,707,909,004.61 Baht (ca. 18,529,007– 52,762,096 USD), while the IRR ranges from 5 – 18 percent with a payback period of 4.4 – 11.1 years. In average, it has the NPV of 1,153,846,474.61 Baht (ca. 35,571,295 USD), IRR of 11.5 percent and a payback period of 7.75 years.

For an 8 MW biomass gasification plant, the NPV ranges from 209,549,620.48– 631,692,500.48 Baht (ca. 6,473,575 – 19,514,752 USD), while the IRR ranges from at 4 - 17% and a payback period of 4.5 – 11.6 years. Averagely, it has the NPV of 420,621,060.48 Baht (ca. 12,994,163.5 USD), IRR of 10.5 percent, and a payback period of 8.1 years. Therefore, the project is financially feasible in both scenarios.

10. Suggestions

The energy potential of corn wastes (stalks, leaves, husks and cobs) can be recovered and made available through the introduction of biomass gasification plant(s). The plant can either be large and centralized for the prefectural level as shown in the pre-feasibility study in the previous chapter or consisted of a number of small-scale and decentralized power plants for the district level. The decision needs to depend on further extensive reviews on financial feasibility for each type of power plants. In any decision, the essential components are similar and can both result in efficient and effective use of biomass waste, higher energy security for rural areas and reduction of open burning, which is the main cause of smog in northern Thailand.

This chapter aims to propose critical success factors for the establishment of a biomass gasification plant. These factors include (1) location, (2) financial support, (3) appropriate technology, and (4) public participation.

10.1 Location

Selecting the right location can strongly save costs and risks for the operation of the gasification plant. The access to major inputs of the process, including the biomass feedstock and water, is considered to have the highest impact on the decision of the location (Tabprayoon, 2007). The selection of location needs to strongly consider about the proximity to the source of water and feedstock, as well as the grit of either Provincial Electricity Authority (PEA) or Metropolitan Electricity Authority (MEA), which are the two major electricity grit operators in Thailand. The close proximity to the grit can help reduce the cost of the connection system for the gasification plant.

10.2 Financial Support

Tabprayoon (2007) suggests that financial support for both investment and operation is one of the crucial success factors due to "the requirement of high initial investment as well as the huge budget to cover the strategy of inventory management to deal with the factor of seasonality", which refers to the seasonal availability of the biomass feedstock.

The main obstacle for financial support is the lack of information and familiarity regarding renewable energy projects of the financial providers. In order to overcome the obstacle, efforts must be made from both the government and the project managers in providing guidelines and information for better understanding about renewable energy of the financial providers. Clear business plan for the project is an essential tool for the project manager to convince the financial provider about the project. Meanwhile, the government should also provide more support for renewable energy from biomass, since the trading adder for energy produced from biomass has the lowest value among other sources of renewable energy as shown in Table 10.1 despite the increase from 0.30 Baht in 2007 to 0.50 Baht in 2008 for power plants with the capacity of less than 1 MW (Energy Policy and Planning Office, 2013). The increase of trading adder can strongly affect the financial feasibility of the project and become more attractive towards financial provider.

Table 10.1 Adder for the power plant under the category of VSPP

Type	**Adder (Baht/kWh)**
Biomass (≤ 1 MW)	0.50
Biomass (> 1MW)	0.30
Biogas (≤ 1 MW)	0.50
Biogas (> 1 MW)	0.30
Municipal Solid Waste	2.50
MSW (Thermal Process)	3.50
Wind (≤ 50 kW)	4.50
Wind (> 50 kW)	3.50
Small Hydro-power Generation (50 kW - ≤ 200 kW)	0.80
Small Hydro-power Generation (< 50 kW)	1.50
Solar	6.50

Source: Energy Policy and Planning Office (2013). Shifting renewable energy trading scheme from ‘adder’ to ‘feed-in tariff’ for biomass. Ministry of Energy, Thailand.

10.3 Public Participation

Public opposition can pose as one of the fatal threats to the establishment of a biomass gasification plant, thus communication and strong public participation are essential for the preparation of the plant. The Energy for Environment Foundation (2010) provides a list of major causes for public opposition to a biomass power plant as follow;

- Neglect of stakeholders’ opinions
- Problems of past projects lead to a misunderstanding of the new project
- Local communities are better informed through various means of knowledge
- Faster and more effective ways of communication (e.g. newspapers, television, internet and community radio)
- Fault or misleading information
- Political issues and selective beneficiary strategies
- Regulations and public perception which encourage communities to involve in decision making process

One of the major misperceptions that the communities usually have regarding a biomass power plant is that it is always as polluting as a coal fired power plant which they have suffered in the past (Energy for Environment Foundation, 2013). On the other hand, solar and wind energy projects do not encounter such opposition from the same misperception as biomass. The solution to solve this misperception is for the company to communicate with the community and provide the right set of information regarding pollution control, which is the threat that most communities worry about most. However, in most cases, the company prioritizes the allowance or license to operate from the government first, and then start the project and communicate to the community. This strategy has proved to be problematic since it normally leads to the lack of trust from the community, even though information is provided afterwards.

Problems between the power plant and the community can be prevented or solved by an effective participation of the community in each stage of the project.

1) Project development stage

   Documents regarding the idea of the project are needed to be provided to the community. Participation between the community and the company is strongly encouraged especially during the location selection process. Public hearing is another essential part in this stage in order to gain insights and opinions from the community. The company can also provide field trips to the similar established power plant(s) for the representatives of the community in order to strengthen the trust from the community.

2) Project planning and construction stage

Provide information about the construction agency. Continuous communication between the community and the company is important in order to ensure that the construction would not cause any negative impacts. The company should also come up with an action plan for the mitigation and solution of environmental problems, in case such problems arise during the construction process. If possible, the use local construction agency and local labor are suggestive.

3) Project operation

During the operational stage, it is suggested that the company consistently provide results of the operation to both the community and the NGOs that are relevant to the issues of the project. Moreover, the power plant should be opened for visitors from the community in order to ensure the safety of the operation.

11. Conclusion

The problem of smog which occurs every year during dry season (mid February to April) in northern Thailand is a serious problem which has yet been solved. The problem of smog has greatly influenced the livelihood of Chiang Mai citizens since 2007. Human health problem is the most significant impact. Within a short period of time, numbers of patients with problems regarding respiratory system soared. The economy of the province is also affected, since it relies mainly on tourism the major source of income, the serious problem of smog has led to the reduction of tourists and slowed down the economic growth.

The major cause of the smog is open burning of biomass residues, most significantly corn, which mainly takes place in or near forested area with high amount of dry biomass as well (Dontree et al., 2011). Each year, over 213,624.82 tons of unwanted parts of corn are left and burned openly in Chiang Mai alone. Mae Chaem district produces the highest amount of corn wastes due to the largest area of corn plantation in Chiang Mai. According to the study by Arjharn (2012), the open burning of all unwanted parts from corn cultivation can theoretically lead to 7.28 tons of particulate matter. This only reflects the capacity of smog generation from open burning of corn wastes in Chiang Mai alone, and does not corporate the influx of particulate matter from other sources of open burning and particulate matter from neighboring provinces and countries; i.e. Myanmar and Laos.

However, the great amount of corn wastes produced in Chiang Mai also means a great opportunity for energy production. Theoretically, the amount of corn wastes produced in Chiang Mai alone can generate electricity up to 200.48 GWh or 8.5 percent of total electricity consumption in the province (Arjharn, 2012). With the introduction of biomass gasification technology, unwanted parts of corn can be revalorized and turned into valuable feedstock for electricity generation. The establishment of a biomass gasification plant within the province also means higher energy security, especially for rural areas where major parts of corn cultivation exist. This also leads to the avoidance of 7.8 tons of particulate matter which is generated from open burning of corn wastes.

According to the pre-feasibility study described in Chapter 9, a biomass gasification plant is financially feasible, thus can be established in Chiang Mai. Two types of gasification plants are suggested; a 21 MW gasification plant which uses corn stalks and leaves as the main feedstock and an 8 MW gasification plant which uses corn husks and cobs as the main feedstock. In conclusion, the 21 MW biomass gasification plant has the investment cost which ranges from 29,103,787 - 42,038,803 USD with the NPV ranges from 18,529,007– 52,762,096 USD, while the IRR ranges from 5 – 18 percent and a payback period of 4.4 – 11.1 years. In average, it has the NPV of 35,571,295 USD, IRR of 11.5 percent and a payback period of 7.75 years. For the 8

MW biomass gasification plant, the investment cost ranges from 11,087,157 - 16,014,782 USD with the NPV ranges from 6,473,575 – 19,514,752 USD, while the IRR ranges from 4 - 17% and a payback period of 4.5 – 11.6 years. Averagely, it has the NPV of 12,994,163.5 USD, IRR of 10.5 percent, and a payback period of 8.1 years. Therefore, establishing a gasification plant in either scenario is financially feasible.

In order to successfully establish a biomass gasification plant, several aspects are needed to be considered. First, the right location for a gasification plant mush be selected and agreed by all stakeholders. The main requirements for the location include the feasible proximity to biomass feedstock, electricity grit and water. Secondly, financial support plays a vital role in the success of an establishment of the plant due to the lack of familiarity with renewable energy projects of financial providers in Thailand, as well as the relatively low adder value for biomass-generated electricity compared to other types of renewable energy. Lastly, the gasification plant can only be successful when there is a strong public participation in every stage of the gasification plant establishment. The development, planning and operation of the plant must be transparent with the right set of information provided to the community in order to prevent misunderstanding and the lack of trust and acceptability from the community.

When all steps and requirements for the establishment of the plant are fulfilled, the introduction of the gasification plant would lead to a more efficient and more effective use of agricultural wastes. Consequently, the magnitude of smog problem in Chiang Mai and northern Thailand would be reduced due to the avoidance of open burning of agricultural wastes. The overall livelihood of Chiang Mai citizens would also be enhanced due to the reduction of risks regarding human health, which also leads to the reduction of costs spent for health issues, and the stable or increase of tourists due to the safe environment for tourism.

The result of this thesis provides a better understanding about the cause of smog problem in northern Thailand, and a possible solution to the problem. However, limitations still exist including insufficient communication between the researchers, government and local villagers in open burning areas, which leads to the lack of awareness about the negative effects imposed on human and the province as a whole which occurred because of the smog. It also leads to the misunderstanding and negative impression of the biomass power plants among the citizens, which are the main limitations for most biomass power plant projects.

In further stage of the research, a feasibility study of a specific biomass gasification plant in Chiang Mai will be carried out. The specified location, type of technology and a more detailed and realistic calculation of the financial feasibility analysis will be covered in order to make the project more practical and can be further developed in the real situation.

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