# CHAPTER 1
# INTRODUCTION

## 1.1 Background and Rationale

With increasing population and economic development worldwide, there is an increasing trend in solid waste production. Appropriate waste treatment and disposal options have become issues of increasing concern with much disparity observed among countries, depending on level of development. Thailand, an agricultural based country, is one of the world's largest producers and exporters of processed food. There are over 12,311 food industries in 2008 in Thailand reported by Department of Industrial Works (DIW) (FDA, 2008). Among the many food crops it produces, Thailand is among the three top largest producers of mangoafter India and China (http://faostst.fao.org, 2011). There are around 172 cultivars have been recorded in Thailand and about ten are grown commercially such as 'Nam Dok Mai', 'Si Thong' 'Maha Chanok', 'Ok Rong', etc (DOA, 2009). In 2005, mangos have been cultivated in 316,032 ha and a production of 2,080,650 tons in Thailand (DOA, 2009). They are mainly produced (84%) for domestic consumption (MOF, 2009), and exported both fresh and processed mango for more than three decades. In 2006 export volume of fresh is 2,494 tons, valued at Baht 133.45 million; and of processed mango, such as canned mango, dried mango and frozen mango at the amount of 11,701 tons, valued at Baht 463.34 million (DOA,2009). Ripe mangos are processed in many forms as frozen, canned, dehydrated, and puree (FAO, 2011). Following processing operations, a large amount of mango seeds and mango peels are discarded as waste in the field, accounting for 35-55% base on a fresh weight (Bhalerao *et al.*, 1989). Only mango peel represented 10-18% as weight of total fresh fruit (Nagel *et al.*, 2010). Since the discards fruits are organic in nature, all of these residues can generate solid waste and many pollutants can be emitted, if it is not treated adequately.

Based on an initial assessment performed as part of an internship study for a mango factory, it was found that mango peel waste was produced and dumped to nearby mango fields during the mango season. This method of disposal may contribute air pollution and health impacts and also creates public nuisance by attracting flies and rats around the disposal areas (World Bank, 2012). Today trends of waste management are to reduce the stream of waste going to landfills and to recycle the organic materials to the soil as nutrients (Koumanova and Saev, 2008).

The study of waste management in this research study aims to improve waste management for a dry mango sheet processing factory with a view to contribute to climate change mitigation (reduced greenhouse gas emissions) using mango waste as feedstock for biogas production. The biogas could be utilized to substitute LPG in the mango factory and solid digestate, by-product from the biogas system, could be used as organic fertilizer to substitute chemical fertilizer in the mango orchard supplying the factory.

## 1.2 Research Study Objectives

The objectives of this research study are as follows:

1. To estimate biogas production potential using mango peel as feedstock.
2. To evaluate the environmental benefits in terms of GHGs (global warming potential) associated with biogas production from mango peels instead of open dumping.
3. To evaluate the financial viability of the biogas system.

## 1.3 Scope of the Research Study

This research study particularly focused on greenhouse gases (GHGs) and financial implications associated with mango peel waste utilization as feedstock for biogas production instead of open dumping in the field. The elements included in the assessment are listed below:

(1) Investigation of amount of mango waste generated over a mango production cycle in one year.

(2) Assessment of waste management strategy followed by the factory to handle mango waste.

(3) Identification of the biogas system required to process the mango waste generated by the factory (technical characteristics and operating conditions).

(4) Assessment of the biogas production potential using mango peel as a substrate.

(5) Assessment of the investment, operating and maintenance costs associated with the biogas system and of the savings associated with LPG and chemical fertilizer substitutions.

(6) Assessment of the GHG benefits and financial viability of the biogas system proposed for the mango factory investigated in this research as compared to the current situation of open dumping of mango waste.

## 1.4 Literature Review

### 1.4.1 Organic Waste and Treatment Technologies

Waste management has become a critical issue worldwide because of the environmental and health problems that may result if not adequately treated (Khalid *et al.*, 2011). With regard to the organic fraction of solid waste, there are many methods available for treatment, including, incineration, landfill, composting, and anaerobic digestion (Smith *et al.*, 2001). Details of such technologies are provided below.

**Incineration:** The current share of biomass in the total energy consumption of Thailand is about 20%. With ample solid waste availability, the burners at drying facilities could be utilized various forms of bio-energy to substitute fossil fuel (Nagle *et al.*, 2010). Energy recovered from waste can replace the need for electricity and/or heat from other sources. Nagle *et al.* (2010) examined potential of fruit processing residues as an alternative fuel for drying process. The result shows good potential for fuel but have to careful in high moisture content and nitrogen content of this type of waste. The breakdown of greenhouse gas fluxes from incineration depends strongly on the material being combusted (Smith *et al.*, 2001).

**Landfill:** There is a variation in the characteristics of managed and unmanaged waste dumping. Unmanaged and absence of disposal operation controlling is called dumping, the small and shallow sites with minimal control on type or quantity of waste entering and no gas collection or leachate management, and the large deep site with multiple liners where the waste is monitored, compacted and cover, gas is collected for flaring or energy use and leachate management. Organic waste degrades and gas was produced slowly over time which contains roughly 50% methane. In landfill site, uncollected and/or no control gas migrate to the surface of the landfill site and is released (Smith *et al.*, 2001). The major GHG emissions from the waste sector are landfilled $CH_4$ (Bogner *et al.*, 2007)

**Composting:** For many centuries, composting has been used as a means of recycling organic matter back into the soil to improve soil structure and fertility. Composting is a natural process that turns organic material into a dark rich substance called compost, which is a wonderful conditioner for soil. During composting, microorganisms, such as bacteria and fungi, break down complex organic compounds (Tweib *et al.,* 2011). Compost utilization on land can return major nutrient (N, P, and K) to the soil. Furthermore, it may contribute to the carbon sequestration and may partially replace peat and fertilizers (Smith *et al.,* 2001). After the compost is produced and applied land, it continues to degrade, releasing more $CO_2$ and forming humic compound. The Intergovernmental Panel on Climate Change (IPCC) has identified carbon sequestration in soil as one of three carbon mitigation measures for agriculture, the other two options being a reduction in agriculturally related emissions and replacement of fossil fuels with bio-fuel (Smith *et al.,* 2001).

**Anaerobic Digestion**: This treatment technology is used to reduce the stream of biodegradable waste going to landfills. There have been a number of reports on the utilization of fruit and vegetable waste (FVW) individual as feedstock for biogas production (Koumanova and Saev, 2008). A summary of results presented in the literature are reported in Table 1.1.

The preceding review indicates that anaerobic digestion is one of the most effective biological processes used to treat a wide variety of solid organic waste products and sludge. However, different factors such as substrate characteristics and composition, and environmental factors such retention time, temperature, pH, type of reactor, and organic loading rate (OLR), would perform to the efficiency of the system. In term of GHG emission, anaerobic digestion from fruit wastes produces biogas with $CH_4$ contents in a range 50-65% (see Table 1.1) and remainder is $CO_2$ as it originates from degradable organic matter. Most of $CH_4$ is converted to short term $CO_2$ during combustion of the gas for energy, but a little may escape through leakage.

Table 1.1 Anaerobic digestions of fruit and vegetable waste

| Type of FVW | Conditions | Results |
|---|---|---|
| **Tomato processing waste** | - Single and two stage anaerobic digestion (AD) | - 80%carbon conversion to total gas<br>- Biogas yield 0.8 $m^3$ $kg^{-1}$VS (65% $CH_4$)<br>- Two stage process yielded a 40-50% increase in the rate and yields of $CH_4$ over the single stage |
| **Orange peels** | - Organic loading rate (OLR) 3.5 kg TS $m^{-3}d^{-1}$<br>- Temperature 37 ± 1°C | - Biogas yield 0.5 $m^3$ $kg^{-1}$TS<br>- $CH_4$ concentration 50-55%<br>- Conversion of solid to gas 98% |
| **Banana waste** | - Batch operation<br>- Temperature 38 °C | - Methane yield 380 $dm^3$ $CH_4$ $kg^{-1}$ TS |
| **Banana peels and pineapple waste** | - Various hydraulic retention time (HRT) | - Biogas yield for banana peel at 25 HRT was 0.76 $vv^{-1}d^{-1}$ with 36% substrate utilization<br>- Biogas yield for pineapple 0.93 $vv^{-1}d^{-1}$ with 50%substrate utilization at HRT 10 days |

*Source: Koumanova andSaev,2008*

1.4.2 Mango Waste Utilization and Treatment

The mango is a very common tropical fruit found in Southern Asia. It is cultivated and grown vastly in many tropical regions and widely distributed in the world. There are several varieties grown in Thailand, "Nam Dawk Mai", "Ok Long", "Keow Savoey", and "Rat". Its harvesting time is between Januarys and May (Sruamsiri and Silman, 2009). Ripe mangoes are processed into frozen mango products, canned products, dehydrated products, and ready-to-serve beverages (Ramteke and Eipeson, 1997).

After consumption or industrial processing of the fruits, its peel and seed are treated as waste, which is approximately 40-50% of the total fruit weight depending on the type (Sruamsiri and Silman, 2009).

Mango seed consists of a tenacious coat enclosing the kernel. The seed composition varies with the type of mango. The value is in a range 9% to 23% of the fruit weight and the seed kernel vary from 45.7% to 72.8% of the seed weight. Mineral content in mango seed kernel includes potassium, magnesium, phosphorus, calcium and sodium. Many studies of mango seed from a review of Kittiphoom (2012) present a potential to produce in functional food ingredients, natural antioxidants, antimicrobial compound, cosmetic, activated carbon, and therapeutic functional food products.

Mango peel is high in phytochemicals, including, polyphenols, carotenoids, vitamin E, dietary fibre and vitamin C. This composition makes it suitable for use in the preparation of bakery products (Ashoush and Gadallah, 2011).

There have also been studies looking at the potential of treatment technologies to process such waste. Due to its biodegradable organic nature, as other fruit or vegetable waste, anaerobic digestion appears to be a suitable technique. Results of such investigations looking at biogas production from mango waste are reported in Table 1.2.

Anaerobic digestion is a suitable process for the treatment of such waste. However, issues of high organic loading have been reported, which may render maintaining the process difficult. As stated by Koumanova and Saev (2008), more studies are required to optimize conditions for the anaerobic digestion of such waste and therefore enhance biogas production.

Table 1.2 Biogas productions from mango waste

| Type of FVW | Conditions | Results |
|---|---|---|
| **Mango peel** | - Feed slurry 6%TS (w/v)<br>- Temperature 30 °C<br>- Semi-continuous fermentation | - Biogas yield 0.36 $m^3$ $kg^{-1}$VS<br>- $CH_4$ concentration 58% |
| **Mango processing waste** | - Salts of trace elements used in the experiment | - Biogas production increase with the increasing of $Co^{2+}$ and $Ni^{2+}$ up to 125 mg $dm^{-3}$<br>- The gas production was highest when $FeCl_3$ was added at concentration 4000 mg $dm^{-3}$<br>- The methane content was not influenced by the addition of cobalt and nickel. |
| **Mango peel** | - HRT 15 days | - Biogas yield 0.33 $m^3$ $kg^{-1}$ TS added<br>- Methane content 53% |
| **Mango peel kernel (MPK)** | - Bioreactor with agitator (100 rpm for 30 min after every 30 min)<br>- Substrate slurry 10%<br>- Temp 30 - 35 °C<br>- pH 6.5 – 7.5 | - Biogas production was higher at 1.5 OLR and continued up to 3.0 OLR<br>- Digestion efficiency 72.8% |

*Source: Koumanova and Saev,2008*