1 Introduction

1.1 Background of the study - energy and environmental problems

The world is comprised of all kinds of problems and dilemmas. Major international challenges include population overload, environmental pollution, resource depletion and energy shortages. It is well documented that the use of coal based energy resources, which is unfortunately still increasing, has resulted in the breakdown of the composition of the atmosphere. In the last 150 years, carbon dioxide quantity in the air has increased by 28 %, the concentration of methane by 50 % and the quantity of nitrogen dioxide by 13 % [10]. This difficult situation compounded by a world-wide decrease in coal, oil and uranium reserves necessitates an urgent change in attitudes towards energy conservation. During 2010 United Nations Framework Convention on Climate Change (UNFCCC) in Copenhagen, the problems caused by climate change were again brought to the forefront of the international agenda as they had been in the Kyoto Protocol of 1997.

Due to these concerns, intense international research and development has focused on the exploration of possible changes to the structure of global energy consumption and the search for practical applications of alternative energy sources. Numerous promising results show possible routes for the future. Among these possibilities, it is clear that regenerative energy sources play a very important role in the conservation of energy on a greater scale. This is a popular topic as the increasing turn to regenerative energy sources has begun to show potential for alleviating the stresses of fossil energy shortages and restricting the speed of environmental and climate deterioration.

Along with the development of research, there have been changes in some policies and regulations. For example, in Europe regenerative energies have been able to replace approximately 2.1 % of power needs in 2000 and by 2010 they made up 4.2 % of total energy consumption. Correspondingly, renewable energy made up 6.25 % of electricity production in 2000 and 12.5 % in 2010 [10]. According to a resolution of the European Energy Council, the target share of renewable energies in relation to total energy consumption is 20 % and the proportion of bio-fuels in relation to the total energy consumption should reach 10 % by the year 2020 [124]. Many other states have also promised to reduce CO_2 emissions and beef up environmental protection strategies. For example, China has proposed a CO_2 reduction of 40-45 % by 2020 in UNFCCC (from a 2005 baseline) and an increase in the forest cover to 20 % [100].

Bio-energy is one of the renewable energy sources that is playing a prominent role in averting energy depletion. Biomass is the main substrate from which

bio-energy is gained. Nowadays, various methods are available to convert biomass to bio-energy, including: combustion, anaerobic and aerobic fermentation. Improvements in process and technology are constantly being made. Contemporary, researchers have already made some progress in materials and technologies, from production to utilization, from a single technology to technology variation. For example, a combination of anaerobic fermentation and aerobic composting has already been put into practice with good effect. Additionally, some types of non-food materials like cellulose and ligno-cellulose are currently being researched in the United States (US) and other countries.

In terms of biomass utilization, there are a lot of technologies that use biomass to produce energy. Bio-fuel energy – such as bio-diesel and bio-ethanol, together with gaseous biogas requires substantial amounts of energy crops, which has caused an increase in the price of grains, and a resultant shortage for animals and human beings in some countries. A lot of biomass has been misused or is irrationally used, which has resulted in an even more serious environmental situation. Some countries have forbidden the use of energy crops for energy to avoid resource shortages, even though the production of renewable energy, especially bio-fuel energy is highly needed in these countries, particularly some Asian countries. This thesis intends to add to the research on bio-energy by examining the usage of raw materials and feasible technologies in order to make better use of the materials and improve environmental and ecological outcomes.

1.2 Purpose and significance of the study

Together with rising oil prices, and the limited resources of fossil fuel energy, biomass energy is well accepted and has been further heralded as a renewable energy source. On the other hand, increasing bio-energy production has caused an increase in global demand for bio-fuel crops and for farmland, putting upward pressure on world prices of bio-fuels, food and feed. Technological improvements may fractionally help to alleviate this situation, yet additional solutions are needed.

There are two main ways to approach the biomass utilization problems mentioned above. One is to find some substitutes kinds of new substitute for crops such as cellulosic materials to produce bio-fuels. Another is to increase the biomass utilization efficiency – to increase the conversion efficiency or make full use of by-products.

The key idea of this study is the exploration of a convenient and suitable way to use the by-product of bio-ethanol production known as stillage. There are a lot of methods to use stillage, which are discussed in the following chapters and this thesis proposes an innovative approach E-M-F or Ethanol, Methane,

Fertilizer, which makes full use of raw materials and produces as much energy as possible.

This study is carried out with the backdrop of global energy issues discussed above and is based on contemporary international research in biological technologies, together with the consideration of the following primary factors:

- Improvement of the environment and energy situation
- Reduction of increasingly extreme changes to the global climate
- Better disposal methods of organic materials
- Full use of all kind of materials to solve the problem of the high cost of feedstock production in all current bio-fuel production systems
- Evaluation of the energy production potential of biomass (with the original biomass to be used firstly in the production of bio-ethanol and secondary stillage to be used in the production of biogas and by-products to be used as bio-fertilizer)
- To carry out a balance analysis, in order to decide to what extent this system could result in a better use of biomass.

The proposed E-M-F-System takes into account the multiple uses of the raw materials and by-products and has not yet been particularly described in any published literature. Available research has considered the use of use of starch and sugar containing stillages as direct fertilizer or as animal feed, and lignin cellulose stillage has been used in the process of gasification to produce heat and electricity as a bonus [31, 34, 36, 37]. There has also been research related to the possibility for stillage to be used in the process of digestion such as in references [4, 5, 64, 65, 94, 95], but further research of digestate as a raw materials for composting has not yet been conducted. Much of the data did not give a clear picture and varied greatly.

This study is carried out mainly to answer the following questions:

- Is it technologically possible and feasible to use the by-product from bio-ethanol production in the course of biogas production?
- Is it reasonable to further use the residues from biogas production in the course of bio-fertilizer production?
- What is the efficiency of this system in terms of energy and ecological effects?
- How does the mass flow during this system?

This thesis is closely related to the UN conference aims in Copenhagen. The study details a new proposed combination system in which anaerobic and aerobic biological methods are sequentially combined, through which liquid, gaseous and solid energies are produced. In this proposed method, there is relatively little waste and odor release, and natural resources, particularly soil are protected through the utilization of bio-fertilizer.

1.3 Research methods of the study – E-M-F-System

The proposed system is not merely a recombination of some existing biological technologies, but a concept of an entire ecological organic circulation. The name of this system originates from the main products of this system – Ethanol, Methane, Fertilizer, thus the E-M-F-System.

Basic technologies to change biomass into different forms of energy have already been well developed by existing implementations of biological biomass disposal. This thesis includes an extensive review of current scientific references in order to investigate methods of utilizing the significant by-product stream of bio-ethanol production, the process of biogas digestion, and rest materials in the process of composting as all three processes are proposed to be used in concert in the E-M-F-System.

Two ways to analyze the feasibility of the E-M-F process are utilized in parallel, firstly through theoretical analysis and secondly through laboratory research. The analysis includes some important new research results as well as focal points, parameters and data taken from the plants in the EU, US and Brazil. Laboratory attempts to analyze the possibility of the biological combinations are detailed in Chapter 4.

Through these investigations and studies, reliable and reasonable data are gathered for the next step – analysis and evaluation, which is completed through an analysis of mass balance, energy balance and $CO_{2\text{-eq.}}$ balance. These results are presented in Chapter 5. The use of two types of bio-fuels in the E-M-F-System - bio-ethanol and biogas together with the use of the rest material as organic compost are presented in detail. This study reveals that the use of this combined system could result in high energy efficiency, biomass utilization efficiency and the reduction rate of greenhouse gas effects.

To understand the background for this proposal, previous uses of biomass, different types of original materials and the use of by-products are discussed in Chapter 2. Besides variable traditional raw materials, non-food feedstock such as lingo-cellulosic material could also be used as an economical and ecological attractive input for ethanol production. Some typical inputs such as sweet potato is taken as an example for detailed analysis of the mass, energy, input and output and calculations of resulting reduction rates of $CO_{2\text{-eq.}}$. A case study of sweet potato usages in China is utilized in the tool box, which is compiled at the end of the study in an Excel spreadsheet and could be utilized in the further projects.

In order to answer the questions above and to support the idea of the E-M-F-System, the following additional work is done:

- A basic study of the characteristics of feedstock in these kinds of biological processes, and a resulting technological investigation.
- Research of the combination of these three kinds of biological processes in the laboratory, so as to see the technological possibilities.
- The assessment of the system in order to support the concept and application feasibility. This would be mainly done together with mass-, energy-, and $CO_{2\text{-eq.}}$-balances.
- Creation of a tool box for this system as a convenient platform for future users of this system to produce bio-fuel energy. This tool box helps the processes of this system to be better understood and assessment of this system would be easily done by the other users.

The whole process of this thesis is laid out in the diagram Figure 1-1, which illustrates the main points and the main course of the study.

1.4 Anticipative study results

The following are the main expected results, which are helpful in designing this efficient combination of three technologies for the degradation of biomass:

- To obtain an optimized combination system of three biological treatment methods
- To get full use of by-products
- To gain more bio-energy: as substitutes for fossil fuel
- To examine the environmental effect of this system: the potential of $CO_{2\text{-eq.}}$ decreasing rate
- To find a suitable bio-fertilizer for plants and crops
- To establish a rigorous and reliable analysis method for the system
- To compile a new tool box according to the analysis results
- To make it possible and suitable to carry out the system in practical projects

1.5 Prospects of the study

With the world situation as a background, all kinds of studies that focus on the protection of environment and human living conditions, are urgently required. Proposals for alternative energy are particularly needed.

This study considered all aspects of mass, energy and environmental effects, concludes that the E-M-D system will be an optimal combination. From the technology aspect, it is in no doubt that all of these three techniques are currently well developed in many counties in the world. From the materials aspect, it is also well considered, as in every country there are various options of

all kinds of biomass that could be used to produce these types of energy. In order better argue the advantages of this system, comparisons of E-M-D with the most popular system in current global use will be made. The study results of this system show that energy and mass can be optimized, without pollution to nature, and with full circulation. This could contribute a well accepted and utilized potential solution for energy problems.

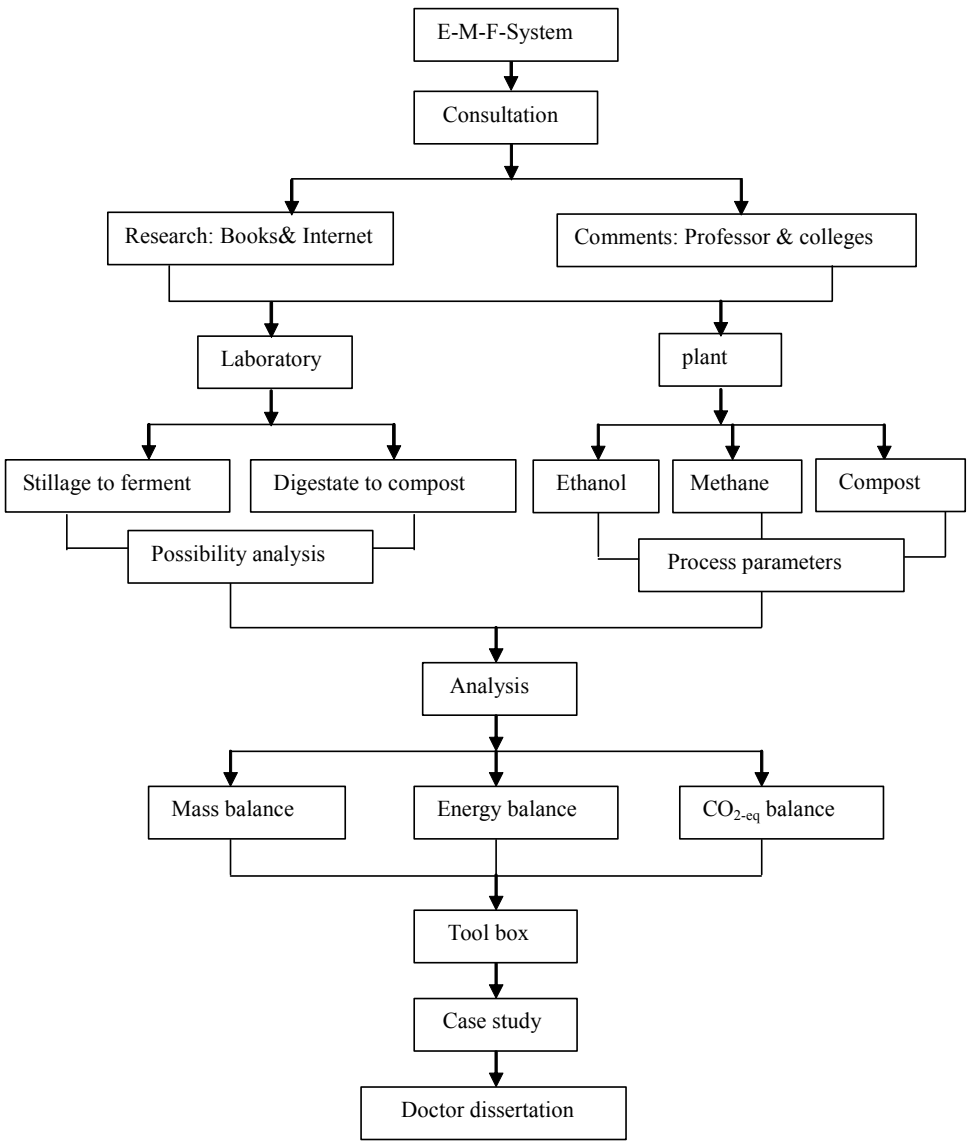

Figure 1-1: Flow chart of the research process in E-M-F-System study