CHAPTER 1

INTRODUCTION

1.1. BACKGROUND

Climate change caused by the extensive use of fossil fuels is one of the challenging issues for scientific communities and nations across the world. The population of many countries is growing rapidly and it is expected the world population to reach approximately 8.5 billion by the year 2030 [1]. At the same time, there is a spike in the economic development especially in developing countries like India and China [2]. Due to industrialization, these countries have entered their most energy intensive phase of economic growth [3]. With increase in population, the demand for energy, food and natural resources will increase substantially over the next decade. Thus, an important challenge faced today is to meet the increasing energy demand and have sustainable energy resources for the future use [4].

In 2013, the world total primary energy supply was 155,505 Mtoe/yr, ~25 times higher as compared to 6,130 Mtoe/yr in 2000 [5]. Currently, fossil fuel meets 86% of the global primary energy demand and thus contributes globally in energy related emissions (Figure 1.1) [6]. The fossil resources, especially crude oil are continuously being exploited and have raised number of concerns worldwide [7]. Firstly, definite availability of crude oil reserves would make the extraction increasingly difficult [3]. Secondly, the available reserves are unequally distributed across the globe [3]. Therefore, a major part of energy demand in many nations depends largely on import of resources [3]. New energy sources are required in coming days as current oil supply would not be able to meet the spiking oil demand [8].

Furthermore, the combustion of fossil fuels substantially contributes to greenhouse gas (GHG) emissions [6]. Carbon dioxide (CO_2) level has enhanced 36% as compared to pre-industrial times and is estimated to rise rapidly with the growth in economic development [9]. Higher level of GHG emissions is responsible for inducing climate change effects such as melting of glaciers, increased sea level and various other natural calamities [10].

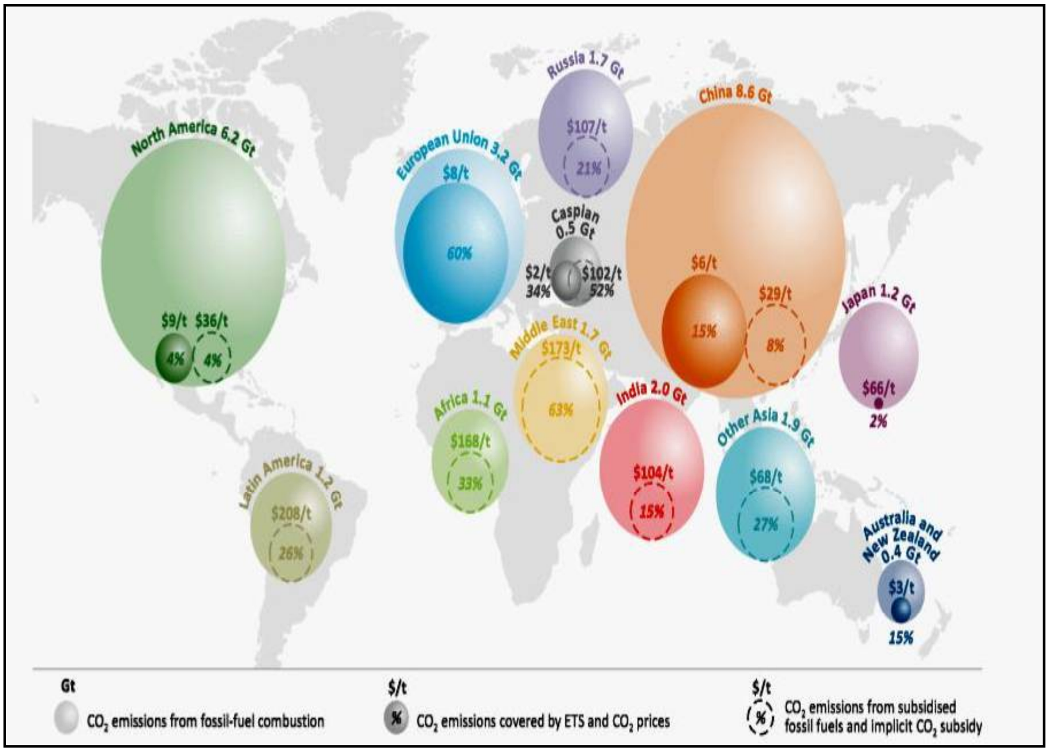

Figure 1.1 CO_2 emissions in selected regions of the world in 2015 [3]

According to world energy consumption by sector, transportation consume 27.6% of total energy in 2015 and ranked as the second largest energy consuming sector [11]. In 2016, the transport sector alone was responsible for 11.7% of world energy related CO_2 emissions [12]. Vehicle emissions in form of CO_2 are increasing source of GHG emissions. The lowering down of vehicle emissions requires advances in engine, fuel technology that can fundamentally help in substantial reduction of emissions [11].

1.2 USE OF BIOENERGY IN TRANSPORTATION

In 2015, the global primary energy demand by fuel accounts largest for crude oil (31.3%), followed by coal (28.6%), natural gas (21.2%), biomass (10.3%), nuclear (4.8%), hydro (2.4%) and other renewables (1.4%) [13]. Of the total primary energy supplies biomass contribution is less than 10% in the industrialized countries whereas in developing countries the contribution goes upto to 20-30% [14]. Most of the biomass in developing countries is for cooking and heating, which is not very efficient way of using energy from environmental view point.

Bioenergy can play a major role in the industrial countries that consume huge amount of fossil energy and are also responsible for increasing CO_2 level [14, 15]. The rising world energy demand, uneven distribution of fossil resources and their continuous depletion along with adverse impact on environment, urge many countries to formulate policies to promote sustainable energy sources [16]. The Energy Independence and Security Act (EISA), 2007 of United States (US) defined a number of mandates with respect to renewable fuels [17]. One of these mandates called for the production of 16 billion gallons of cellulosic fuel by the year 2022 [18]. In US, one of the policies to promote biofuel is described by Renewable Fuel Standard (RFS) that dictates to increase the current biofuel usage from 7.1 to 15% in transportation fleets. [19]. Similarly, European Commission (EC) in 2007 mandated that out of total energy use, 20% needs to be achieved from renewable sources and out of that, 10% to be used in transportation by 2020 [20]. The biofuel policies of different countries of the world are summarized in more detail in Table 1.1.

The use of bioenergy includes solid, liquid and gaseous biofuels, bioelectricity and process heat derived from forest, agricultural residue and lignocellulosic waste [21]. Biofuels are potentially low carbon energy source that can be an alternative for the conventional fuels in transportation sector [3]. The foreseeable future will use low carbon liquid fuel to be used in existing internal combustion engines of transportation vehicles. With the available conversion technologies, biofuels may substantially contribute to the renewable energy targets in the near future. The policy makers are being informed about the benefits drawn from bioenergy systems and initiatives have already started to increase the use of biofuels all across the world. The price volatility of oil, energy security and climate change has led to an increased interest in developing and promoting alternate fuels all across the world. Intergovernmental Panel on Climate Change (IPCC) has reported a temperature rise of 0.6°C during last three decades and this has created an alarming situation for many countries to reduce their emissions [22]. The four largest GHG emitters are China, US, EU and India, all together contribute to ~ 61% of global emissions [23]. Emissions from energy represent 60% of global emissions in CO_2 equivalent (eq.). Therefore, there is a need to promote the use of biofuels in order to achieve energy security, mitigation of GHG emissions and social well being of rural people.

Biofuels in the form of wood have been in use ever since the discovery of fire. The people of ancient civilization used wood as a fuel for heating and cooking. The exploration of the fossil fuels like oil, gas and coal lead the biofuels suffered a setback [24]. The advantages placed by the fossil fuels helped them to attain popularity in the developed countries. Liquid biofuels are in use in the automobile industry since 1892, when Rudolf Diesel designed first diesel engine to run on peanut oil. Later on, Henry Ford designed the Model T car in 1926 to run on biofuel derived from hemp [25]. Liquid fuels are easy to store, transport and offer higher heating values as compared to solid fuels. Biofuels are the potential liquid fuels, however, cheaper petroleum products beaten their use in automotive industry for more than a century [26]. Due to diminishing oil reserves, increase in energy demand and more importantly rising GHG levels has again created an interest on biofuel usage [27]. Biomass captures solar energy via photosynthesis and is available worldwide for further processing to food, animal feed, chemicals and fuels. Liquid biofuels produced from agricultural crops, dedicated energy crops, agricultural, forest residues and other feedstocks have been promoted in the US, EU and elsewhere, aiming towards the reduction of oil dependence and GHG emissions [5]. Ethanol can be blended with conventional gasoline, typically 5-20% (v/v) and can be used in existing vehicles without modifications in engine. However, to use higher ethanol blends of 85-100%, specifically modified engines are required [28].

The largest producers of ethanol are Brazil and the United Sates, each of which accounts for 45% of the total worldwide ethanol production in the year 2015 [29]. The production of biofuels has grown substantially in last decade and is expected to grow further in many regions of the world as shown in Figure 1.2. Targets and mandates have been put in place for use of biofuels as a part of many national energy policies, considering their role in enhancing energy security and mitigating climate change at the regional and national level [30].

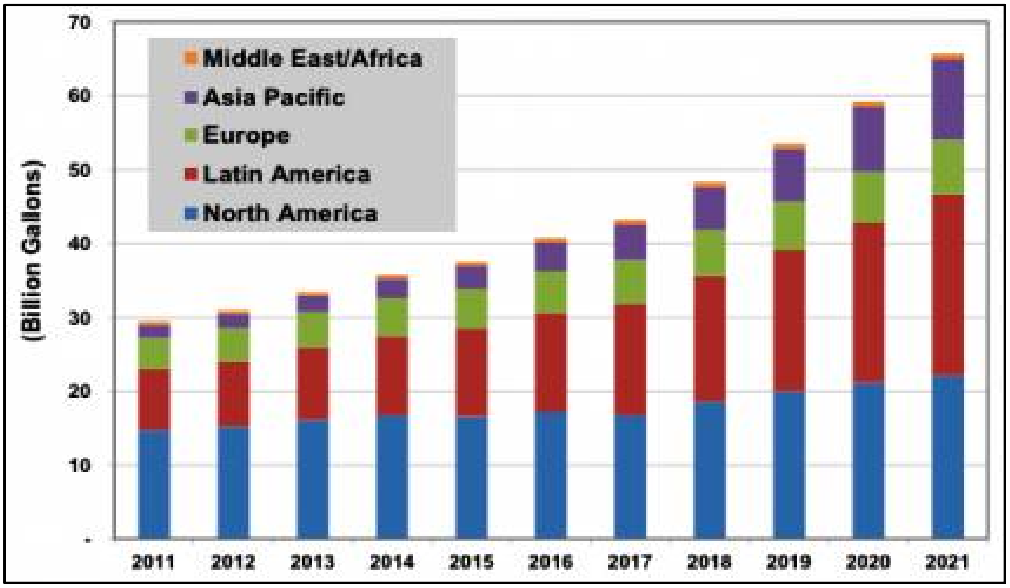

Figure 1.2 Projected biofuel production in major ethanol producing countries in the world [31]

1.3 NEED OF BIOFUELS IN INDIA

The primary energy demand of fuel in India has increased from 441 Mtoe in 2000 to 775 Mtoe in 2013 as shown in Figure 1.3 [32]. Out of total 775 Mtoe use of energy in 2013, coal and petroleum accounted for 66% followed by biomass and waste (23%), natural gas (6%), nuclear (1%), hydroelectric (2%) and other renewable (1%) [32]. During 2013, India consumed about 141 MMT of crude oil out of which 77% was imported, indicating a very high import dependency of country [33].

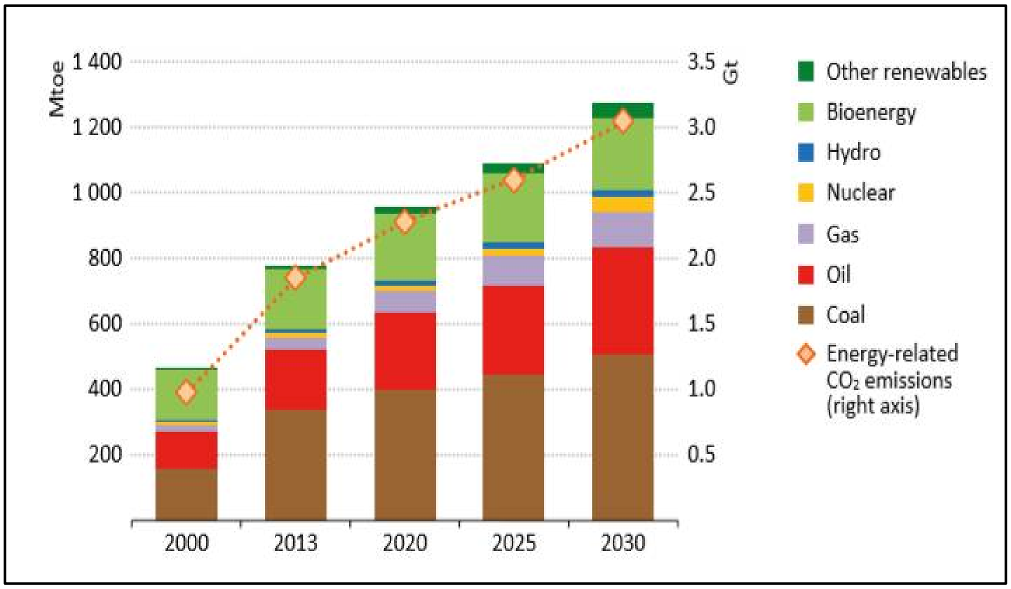

Figure 1.3 Primary energy demand in India by fuel type and related CO_2 emissions [32]

The import of crude oil in India would rise to 953 ML per day by 2030, and this would make country ranking as third largest importer of oil [7]. In terms of end use, transport sector is the largest consumer of the petroleum product and contribute to the major source of GHG emissions. Concerns about sustained oil supplies, volatile prices and environmental issues have led India to search for alternative to fossil fuels. Biofuels in form of ethanol and biodiesel could be a viable option in India to substitute petroleum fuels [34]. With these dynamics in mind, Government of India, in 2001 launched a national policy to promote use of biofuels. The policy aimed to contribute in reduction of GHG emissions, oil imports and generate employment opportunities in rural areas [35].

After Brazil, India is second largest producer of sugarcane in world and therefore, current ethanol demand for potable and industrial use is met from molasses, a by-product of sugar industry. Government of India in 2009 mandated a 5% ethanol blending target across 20 states and four union territories and proposed an indicative blending target of 20% by 2017 [36]. However, this target has not been met completely due to cyclic nature of sugarcane production. As a consequence, molasses availability gets fluctuated and therefore, Government kept the blending target of 5% only [34].

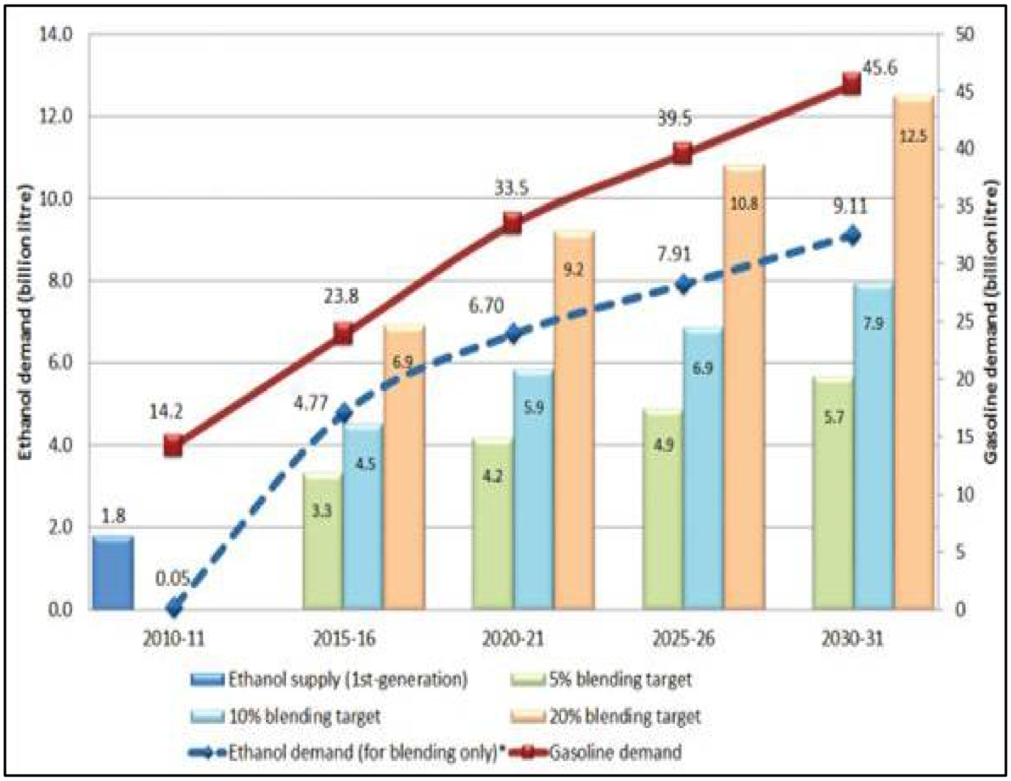

Figure 1.4 Ethanol demand with blending targets (%) in India [34]

It can be seen from Figure 1.4 that demand of ethanol would increase in future for 5, 10 and 20% blending in gasoline in India. Therefore, apart from sugarcane molasses there is a need to explore other technologies and feedstocks such as lignocellulosic biomass for ethanol production.

1.4 TYPES OF BIOREFINERY FOR BIOFUELS PRODUCTION

Biorefinery is defined as integrated facility for conversion of biomass to fuel, power, and chemicals [37]. Ethanol production from biomass is regarded as a multifunctional system that includes production of electricity, biogas, vinasses, chemical etc. along the production chain [38, 39]. Value added co-products derived from biomass help in strengthening the bio-economy. Brazilian and Indian ethanol industries have already demonstrated the success of a multi-output production, converting sugarcane into sugar and at the same time producing ethanol and electricity by using co-generation [37, 40]. The electricity generated in such a system is also used internally and the surplus is sold to the national grid. The value derived from biomass is increased by producing multiple products and integrating waste management

[41]. Therefore, a biorefinery helps in sustainable development in terms of economy and environment [42]. Broadly, biorefineries can be categorized into phase I, II and III [43].

Phase I biorefinery has fixed processing capabilities and produces a fixed amount of ethanol and other feed products, while phase II biorefinery has the capability to produce various end products and has far more processing flexibility. Typical examples for phase I and II biorefinery are corn dry milling and corn wet milling, respectively [44]. The most promising is Phase III biorefinery to be developed in near future that can use a mix of biomass feedstocks and yields wide array of products by employing multiple feedstocks and various technologies It allows use of multiple agriculture feedstocks by integrating various types of processing methods in order to yield product like ethanol in high volume and other value added co-products. Lignocellulosic feedstock (LCF) biorefinery is an important phase III biorefinery [45]. In a LCF biorefinery, cellulosic biomass including agriculture residue, forest residue and energy crops are degraded into three fractions (cellulose, hemicellulose and lignin) via biochemical conversion. The cellulose and hemicellulose are further processed to produce useful products such as fuels and chemicals, and the left over lignin residues is used in direct combustion to generate steam and electricity.

1.5 SUSTAINABILITY ASSESSMENT OF BIOFUELS

Various concerns related to the environmental impacts of biofuels production have recently been identified and raised question on the expansion of biofuel production. The debates related with production of biofuels include the food Vs fuel debate, air and water quality, deforestation, soil erosion [46]. At the same time, efforts have been made to analyze that produced biofuel must meet the sustainability criteria and standards [47]. Biofuels could significantly contribute to the sustainable development if they meet the standard emissions reduction criteria. The produced fuel ethanol should comply with international biofuel or renewable policy such as Renewable Energy Directive (RED) [20], Renewable Fuel Standard (RFS) [18] and Low Carbon Fuel Standard (LCFS) [48]. US Environmental Protection Agency

(EPA) has classified advanced biofuels as one which reduces the GHG emission more than 60% as compared to gasoline. US EPA has categorized each biofuel with distinct identification number and with GHG reduction potential. For example, cellulosic ethanol has to reduce minimum 60% GHG emissions while corn ethanol has only 20% reduction mandate. Therefore, a refiner can either blend 3 volumes of corn ethanol or 1 volume of cellulosic ethanol for some compliance of norms. Thus, it is not sufficient to produce biofuel, but the produced fuel must show the minimum legislated GHG reductions.

In the US and the Europe, the financial incentives are extended only to those biofuels, which meet GHG reduction criterion and India is also likely to follow the same practice. With this mindset, it is essential to carry out Life Cycle Assessment (LCA) of biofuels in India to understand the environmental and energy performance of biofuels. LCA is a technique or tool that access the potential environmental impact associated with product, process and service. It is considered to be an adequate instrument for environmental decision support and for policy makers to make an informed decision.

1.6 AIM AND RESEARCH QUESTIONS

The main objective of the thesis is to assess the sustainability of ethanol production in India, with a focus on the GHG emissions and Net Energy Ratio (NER). The thesis is divided into 3 research objectives and attempts to answer the following research questions.

(i) LCA of first generation fuel ethanol from sugarcane molasses in India

EBP in India utilizes sugarcane molasses, by-product of sugar industry for ethanol production. Sugarcane is grown in the northern and western region of India and these regions also account for largest ethanol production. The study aims at establishing the impact of regional differences in outcome of LCA. The study further aims at finding the unit process which has high impact on environmental performance and energy use of molasses ethanol production. The LCA method used in the study finds GHG emissions along the production chain, GHG emission reduction potential and NER of ethanol using three different allocation approaches. Within this research topic, four overall research questions are formulated:

Q1: *Which factors have the main influence on environmental and energy use of fuel ethanol from molasses in India?*

Q2: *How LCA results are affected while producing ethanol in two different regions of the country?*

Q3: *How different allocation approaches can affect the outcome of LCA study?*

Q4: *What are the impacts of ethanol blends on GHG emissions and NER as compared to gasoline?*

(ii) LCA and Life Cycle Costing (LCC) of second generation ethanol from rice straw in India

Rice straw is identified as the most abundant surplus feedstock which can be utilized for the ethanol production. In India, the technology to produce cellulosic ethanol is in the developmental phase and would soon come up for commercialization This study aims to compare two different pretreatment technology of dilute acid (DA) and steam explosion (SE) for the production of ethanol from rice straw. LCA is used to estimate GWP and energy analysis of second generation ethanol. The main factors that determine the emissions and energy use in the production process are determined. A comparative LCC is conducted for a modified pretreatment method for ethanol production. The questions relevant to this study are:

Q.5 *Is cellulosic ethanol production sustainable in terms of GHG balance, net energy ratio and cost?*

Q.6 *How modified pretreatment method developed by the Centre can affect the environment and economics of ethanol production in India?*

(iii) Identification of the potential rice straw utilization practice in India based on the environmental performance.

Rice straw is the most abundant lignocellulosic biomass available in India. The most common practice to manage straw is to burn it in the field, which adversely affects the environment. Therefore, efficient utilization of rice straw for different purposes and choosing the best practice from LCA perspective would help reduce the burden on the environment. LCA is conducted to compare four different rice straw utilization practices which include incorporation into the field, use as animal fodder, for electricity and biogas production. The question raised in this study is:

***Q.7** What is the most preferable option for utilizing rice straw in India?*

1.7 ORGANIZATION OF THESIS

Proposed chapters for thesis are discussed below and layout of the thesis is shown in Figure 1.5.

Chapter 1: Introduces the research topic and the motivation towards the work. It also emphasizes the importance of LCA in establishing sustainability of biofuels in India.

Chapter 2: Provides a detailed literature survey based on LCA studies conducted in various countries on first and second generation ethanol. The lignocellulosic ethanol is an area of interest for technology development of commercial scale in the future; therefore, the review also includes studies on the economic analysis of lignocellulosic ethanol. The major inferences and gaps found from the literature review are also covered.

Chapter 3: This chapter describes the procedure of conducting an LCA based on International Organization for Standardization (ISO) guidelines and the deeper analysis of the methods followed in research objectives. This includes details of goal and scope definition, system boundaries, functional unit, allocation methods, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation.

Chapter 4: This chapter investigates the LCA of fuel ethanol from sugarcane molasses in northern and western region of India and its impact on Indian biofuel programme. GHG emissions and net energy ratio are the selected impact categories and calculated using without, mass, energy and market price allocation. Sensitivity analysis on sugarcane yield is conducted and its impact on LCA results is analyzed.

Chapter 5: This chapter is on LCA of fuel ethanol from rice straw using two different pretreatment technologies, dilute acid (DA) and steam explosion

(SE). The data is collected based on the experiments conducted at pilot plant established at Indian Oil Corporation Limited (IOCL). GWP, energy analysis, GHG emissions reduction with respect to gasoline are calculated.

Chapter 6: IOCL has developed a new method of pretreatment to lower down the enzyme dosage in the ethanol production process. Therefore, this chapter conducts the LCA of fuel ethanol from rice straw using modified pretreatment (MP). Life Cycle Costing (LCC) of ethanol is also performed for MP and compared with the conventional pretreatment (CP) method.

Chapter 7: This chapter includes the LCA of current rice straw utilization practices in India such as: incorporation into the field and use as fertilizer, use as animal fodder, use for electricity production, use for biogas production and ethanol production. The following impact categories are analyzed: global warming potential, eutrophication potential, acidification potential and photo-chemical oxidation creation potential.

Chapter 8: Provides the conclusions and recommendations.

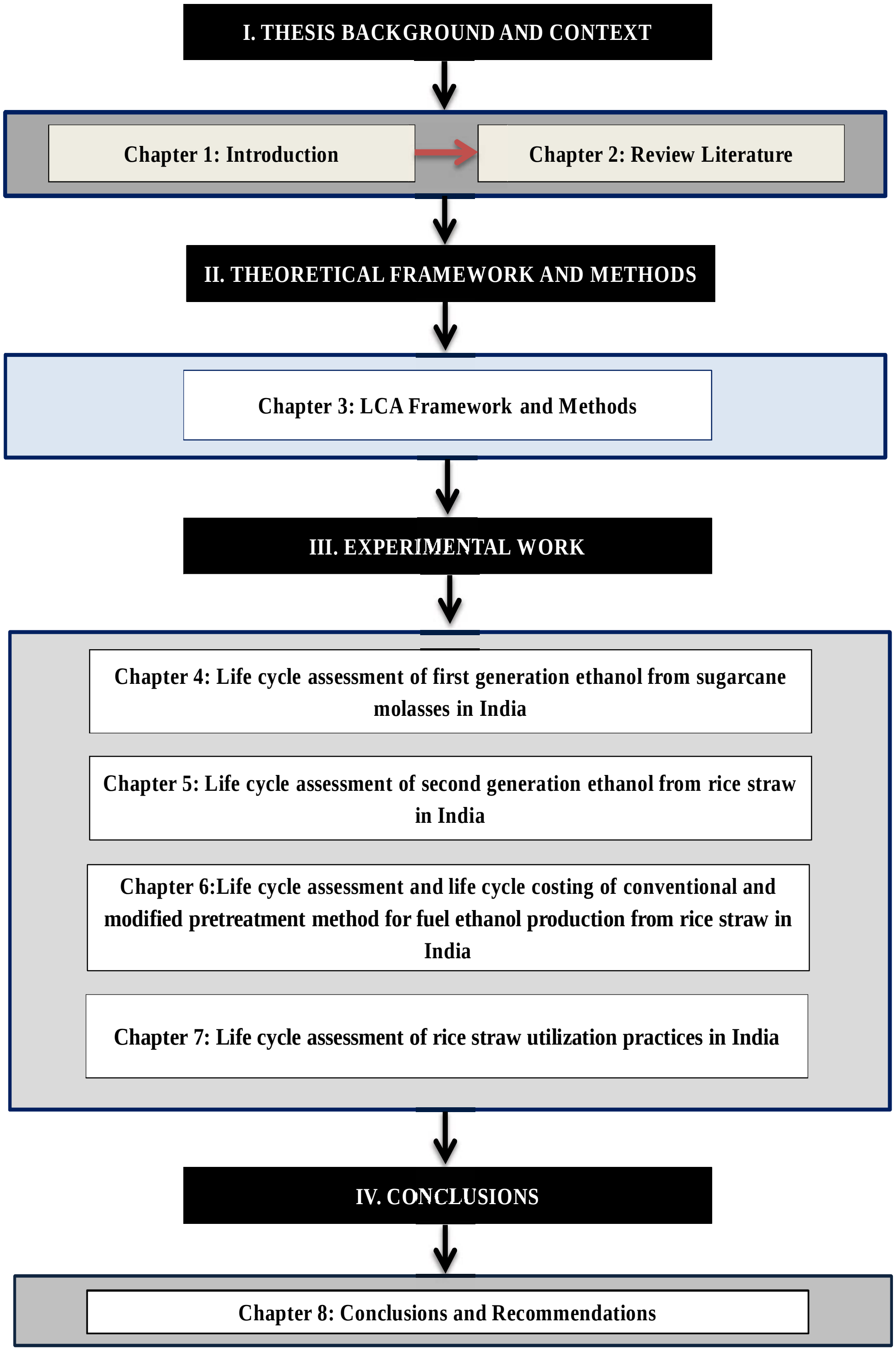

Figure 1.5 Layout of Thesis