CHAPTER 1

INTRODUCTION

1.1. Background & Significance

A nation's industries, homes, vehicles and offices, are all powered by energy, which thus can be said to have driven the economic growth of the world [1]. Strong economic growth continues to increase the energy uses [2]. As a result of economic growth, the energy uses have increased by 60% during the last quarter-century. Not only that, it has also increased the investments in the transportation and energy production infrastructure simultaneously [3]. This clearly shows a direct link between economic growth and energy demand.

Petroleum based fuels currently provide the majority of human energy requirements [4]. A few energy sources include petrochemical sources, natural gases and coal [5]. Figure 1.1 shows the world energy consumption by different end use sectors, while Figure 1.2 shows the world energy uses by energy type.

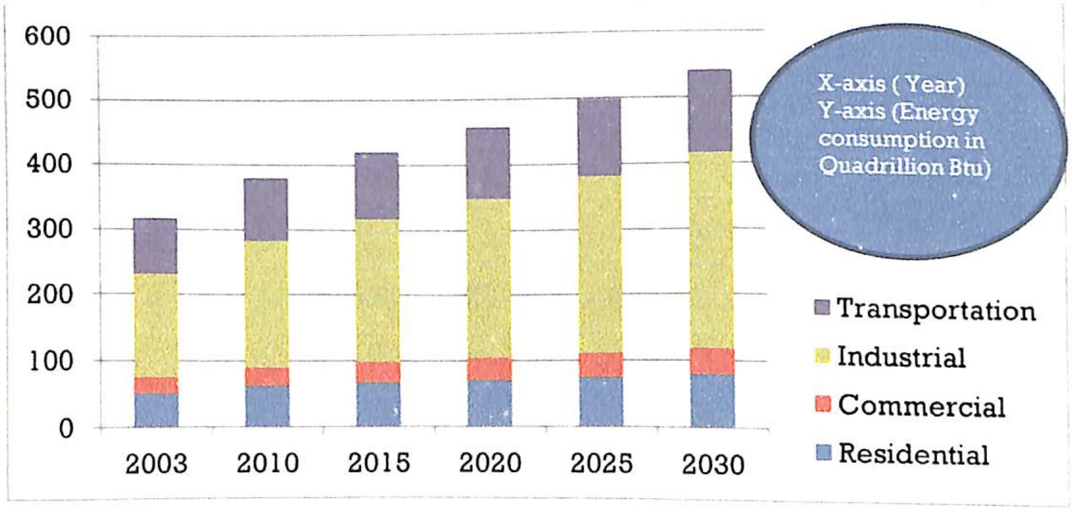

Figure1. 1: World Energy Consumption by End Use Sector- 2003- 2030 [2]

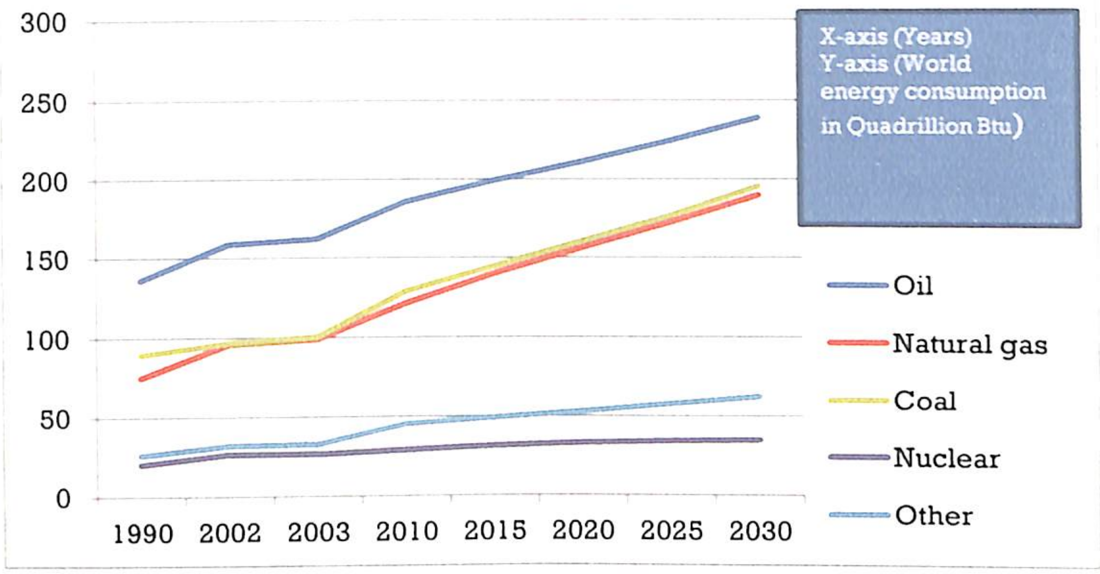

Figure1. 2: World Marketed Energy Use by Energy Type, 1980-2030 [2]

Being limited reserves, petroleum-based fuels exist only in certain regions of the world [4], and are thus approaching depletion [5]. According to the World Energy Forum prediction, reserves of fossil fuels will exhaust in less than another ten decades [6]. Further, according to energy monitor in view of the increasing demand and diminishing supplies, in next 20 years the demand supply gap for oil is expected to increase from the current 70% to well over 80% [7], which is also very well substantiated by Figure 1.3.

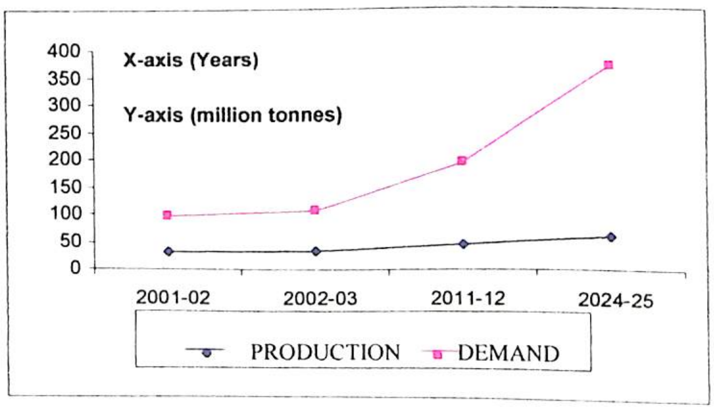

Figure1. 3: Demand Supply Gap for Oil [7]

The depletion rate of energy resources is directly linked to global population and rate of industrial growth [8]. To think of a world without fossil fuels is indeed beyond imagination of mankind, primarily because we are highly dependent on them. But the scenario anticipated is a reality. Formation of fossil fuels takes million of years, and they are also limited in nature, therefore, the only way to prolong their availability is by decreasing their consumption rate [6].

Moreover, like any other commodity, even the crude oil prices fluctuate due to shortage, oversupply, change in demand, and geopolitics, and that influences both OPEC (Organization of Petroleum Exporting Countries) and non-OPEC supplies. Figure 1.4 befittingly demonstrates the effects of the various world events on the crude oil prices.

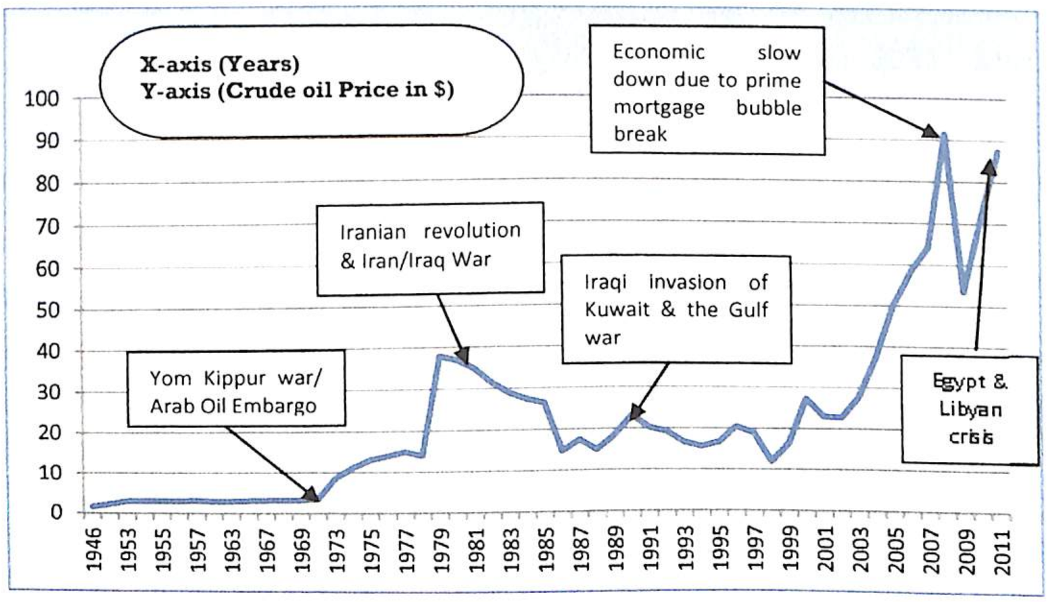

Figure1. 4: World Events and Crude Oil Prices 1946-2011 [9]

Fluctuating fossil fuel prices are of deep economic risk, both to producers as well as to consumers. For example, lack of sufficient supply and signs of economic recovery led to the rise of oil prices in the year 2010. Later at the end of 2010 and start of 2011, unfolding of political turmoil in various regions of Africa and Middle East further raised the oil prices from $82 per barrel in November end 2010 to more than $112 per barrel in April 2011. Fluctuating prices and regional supply disruptions lead to considerable uncertainty to the near-term outlook [10].

Apart from diminishing supplies, price fluctuations and availability, the impact of energy resources on environment is also an important issue, which will play a vital role in the development of the world, and our planet. Their continuous uses have had damaging effect on the environment [5]. Carbon dioxide, one of the most common greenhouse gases, is formed during fossil fuel combustion, and has thus made energy consumption as one of the most debatable climate change topics. According to International Energy Outlook (IEO), 2011 carbon dioxide emissions from energy uses have increased from 30.2 billion metric tons in 2008 to 35.2 billion metric tons in 2020, and the phenomenon is expected to go up to the level of 43.2 billion metric tons by 2035 . Much of the increase in emissions is expected to come from fast developing, non-OECD (Organization for Economic Co-operation and Development) nations, which heavily rely on fossil fuels for their energy needs [10]. Figure 1.5 endorses the sense.

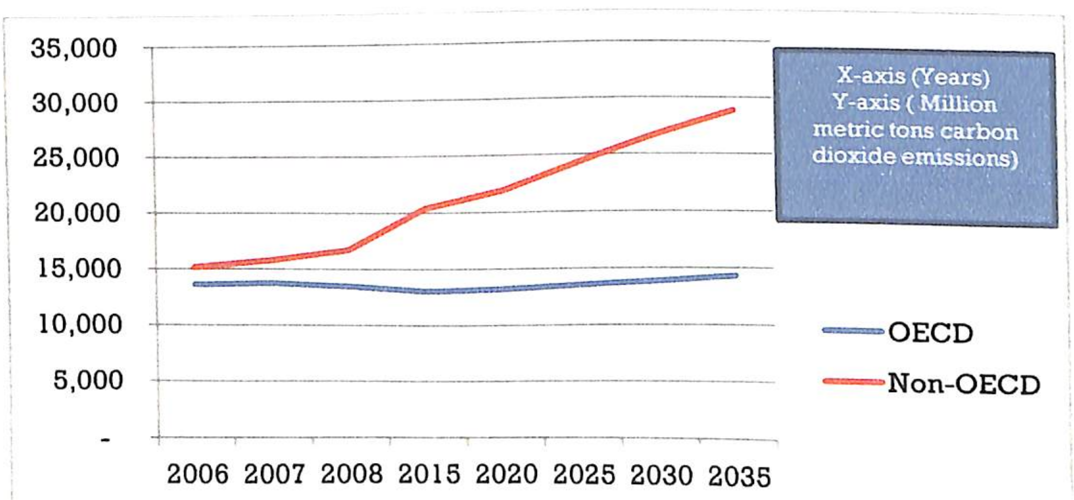

Figure1. 5: World Energy Related Carbon Dioxide Emissions, 2006-2035 [11]

According to "The economist" (Dec. 2009), at the current rate of increase, the carbon dioxide emissions are expected to increase by three times, thereby increase the global temperature almost by 5 °C. This temperature would cause ice to melt faster, resulting in increase in sea level, which in turn will enhance the frequencies of different diseases, droughts, mass migration and agricultural collapse. The only possible way to solve this problem is transit from carbon intensive to low carbon economy [12].

Although fossil fuels are expected to remain the largest source of energy, their increasing prices would force many users to switch from fossil to alternative fuels when feasible [11] . Therefore, in spite of the fact that non-renewable fossil based fuels are dominant in the current scenario, renewable energy resources are believed to have considerable impact on future energy demand outlook [13]. Renewable energy is one of the fastest growing energy sources, with an expected increase from 10% in 2008 to 14% in 2035 [10].

Renewable energy sources (RES) exist naturally in the environment, and can readily be renewed and replenished in a short time span. This makes them inexhaustible. When compared to conventional energy sources, they are cleaner and emit less greenhouse gases [4]. Moreover, being indigenous, they reduce the dependency on oil imports, and thus, increase supply security [5].

RES (like biomass, solar, wind, etc.) that use indigenous resources have the potential to provide energy with negligible emissions of air pollutants and green house gases [14]. Intelligently designed, carefully planned, and well managed renewable energy projects can lead to economic and social development. Considering the foregoing, various research programs on renewable energy from different sources have been developed worldwide. To lessen the fossil fuel uses various nations have successfully tried employing renewable energy sources [15]. Every nation has access to some or the either form of renewable energy [4], biomass, geothermal, hydropower, solar and wind being the major ones [6]. Currently, RES supply 16% of the total world energy demand [14].

1.2. Renewable energy scenario in India: an overview

India has a very large potential for harnessing renewable energy sources [16]. The long history of renewable energy use in India includes, solar, geothermal, ocean, wind, small hydro and biomass [14].

India has abundance of ***solar energy*** [14]. Most parts of India have 250-300 sunny days in a year and receive 4-7 kWh of solar radiation/m^2/day. Western Rajasthan receives the highest annual radiation energy while North-eastern region receives the lowest [17]. Ministry of New and Renewable Energy (MNRE) has recently estimated the potential of solar power to be 50,000 MW, however, the basis of this estimation is not quite clear [18]. Moreover, in India the applications of solar thermal are mostly limited to cooking and water heating. While other technologies like, drying, solar pond and desalination have attracted very limited interest [18].

Among the different renewable energy sources, ***wind energy*** has made a significant contribution to the installed capacity of power generation and is emerging as a competitive option. India, with an installed capacity of about 3000 MW, ranks fifth in the world after Germany, USA, Spain and Denmark [14]. Wind power potential in India, excluding off-shore potential, as estimated by MNRE, is 45,000 MW, while according to Indian wind energy association it is about 65,000 MW. Planning Commission of India has quoted a potential of 65,000 MW, inclusive of offshore potential [18].

Hydropower is the main source of renewable electricity generation in India [14]. The potential of small hydro (up to 25 MW) in India is estimated to be 15,000MW. Reliable estimates of ocean thermal energy conversion, tidal, wave and geothermal energy in India are yet not available. The potential of tidal energy has been preliminarily estimated to be about 8000–9000MW. The power potential of hot springs has been estimated to be about 10,000MW; although no estimate is available yet, the potential of hot dry rock appears to be very high [18].

Geothermal energy is at present contributing about 10,000 MW over the world, and India's small resources can augment the above percentage. 340 hot springs, distributed in seven geothermal provinces, have been observed by the studies conducted by the geological survey of India. The provinces, although found along the west coast in Gujarat and Rajasthan and along a west south west-east-northeast line running from the west coast to the western border of Bangladesh (known as SONATA), are most prolific in a 1500 km stretch of the Himalayas. At present the resource use is very small, and in this regard the Government has an ambitious plan to more than double the current total installed generating capacity by 2012 [17].

In recent years, the interest in using ***biomass*** as an energy source has increased. With capacity of 16,881 MW (agro-residues and plantations), 5000 MW (bagasse cogeneration) and 2700 MW (energy recovery from waste), India is very rich in biomass. Biomass power generation industry in India attracts more than Rs. 600 crores investments every year. It generates more than 5000 million units of electricity and annually employs more than 10 million man-days in the rural areas [17]. Figure 1.6 clearly shows the increasing interest in the growth of renewable energy sources; particularly biomass based liquid biofuels [4].

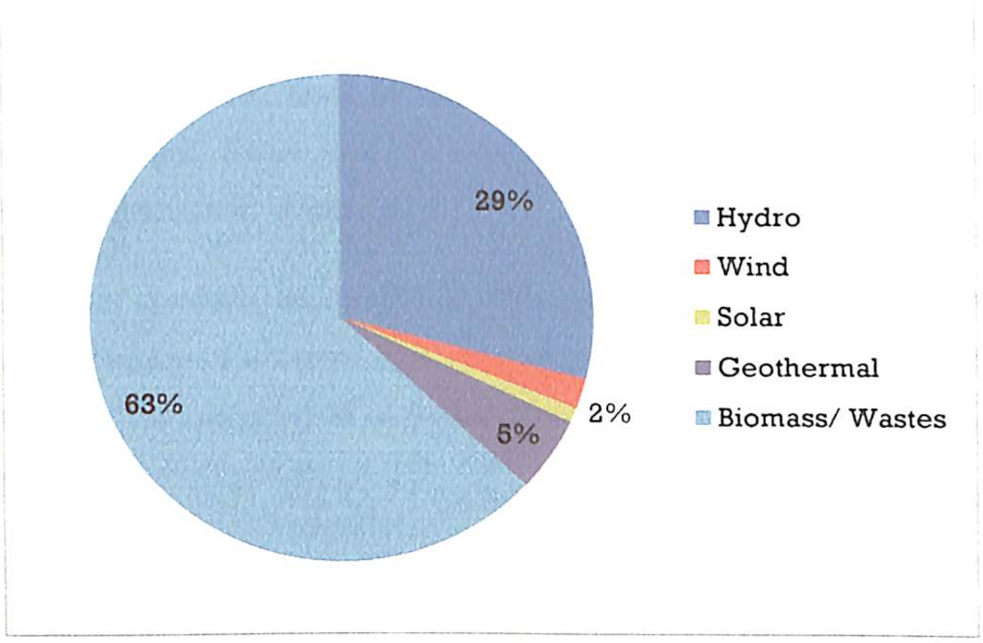

Figure1. 6: The Percentage Share of Each Renewable Energy Source in 1995 [4]

Moreover, awareness of the benefits of renewable energy has been steadily growing and it is expected that the share of renewable energy in the total generation capacity will increase in future [14]. The current study is focused on production of bioenergy called green diesel of biodiesel, which is a biofuel derived from biomass and thus a detailed description of bioenergy, biomass and biofuels is placed in the subsequent section.

1.3. Bioenergy, Biomass and Biofuels

Bioenergy, energy obtained from biomass, has been in use for thousands of years, ever since mankind started using fire. In fact, wood was the world's most common source of energy for cooking, heating and manufacturing, and it is still the largest biomass resource for bioenergy [4].

Photosynthetically derived biological materials, which store sunlight in the form of chemical, are called biomass [4]. They are one of the most important renewable energy sources which can supplement diminishing fossil fuel resources [19].

Bioenergy crops consist of fast growing trees, such as: hybrid poplar, silver maple, willow, black locust, and many other byproducts, such as, agricultural and forest product residues, municipal solid waste from different agricultural processes [4].

Apart from obtaining energy directly from combustion of solid wood fuel, energy can also be obtained by converting biomass into liquid or gaseous fuels [4]. Thus, solid liquid or gaseous fuels derived mainly from biomass are called biofuels [20, 5, 19, 21].

Biofuels have attracted attention from many countries across the world as an alternative to fossil fuels [22]. About 15% of the world's primary energy consumption and about 38% of the developing countries primary energy consumption comes from biomass energy [4]. After Brazil and America, China is world's third largest producer of biofuel [22].

The liquid biofuels, obtained from biomass, can also be used as transportation fuels, which is one of the very important energy consuming sectors. Transportation consumes nearly one third of our nation's energy [4]. Corn, cassava, sorghum, sugarcane, sugar beet, rapeseed, soybean, and castor-oil plants are a few traditional energy plants from which liquid fuel can be obtained. Initially, these plants were grown for food and feed, but now a part of them is used for obtaining fuel for transportation [23].

Bio-ethanol, biodiesel and bio-hydrogen are a few bio-origin fuels, which have emerged as attractive choice for the future transport sector [19]. In the year 1900, Rudolph Diesel for the first time showed the use of biodiesel from different of crops in 1900 [20]. At the Paris Exposition of 1900, peanut oil was used by him to fuel one of his engines [24].

Renewable energy sources, like, biomass are very important for development and sustenance of civilization [25]. There are many benefits of biofuels. They are biodegradable, renewable, environmentally friendly and sustainable [19, 26]. Hence, these can be considered as promising supplements for diminishing and high pollutant fossil fuels derived from conventional sources [4, 26].

Based on their production technology, biofuels can be classified into: first, second, third and fourth generation biofuels. First generation biofuels (FGBs) refer to biofuels made from food crops, such as sugarcane, corn, wheat grains, sunflower oil, other edible vegetable oils and animal fats using conventional technology [21].

The most important concern of first generation biofuels is their inefficiency and sustainability. These concerns can be avoided by using second generation biofuels [21], as they are obtained from non-food feedstock [20]. Concerns like food security, energy security and environmental degradation can be addressed by using second generation biofuels [20], which are made from agricultural and forest residues, non-food crops and purpose grown energy crops using advanced technology [21].

Third generation biofuels include biofuels from algae. On the other hand, a fourth generation, which is almost at the verge of taking shape, is based on the conversion of vegetable oil and bio-diesel into bio-gasoline, using most advanced technology [21]. Table 1.1 summarizes the various generations of biofuels based on their production technologies.

Environmental concerns like global warming and air quality have recently led to increased interest in renewable energies. In order to make them cost competitive with fossil fuels and further increase their efficiency and reliability, the developed countries are using modern and efficient bioenergy conversion technologies [4].

Table1. 1: Various Generations of Biofuels, Classified on the Basis of Their Production Technologies [21]

First Generation Biofuels	Second Generation Biofuels	Third Generation Biofuels	Fourth Generation Biofuels
➢ Made from conventional technologies. ➢ Include food crops. Eg. Sugarcane, wheat grains, sunflower oil, other edible vegetable oils ➢ Also include animal fats.	➢ Made from advanced technologies ➢ Include agricultural and forest residues and non-food crops. ➢ Also include purpose grown energy crops.	➢ Made from advanced technologies ➢ Include algae	➢ Made from most advanced technologies ➢ Include bio-gasoline from conversion of vegetable oil and biodiesel.

At present, the two most important liquid biofuels, being produced on industrial scale, are bio-ethanol and biodiesel. Bio-ethanol is produced from agricultural crops, such as: sugar beet, maize (corn), sugarcane, sorghum and wheat, while biodiesel is produced from oil bearing seeds. Both can be used to run internal combustion engines in place of petroleum fuels [20, 27]. Bio-ethanol is used in combination with gasoline, while biodiesel is used with diesel to fuel diesel engines.

Among various alternatives, biodiesel has been recognized as the most suitable fuel for diesel engines applications [28]. Biodiesel is a mixture of mono-alkyl esters derived from vegetable oils obtained from palm, corn, soyabean, jatropha, canola, rapeseed, sunflower, peanut, and cottonseed. Apart from vegetable oils, the other sources of biodiesel include animal fat (beef tallow, lard), waste cooking oil, greases (trap grease, float grease) and algae [29].

Demand, essential policy support and technological availability are helping in fast expansion of bio-diesel [25]. In order to protect environment, establish energy security and sustainable growth, many countries across the world have passed legislations which require diesel to contain a minimum percentage of biofuels. Czech Republic has made an excellent record, by insisting on 100% biofuel use for transportation [28]. In 1991, the European Community (EC), proposed a 90% tax reduction for the use of biofuels, including biodiesel [28].

The world's two energy crises in the years 1973 and 1978, rapid depletion of fossil fuel reserves, increasing crude oil prices due to global political unrest, and increasing apprehensions on global environmental protection norms, etc., revived the importance of vegetable oil or biodiesel use in diesel engines. Since then, serious efforts have been made to replace diesel fuel by alternative fuels [28]. The environmental and economic concerns (Kyoto Protocol) have also encouraged resurgence in the use of biodiesel all over the world. Global bio-diesel production is expected to grow at slightly higher rate than bio-ethanol and reach 24 billion liters by 2017 [25]. Figure 1.7 shows the world biodiesel production trend.

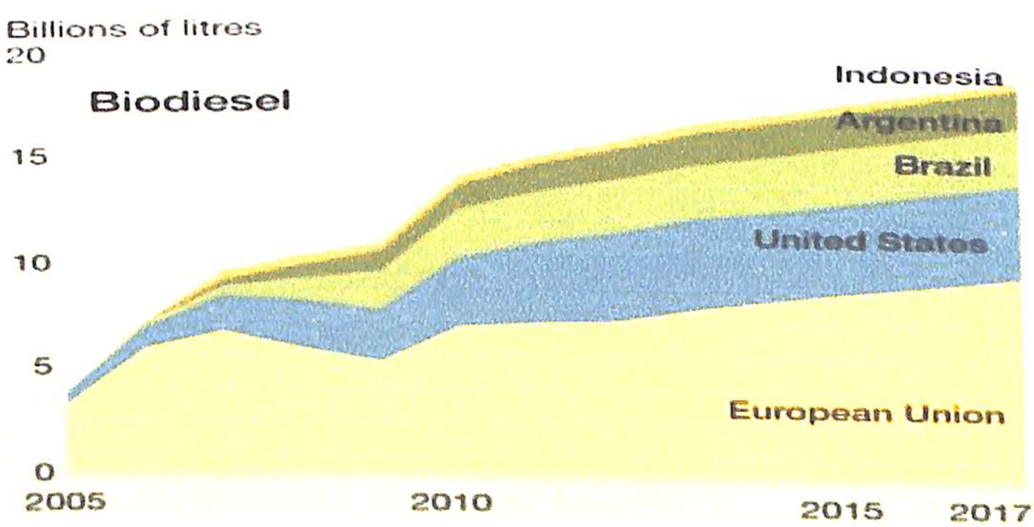

Figure1. 7: World biodiesel production trend [30]

Bio-diesel production from vegetable oils during 2004–2005 was estimated to be 2.36 million tons globally. Of this, EU countries (1.93 million tons) with expectation of 30% annual increase and the USA (0.14 million tons) together accounted for 88% and rest of the world (0.29 million tons) for the remaining 12% [25] .

1.4.Rationale and motivation for promoting Renewable energy especially Green diesel/biodiesel in India

At present rapid economic development, energy and environment are topics of high concern [31]. When it comes to concern over these issues, India is not secondary to any other nation. As energy is the backbone of every country's economic development and prosperity, so it is for India. Therefore, the above context applies for sustainable energy development in India too.

With the total primary energy demand of 621 Million tons of oil equivalent, India is currently the world's fourth-largest energy consumer. It is projected to become the second largest contributor to the increase in global energy demand by 2035, accounting for 18% of the rise. By 2035, India's energy consumption is predicted to be more than double, growing on average by about 3 percent per year, a growth rate considerably higher than in any other country. India is expected to show the most rapid per-capita energy consumption increase [3].

With high rate of economic growth, and 15% of the world's population, it imports 68% of its oil uses and is expected to become the fourth largest net importer of oil in the world by 2025, following the United States, China, and Japan [32]. India's yearly oil import bill, currently about US$17–18 billion (India, 2004), is projected to increase manifold until 2030 [33]. Even the recent oil and gas discoveries in India have failed to keep pace with the energy demand [32].

Moreover, India is the fifth largest CO_2 emitter, 982 million tons (2002) with 68.3% increase in emission since 1990 [34]. India's CO_2 emissions have been increasing by 2.7 percent per year, since 1990 and are expected to show the same trend till about from 2035 [10].

Therefore, local production of renewable energy can be a viable option for promoting sustainable development, and thus, mitigating environmental concerns in India too. Alternative fuel should be technically feasible, economically competitive, environmentally acceptable, and easily available. One such fuel that exhibits great potential is biofuel [35].

As mentioned earlier, there are many different types of biofuels, produced from biomass, such as biodiesel, bio-ethanol, vegetable oils, bio-oil, bio-syngas, and bio-hydrogen [36]. However, India consumes five times more diesel than gasoline fuel [37]. Share of petro-diesel is almost 40% of total petroleum products consumed [26]. Biodiesel being the best candidate for diesel fuels [38], is thus attracting increasing attention as a blending component or a direct replacement for diesel fuel in vehicle engines [38, 31].

1.5.Rationale for choosing Jatropha and Algae for current study

Selection of suitable feedstock is an important dynamic in the biofuels industry. Choice of raw material depends mainly on its availability and cost. Developed nations like USA and other European nations use edible oil, like, soybean, rapeseed, groundnut and sunflower etc. for production of green diesel. But Countries like India have dearth of huge quantity of edible oil. Moreover, they also have a huge competition with the other food plants and the fertile land use to grow them.

After experimental studies *Jatropha curcas* was thought to be promising biodiesel crop by Planning Commission of India. It was considered to be one of the most promising oil plant due to its hardiness, easy propagation, drought endurance, high oil content, low seed cost, short gestation period, rapid growth, adoption to wide agro-climatic condition, bushy/shrubby nature and multiple uses of different plant parts. This crop seemed to overcome all the above mentioned problems caused due to the crops producing edible oil. But the initial failures of Jatropha projects broke many myths related to it. However, recent research and studies on Jatropha show that, due to lack of understanding and awareness about the crop, its full potential could not be realized. When detailed literature review was done, it was found that though there are viability studies (which have used Net energy balance and Net energy ratio as viability indicators) already done on Jatropha, they have not taken care of the recent findings about it. Thus, the current study aimed to find out the impact of the recent findings on the viability of Jatropha as an energy crop.

Moreover, in the recent years, "Algae for fuel" concept has gained renewed interest for production of green diesel. The characteristics that drive interest for its utilization are high biomass and oil yield, short growth period and high utilization of carbon dioxide. Though, there are viability studies already done on algae but many have not included the entire value chain, and the others have considered only a few of many available ways and techniques of biofuel production from microalgae.

A detailed literature review with proper citation has been done in Chapter-2, which on the basis of the above rationale, has tried to show the gap between the current viability studies and the required viability studies for production of green diesel from Jatropha and algae.

1.6.Business Problem

In order to establish energy security, and overcome environmental problems, government of India has launched a biofuel policy, which talks of 20% blending with fossil diesel. This has also opened up a scope for entrepreneurs to invest into biofuels, and thus, will also generate more employment opportunities. However, selection of suitable feedstock for green diesel production is one of the most challenging issues for biofuel industry. The two most talked about energy crops in India as of now are Jatropha and algae but both of them have their own pros and cons. The business problem hence can be stated as which of the two i.e. Jatropha and algae is the more suitable energy crop for green diesel production, in which the entrepreneurs can invest into.

1.7. Significance of the study

Depleting fossil fuels and increasing environmental concerns have led to the development of renewable energy sources. Transportation fuel is one of the very important energy consuming sectors, which nearly consumes one third of India's energy. India consumes five times more diesel than gasoline fuel. Among the various renewable sources liquid biofuels, especially green diesel i.e. biodiesel produced from biomass is being recognized as the most suitable fuel for diesel engines applications. Accordingly, production of more indigenous green diesel would help in reducing the huge oil import bills of India, especially diesel import bills.

As discussed in Section 1.5, it is very important to select a suitable energy crop for green diesel production. As of now, in Indian context, the two most talked about energy crops are Jatropha and algae. This study will help to find out the most suitable energy crop between the two, and help to develop new entrepreneurs and provide new job possibilities for the Indian talents.

1.8. Organization of the Report

The thesis consists of seven chapters. The first chapter, ***Introduction***, talks about the importance of energy in India and worldwide. It establishes the need for the study of renewable energy sources with special focus on green diesel or biodiesel. It also elucidates the importance of Jatropha and algae for production of green diesel.

The second chapter, ***Literature Review and Research Methodology***, discusses about the methodological approach adopted for comparing Jatropha and Microalgae as an energy crop. It focuses on the gap between the current viability studies and the required viability studies for production of green diesel from Jatropha and algae. It is followed by the research problem, objectives of the study, research questions, scope of the study and a detailed research methodology to meet the set objectives.

The third chapter, ***Value Chain of Jatropha***, outlines the various stages in the value chain of *Jatropha curcas* for biofuel production. It also provides a comprehensive understanding of each and every stage along with all possible methodologies and technologies developed till date for the production of green diesel. Once the value chain is in place, this chapter would build up the base for the further life cycle study for the calculation of net energy balance and net energy ratio for Jatropha green diesel production system. Each and every stage of the value the chain has influence on the LCA result.

The fourth chapter, ***Value Chain of Algae***, outlines the various stages in the value chain of algae for biofuel production. It also provides a comprehensive understanding of each and every stage along with all possible methodologies and technologies developed till date for the production of green diesel. Once the value chain is in place, this chapter would build up the base for the further life cycle study for the calculation of net energy balance and net energy ratio for algae green diesel production system. Each and every stage of the value the chain has influence on the Life Cycle Assessment (LCA) result.

The fifth chapter, ***Life Cycle Assessment of Jatropha Green Diesel Production System***, discusses in detail the various challenges of Jatropha cultivation and Jatropha green diesel production system. It talks about the various reasons for failure of Jatropha projects for biofuel production in India and suggests measures to overcome them, from the learning over the years. Keeping the measures in mind, life cycle energy balance for Jatropha green diesel production and green house gas emissions from post-energy use and end combustion of biodiesel has been examined. It also talks about the cost economics of the ibid system.

The sixth chapter, ***Life Cycle Assessment of Algae Green Diesel Production System***, based on the value chain and various agronomical practices and the techniques of green diesel production as reviewed in chapter 3, will aim to find out if the net energy balance can further be increased by using a combination of many available agronomical practices and the techniques of green diesel production from microalgae. It also talks about the cost economics of the best route.

The seventh chapter, ***Comparative Study of Jatropha and Microalgae Based Green diesel Production System***, provides a detailed comparative analysis of green diesel production from Jatropha and microalgae on the basis of four parameters agronomical practices and challenges, technical suitability, environmental acceptability and economic competitiveness. While doing so, this chapter also compiles the entire thesis and its results.

1.9.Concluding Remarks

Depleting energy resources, growing energy demand and escalating prices of oil and petrol has led to an increased interest in renewable energy sources. When it comes to concern over these issues, India is not secondary to any other nation. That notwithstanding, the recent oil and gas discoveries in India have failed to keep pace with the energy demand. Renewable energy sources (like biomass, solar, wind, etc.) that use indigenous resources have the potential to provide energy with negligible emissions of air pollutants and green house gases. Biofuels have attracted attention from many countries across the world as an alternative to fossil fuels. Considering that India consumes five times more diesel than gasoline fuel, it is of paramount importance that biofuels, particularly biodiesel, should get more attention in India. Moreover, biodiesel has been recognized as the most suitable fuel for diesel engines applications.

After experimental studies, *Jatropha curcas* was thought to be a promising biodiesel crop by planning commission of India. Moreover, in the recent years, "algae for fuel" concept has gained renewed interest for production of green diesel, due to their high oil productivity.

However, viability studies done on Jatropha have not taken care of the recent research on it, and that done on algae have either not included the entire value chain or have included only a few of many available technologies for biodiesel production. Therefore, this study aims to do fresh viability studies on both the crops, and also do a detailed comparison of the two, on the basis of four broad parameters, which include agronomical practices and challenges, technical suitability, environmental acceptability and economic competitiveness, and find out the more suitable energy crop between the two, for green diesel production in Indian context.