1.1 Introduction

Energy magnanimously affects human activities in economic and social development. There are many forms of energy. Energy can neither be created nor destroyed; rather, it can only be transformed from one to another form. Energy is classified into two major classes- potential energy and kinetic energy. The potential energy is stored form of energy such as chemical, gravitational, mechanical, nuclear energy, etc., whereas, kinetic energy is the motion energy in form of electricity, radiation, thermal, motion, sound. These forms of energy are used in communication, transportation, food production, mining and construction [Asif and Muneer, 2007]. The sources of energy are classified into two categories; non-renewable (exhaustible) and renewable (non-exhaustible) sources. Non-renewable energy sources cannot be replenished in a short period of time and will be exhausted as a result of unlimited use. The fossil fuels such as coal, petroleum and natural gases are the non-renewable energy sources. Renewable energy sources are restored by nature in relatively short period of time and can be used over and over again. These include solar, geothermal, wind, hydropower and biomass [Demirbas and Demirbas, 2010]. The current energy supply system of world is highly dependent on fossil fuel reservoirs and nearly 85.2% energy needs are satisfied by coal (27.6%), oil (34.2%) and natural gas (24.3%) (Figure 1.1). At current consumption rate of these resources, they will be diminished by the end of 21th century. Intensifying global energy requisition and diminishing resources of fossil fuels have motivated the scientific community to seek alternative energy resources to sustain the future energy supply. The renewable sources are clean and sustainable diversification of these dwindling fossil fuels. The challenges of renewable energy are difficulty in generation of large quantities of power, low efficiency and

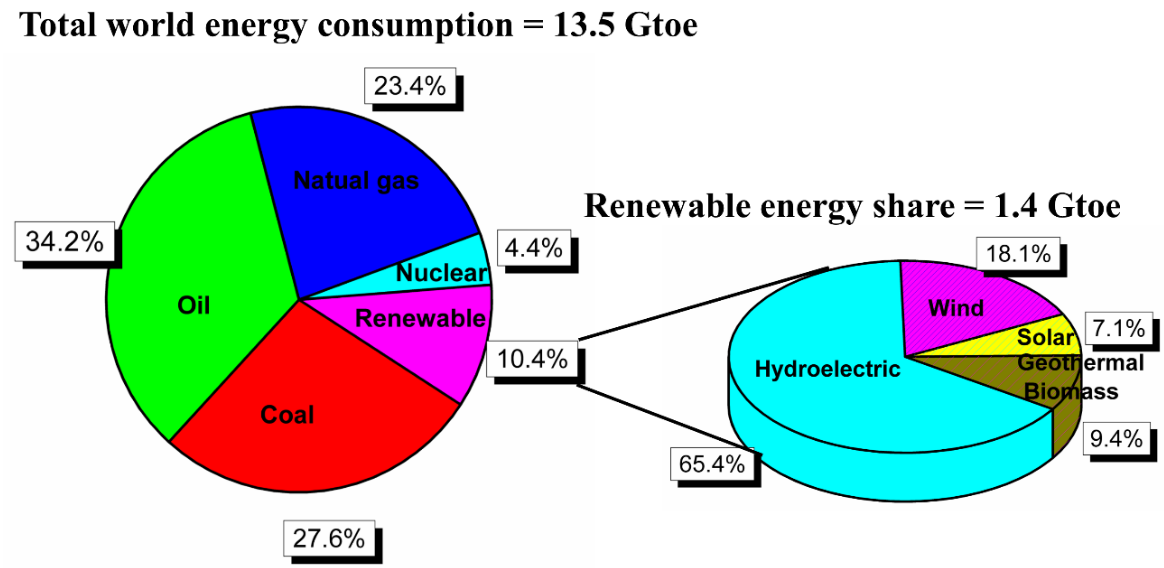

Figure 1.1 Global energy consumption in fraction of year 2017

high installation cost. Renewable energy sources share only 1.4 Gtoe of energy in total energy consumption i.e. 13.5 Gtoe [BP Statistical Review, 2018].

1.2 Energy crisis

Industrialization and population growth have led to a rise in global demand for energy in recent years. The report of IEA-2017 states that world energy consumption will inexorably expand from 575 quadrillion British thermal units (Btu) in 2015 to 663 quadrillion Btu by 2030 and then to 736 quadrillion Btu by the end of 2040. The energy consumption increment will be high for non-OCED (Countries outside the Organization for Economic Co-operation and Development) countries i.e. 41% during the period of 2015- 2040, whereas 9% increment will be observed for OECD (Organization for Economic Co-operation and Development) countries. Energy demand in non-OECD Asia region that includes China and India is projected to increase by 51% (102 quadrillion Btu) between 2015 and 2040

[International Energy Outlook, 2017]. The reason for such energy consumption trends in developing countries is the result of easy accessibility of energy market, strong economic growth and escalating population.

After industrial sector, the transportation sector is the second largest energy consumer accounting for 30% of the total energy consumption. The steady growth in transportation sector because of increasing numbers of vehicles in the past 30 years has raised the demand of global transport energy. In the years 2005 to 2035, energy consumption in transportation sector is expected to grow at a rate of 1.8% per annum while transportation sector is almost dependent (97.6%) on liquid fossil fuels with small amount from natural gas. Moreover, the liquid fuel consumption is projected to rise from 95 million barrels per day (bpd) to 113 million bpd in between 2015 and 2040. The maximum, 1.3% per annum increment in liquid fuel consumption is announced for Non-OECD countries with a slight decrease in the OECD by use of crude and lease condensate production. The use of liquid fuels for transportation in China and India will increase by 36% and 142% from 2015 to 2040. The World Energy Forum has predicted that liquid fuel reserves will be diminished in less than another 10 decades [International Energy Outlook, 2017].

1.3 Environmental pollution

Globally, the majority of air pollution is generated by the combustion of fossil fuel (coal, diesel fuel, gasoline, oil, and natural gas) for electricity production, heating, transportation, and industry [EPA, 2018]. Fossil fuel combustion emits primary air pollutants in form of carbon monoxide (CO), nitrogen oxide (NOx), sulfur dioxide (SO_2), particulate matter (PM10 and PM2.5) as well as volatile organic compounds (VOCs) which are responsible for greenhouse effect, global warming, and acid rain [Demirbas, 2009]. Transportation sector emitted 28.9% of total global greenhouse gas in 2010, as it is almost totally dependent on fossil fuel. Atmospheric CO_2 concentration is increasing with the escalated use of fossil energy and reached to 406.55 ppm in 2017 from 383.79 ppm in 2007. It is expected that about 4.1 billion metric tons of carbon dioxide will be released to the atmosphere from 2007 to 2020. Moreover, it is estimated that another additional 8.6 billion metric tons carbon dioxide will be released to the atmosphere from 2020 to 2035. This is estimated to be about 43% increase for the aforementioned projected period [Friedlingstein et al., 2014]. As per report of Global Carbon Budget, worldwide, 9.9 billion metric tons of carbon dioxide was released in air during 2016 and is projected to increase by 2.7% by 2017 [Global Carbon Budget, 2018]. India is the fourth largest emitter of CO_2 and emits 1.8 tons of CO_2 per capita. India's CO_2 emissions grew by an estimated 4.6% in 2017 [CarbonBrief, 2017].

1.4 Uneven distribution

Nonrenewable energy sources are unevenly distributed over the globe and are typically found in specific parts of the world making them more plentiful than the other nations. More than half of the reserves of petroleum are found in Middle East and North Africa, and close to 40% of natural gas is found in Russia and the former Soviet Union states [Asif and Muneer, 2007]. The situation is somewhat different for petroleum of which North and Latin America potentially possess significantly higher global shares. The OPEC countries have 73% of total fossil fuel reserves (Figure 1.2). The total volume of proved oil reserves are 1696.6 thousand million barrels globally in which 47.6% oil reserves are located in Middle East. Natural gas in turn is distributed quite evenly throughout the world, with North America holding most (roughly 25% of global resources). Uneven distribution of fossil fuel reservoir over world

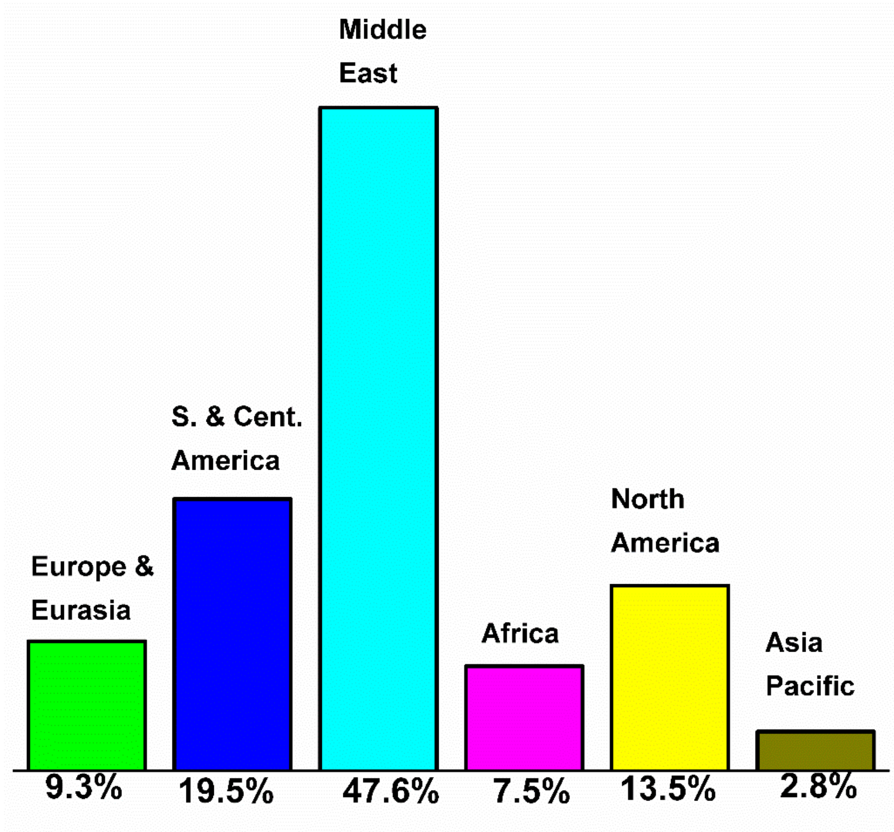

Figure 1.2 Distribution of proved oil reserves in 2017

causing socio-economic disturbance, dominance and price instability internationally [BP Statistical Review, 2018; Shafiee and Topal, 2009].

The shrinking reserves, rising demand and the resultant rise in prices of petroleum, coupled with the concerns for global climate change and energy security are forcing the world to look for its long-term alternatives. Renewable resources are more evenly distributed than fossil resources and also help in diversifying fuel supply sources, reducing greenhouse gas emissions as well boosting the decarburization of transport fuels [Bilen et al., 2008].

1.5 Renewable energy technology

Renewable energy is clean energy source generated from natural sources or processes that are constantly replenished. Renewable energy technologies are used in power generation, heating and cooling, and transport sector. These sources have potential to boost national energy security and economic growth, creating jobs, developing new industries, reducing emissions and local pollution, and providing affordable and reliable energy for all citizens. The main forms of renewable energy are wind, solar, hydro, geothermal and biomass [Bull, 2001]. Most renewable energy comes either directly or indirectly from the sun [Bilgen et al., 2008]. Biomass is renewable contributor to global final energy demand, providing nearly 13% of the total [International Energy Agency, 2018]. The traditional use of biomass in developing countries (for cooking and heating) accounts for almost 8% of this, and modern use for the other 5%. Modern bioenergy provides about 4% of heat demand in buildings and 6% in industry, as well as some 2% of global electricity generation and 3% of transport needs. Unlike other renewable energy sources, biomass can be converted directly into liquid fuels, called "biofuels" to meet transportation fuel needs [Goldemberg, 2006]. Biofuels are energy carriers that store the energy derived from biomass. Biofuels can be classified according to source and the type. They may be derived from forest, agricultural or fishery products or municipal wastes, as well as from agroindustry, food industry and food service by-products and wastes. They may be solid, such as fuel wood, charcoal and wood pellets; liquid, such as bioethanol, biodiesel and pyrolysis oils; or gaseous, such as biogas [Global Bioenergy Statistics, 2017]. Advantages of bio-fuels are the following:

- Bio-fuels are easily available from common biomass sources.

- They represent a CO_2 cycle in combustion.
- Bio-fuels have a considerable environmentally friendly potential.
- There are many benefits to the environment, economy and consumers in using bio-fuels.
- They are biodegradable and contribute to sustainability.

Fatty acid alkyl esters, commonly referred as "biodiesel," are technically competitive with or offer technical advantages compared to conventional petroleum diesel fuel. Biodiesel is oxygenated, non-toxic, and inexhaustible fuel and is viewed as implementable alternative fuel for automobile engines and has been approved as global fuel [Sharma and Singh, 2009]. Biodiesel is derived from lipid feedstocks such as edible/non-edible vegetable oils, animal fats, waste oil and microalgae oil via methyl-transesterification reaction in presence of acid/base catalyst [Janaun and Ellis, 2010]. It differs in oxygenated ester moiety with diesel fuel which ameliorate its physical and chemical characteristics as follows;

- Substitute to petroleum diesel fuel and can be applied in blended or alone in diesel engines.
- Oxygenated fuel: complete combustion increase the energy output.
- Better lubricant: increase the usable life of fuel injection equipments of engine.
- Carbon neutral: released carbon dioxide will be consumed by plants for feedstocks production.
- High flash point and high fire point: provides handling safety at high temperature.
- Comparable calorific value: ~90% of diesel fuel
- High cetane number: lowers ignition delay.

- Biodegradable: made out of organic substances, which are biodegradable.
- Reduce imported oil dependence
- Grown, produced and distributed locally: produced from domestic energy crops.

Biodiesel is the only alternative fuel to successfully complete the EPA's rigorous emissions and health effects study under the Clean Air Act. Biodiesel provides significantly reduced emissions of carbon monoxide (-48%), particulate matter (-47%), unburnt hydrocarbons (-67%), polycyclic aromatic hydrocarbons (-80%) and sulfates (-80%) compared to petroleum diesel fuel [Sharma et al., 2011]. Additionally, biodiesel reduces emissions of carcinogenic compounds by as much as 85% compared with petrodiesel. When blended with petroleum diesel fuel, these emissions reductions are generally directly proportional to the amount of biodiesel in the blend.

From the literature, it has been found that feedstock alone represents 75% of the overall biodiesel production cost [Demirbas, 2009]. At commercial scale successful implementation of biodiesel, the feedstocks should fulfill three main requirements: non-food materials, low production costs and availability in large amount. The availability of feedstock for producing biodiesel depends on the regional climate, geographical locations, local soil conditions and agricultural practices of any country [Sharma et al., 2008]. Biodiesel has a massive potentiality to be a part of a sustainable energy mix in the future. Biodiesel has been in use in many countries such as United States of America, Malaysia, Indonesia, Brazil, Germany, France, Italy and other European countries.

1.6 Biofuel policies

Biofuels have emerged as renewable and eco-friendly energy sources which could help in enhancing the self-sufficiency in energy and boost the decarburization of transportation fuels, have motivated the production and use of biofuels at both legislation and formal directives. Governmental policies have played a pivotal role for biofuels and will likely continue for the foreseeable future by encouraging and impeding sustainable approaches, reducing barriers, and highlighting information or funding needs [Rosch and Skarka et al., 2009]. Towards this endeavor, the Governments in Brazil, China, EU, India, Indonesia, Canada, Malaysia, Thailand, USA and other developing countries have initiated several programs to augment the policies supporting and subsidizing production and consumption of biofuels during the past decades or so [Araujo et al., 2017]. Brazil and U.S. have the most developed and integrated biofuels program in the world initiated in oil crisis of 1970s. These have pioneered the development of an economically competitive national biofuel sector based largely on sugar cane and maize respectively [Sorda et al., 2010].

1.6.1 Biofuel policy of India

India is third largest consumer of crude and petroleum products consuming 4.1 million bpd, after U.S. (19.39 million bpd) and China (11.96 million bpd). The growing population and rapid socio-economic development have triggered an increase in energy consumption of India across all the major sectors of the Indian economy. It is also expected that the demand of petroleum diesel would hike at the rate of 6–7% over the next couple of decades with expanding vehicle ownership. However, due to limited availability of domestic energy resources and escalating crude oil prices, India has to rely on its imports that result in huge outflow of its foreign exchange [Saravanan et al., 2018; Ravindranath et al., 2011]. Therefore, in order to meet such energy crisis and to ensure country's energy security, it has become necessary to focus on some alternatives of transportation fossil fuel based on indigenously produced renewable feedstock. In order to promote the production of biodiesel, Indian government had launched National Biofuel Mission in 2003, as a frontrunner initiatives, with Ethanol Blended Petrol Programme (EBPP) and Biodiesel Blending Programme (BDBP) as its integral components. These programmes initiated time bound targets for blending of 5%, 10% and 20% of biofuels with petrol and diesel in a phased mannered i.e. 5% blending till the end of the year 2006–07 and up to 20% blending at the end of 2011–12, to transform fossil fuel based transport system to a partially biofuel-driven system [National Policy on Biofuels, 2008]. It also mentions the identification and utilization of inedible feedstocks, molasses for bioethanol production and *jatropha* and *pongamina* for biodiesel production at commercial scale as India is not self-sufficient in edible oils. Inedible oil crops can be grown using low inputs on unproductive lands, in degraded forests, cultivators' field boundaries as well in public lands such as along railways, roads and irrigation canals that minimize competition with existing agriculture resources. Thus utility of wastelands for inedible oil crop plantation in lieu of agriculture land is promising solution of reported shortage of grains and other basic food crops in developing countries and malnourishment of nearly 60% of humans in the world. According to studies of Wastelands Atlas of India in 2008-2009, the total wasteland in India is 467,021.16 km^2 which is 14.75 percent of total geographical area.

Table1.1 Biofuel policies of various countries and their mandate

Countries	Important mandate	Energy resources
Brazil	5% biodiesel blending in diesel by 2013	Soybean oil, palm oil, castor oil
	25% bioethanol blending in gasoline since 2003	Sugarcan
China	2 million tons of biodiesel by 2020	Waste oil, Jatropha
	10 million tons of bioethanol by 2020	Maize, wheat, sweet sorghum,
EU	10% of all energy in road transport fuels, be produced from renewable sources by 2020	Wheat, sugar, beet, canola, sunflower, soybean
India	5 % biodiesel blending by 2012	Jatropha palm oil(import)
	10% bioethanol by 2008	Molasses, sugarcan
Indonesia	10-15% biodiesel blending in diesel for transportation and industrial use as well as 25% blending for electricity generation by 2015.	Sugarcane, cassava, palm, Jatropha
Canada	5% bioethanol blending in gasoline by 2010	Maize, wheat, straw
	2% biodiesel blending in diesel by 2011	Animal fats, vegetable oil
Malaysia	5% biodiesel in public transportation	Palm oil
Thailand	10% bioethanol by 2018	Molasses, sugarcane, cassava
	10% biodiesel by 2018	Palm oil, waste oil
USA	136 Mio m^2 bioethanol by 2022	Maize
	3.78 Mio m^2 biodiesel by 2012	Soybean and other oleiferous fruits

The state Andhra Pradesh has total 275,068 km^2 and Rajasthan has 342,239 km^2 waste land which is 13.56 and 24.82 percent to total geographical area of state respectively [Findlater and Kandlikar, 2011]. The inedible crops can be cultivated easily in these wastelands without affecting forest area as well regular fertile cultivated area thus reducing fuel vs. food security conflicts [Baka, 2014]. Fiscal incentives including minimum purchase price (MPP) for bioethanol as well as biodiesel, minimum support price (MSP) for *jatropha* seeds, exemption from the central excise tax (4%), subsidized loans for constructing bioethanol production unit in sugar mills were announced by Government of India. The key features of Indian Biofuel policy 2008 are listed as bellow:

- It encourages the utilization of non-edible feedstocks for biofuels to be cultivated on waste and marginal land.
- It reduce the dependency on imports and increase the energy security.
- It stimulate rural development, boost infrastructural investment in rural areas, and generate employment opportunities.

1.7 Global biodiesel production

The concept of alternative and renewable energy was created by Rudolf Diesel [1893] as the inventor of the first diesel engine which was originally designed to run on fuel derived from peanut oil. Unfortunately because of low cost of petroleum at that time, the diesel engine was modified to use it. Firstly, significant large scale push for biodiesel production was announced globally as the response to the 1973 oil export embargo by Arab members of OPEC as well as Clean Air Act 1990 [Demirbas, 2008]. First biodiesel initiatives were reported in 1981 in South-Africa, then in 1982 in Austria, Germany and New Zealand based on canola and sunflower oils. In order to assure high quality of fuel, first fuel standard ON C 1190 for biodiesel was proposed by Austria in 1991. Since 1992, biodiesel has been commercially manufactured across Europe, USA, etc. The year 1996 was a big step in direction of large industrial scale biodiesel plants in France and Germany. In the same year, European Biodiesel Board was established for further growth of a young industry [Pousa et al., 2007; Lin et al., 2011].

Because of reduced dependence on imported fossil fuels and carbon neutral nature of biodiesel, governments around the world become interesting in promoting their production and use. As a result, production of biodiesel grew rapidly [Peters and Thielmann, 2008]. Worldwide, biodiesel production grew from about 1 billion litres in 2001 to 34.08 billion litres in 2016 and 39.30 billion litres is projected in 2027. Presently, numerous biodiesel production based research projects in research institutions, plants, industries are established all over the world to go ahead in biofuel era [UFOP Report, 2017]. Figure 1.3 shows worldwide contribution of various countries in biodiesel production in the year 2016. The European Union is the major producer of biodiesel which accounts for almost 37% of global output and production should reach to 12.9 billion litres by 2027. In United States, the second major biodiesel producer, biodiesel production should increase 6.9 billion litres in 2017 to a record 7.2 billion litres in 2019. Brazil is the third major biodiesel producer and contributes to more than 50% of the global biodiesel production expansion, because of its 10% domestic mandate. By 2027, Other countries such as Indonesia, Argentina, Thailand, Singapore and India are significant players in production of biodiesel which produce 3.1 billion litres, 2.6 billion litres, 1.1 billion litres, 0.9 billion litres and 0.2 billion litres of biodiesel with global output 9.24%, 7.8% 3.4% and 2.9% respectively in 2016 [Global Biofuels Market Outlook Report, 2018].

On the other hand, the biodiesel consumption is mainly depends on its environmental benefits, and availability of financial incentives. The world biodiesel consumption grew sharply from 1.3 billion litres in 2001 to 35.2 billion litres in 2016 for on-road transportation and electricity generation in which 58% was consumed by five countries US (7.94 billion litres), Brazil (3.78 billion litres), France (3.4 billion litres), Indonesia (3 billion litres) and Germany (2.64 billion litres). The European Union consumed 15.8 billion litres of biodiesel in 2018 for on-road transportation in 2018. The biodiesel consumption in Brazil was 4.8 billion litres in 2018 in which 3.5 billion litres was used for on-road transportation with 8.8% of blending mandates. In 2018, biodiesel consumption in Indonesia increased from 2.57 billion litres in 2017 to 3.3 billion litres in which 90% consumption accounts for on-road transportation and 10% for electricity supply.

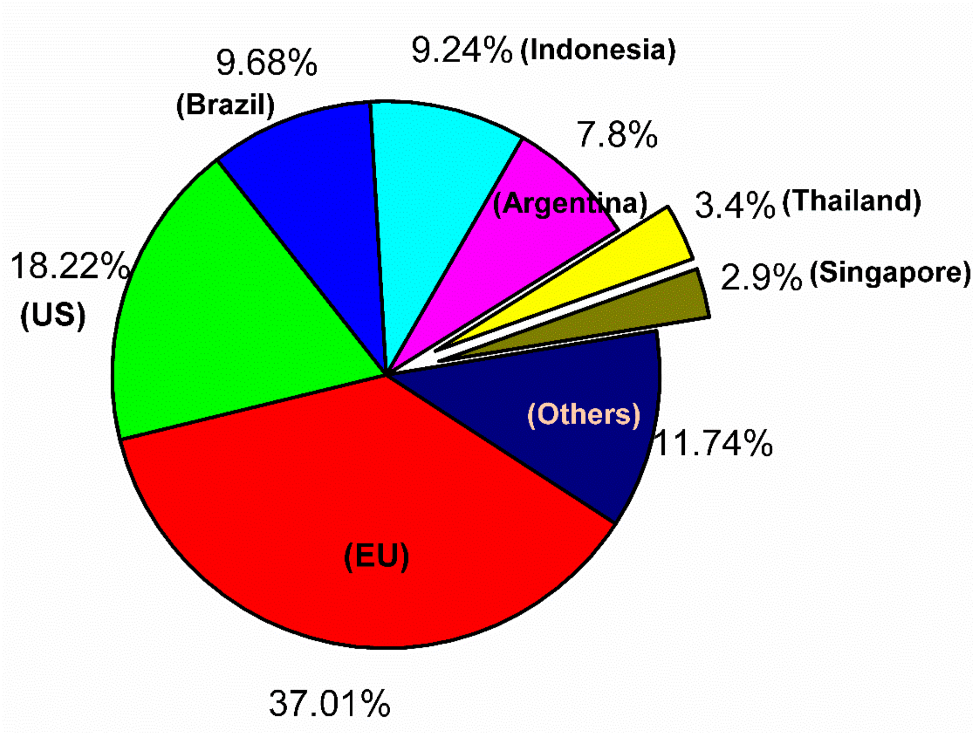

Figure 1.3 Global biodiesel production (2016)

1.7.1 Biodiesel production in India

The promotion of biofuel development appears highly attractive for a developing country like India because of its potential of creating self-sufficiency in energy and employment for the rural areas, offering opportunities for promoting local level entrepreneurships. Unlike other countries, India is using non-edible oils for the production of biodiesel [Barnwal and Sharma, 2005]. It is because, India is not self-sufficient in edible oils production and depends on imports of palm oil and other vegetable oils in large quantities to meet the domestic demand. The 40% of the total edible oils requirement of the country is met through imports [Jain and Sharma, 2010]. However, utilization of non-edible seed oils extracted from trees and forest sources does not interfere with food security directly. The non-edible feedstocks grown on marginal/waste land do not compete with food production [Tripathi et al., 2016]. Every year, around 1.2 million tonnes of tree-borne non-edible seed oils are produced in the country. In India, biodiesel is produced mostly from the non-edible oils extracted from the seeds of plants like *jatropha* and *pongamia*. Moreover, several existing biodiesel plants shifted operations to adopt multiple feedstock technology. For instance, they use used cooking oils, animal fats and imported crude vegetable oils to produce biodiesel. According to the Union Ministry of Petroleum and Natural Gas, the biodiesel production of India has reached to 200 million L in 2017 from 45 million L in 2007 as a result of Biofuel policy [MoP&NG, 2018]. However, the current biodiesel industry in India is still at a nascent stage because of limited availability of oil feedstocks and relatively high production costs. India consumed only 48 million litres of biodiesel for on-road transportation in 2018. Although, the Government has ambitious plans to expand this sector by exploring other possible feedstocks for biodiesel.

1.8 Research motivation

World energy demand up to 85% was contented by fossil fuel reservoirs specifically petrochemical, coal and natural gas as indicated by International Energy Agency (IEA-2018) and expanding day by day. In the year 1971 to 2001, world energy consumption has been doubled and at the end of the year 2030, it will increase through 53%. The price instability of fossil fuel and contribution to environmental deterioration in term of global warming requires the sustainable alternative fuel. According to World Energy Outlook (WEO) report [2018], the energy scenario in Indian prospect, domestic production of crude oil satisfies only 18% of national requirement and nearly 172 million tonnes of crude petroleum imported to meet the demand of energy market. Reports of IEA-2018 indicate that India's primary energy demand will increase from 724 Mtoe in 2016 to 1921 Mtoe in the 2040 year [International Energy Agency, 2018]. World Fact Book report states that other developing countries such as Brazil, South Africa, Malaysia, Thailand, Singapore and Israel import crude oil 178,600; 434,500; 194,400; 830,500; 906,700; and 215,600 barrel/day respectively. Brazil, Thailand, Singapore, Israel and Malaysia spent up to 17%-50% export earnings for oil imports while South Africa devotes 40%-90% of exports earning [World Fact Book, 2018]. For developing countries such as India, it is obligatory to search environmentally benign alternatives, particularly for petroleum products to sustain continued energy supply and foreign exchange savings. As a consequence, energy derived from plant-based biofuel i.e. biodiesel is appraised most propitious alternative as produced locally as well as supporting agricultural and rural development [Atabani et al., 2013]. Biodiesel, a potential substitute to petroleum diesel fuel in terms of viscosity, lubricity, flash point, cetane number and can be applied in existing internal combustion and ignition diesel engine without any modification for low blend of 5-30% with petroleum diesel [Yusuf et al., 2011]. It is a clean burning, high energy returns (~90%), oxygenated (~10%), sulfur free fuel which results into reduction in the exhalation of CO, SO_2, NO and CO_2 respectively [Jacobson et al., 2008].

Chemically, biodiesel is composed of the monoalkyl esters of long chain fatty acids derived from vegetable oils and animal fats feedstock. The current feedstock for commercial production of biodiesel is food based virgin oil such as soybean, rapeseed, corn, sunflower, peanut and palm oil that contribute worldwide instability of food reserves and safety. Also, the higher costs of feedstock than petrochemicals are another major impediment in commercialization of biodiesel [Knothe, 2006]. Farooq et al. [2013] deliberated that the cost of feedstock contributes approximately 70-95% of total biodiesel production cost. Economic production of biodiesel motives the researcher to explore the utilization of of non-edible and waste oil as feedstocks that lessened cost up to 60-70%.

Transesterification reaction is the most acceptable method for biodiesel production in which triglycerides react with short chain C_1/C_2 alcohols in presence of homogeneous or heterogeneous catalysts [Woodford et al., 2012]. The presence of the catalyst is required to lessen the reaction time as well as to enhance product selectivity. Usually, homogeneous acid (sulphuric acid) and base (hydroxides and alkoxides of sodium and potassium) catalysts were used for biodiesel production by means of high catalytic activity, mild reaction conditions and shorter reaction time [Zhang et al., 2003]. However, highly corrosive nature and separation obstacle requires several washing of biodiesel in presence of homogeneous catalyst which results in loss of yield along with increment in energy and cost. Homogeneous acid/base catalyst cannot be recovered after utilizing in reaction because these are completely consumed in the reaction [Vicente et al., 2004; Liu et al., 2016]. Thus, nowadays exploration of large scale production, environmentally safe, more efficient, easy separation and cheaper heterogeneous catalysts is fascinating area for researchers.

1.9 Objectives

The objectives of the proposed thesis are as follow below:

i. To investigate the suitability of non-edible and waste oil feedstocks for biodiesel production at laboratory scale

ii. To synthesize efficient heterogeneous base catalyst barium aluminum oxide and potassium aluminum oxide

iii. To characterize the synthesized catalyst by thermo-gravimetric (TG) - differential thermal (DT) analysis, X-ray diffraction (XRD), attenuated total reflectance Fourier transform infrared spectroscopy (ATR-FTIR), high-resolution scanning electron microscopy (HRSEM), energy dispersive X-ray spectroscopy, Brunauer-Emmett-Teller (BET) surface area analyzer – Barrett-Joyner-Halenda (BJH) pore diameter analyzer and basicity by Hammett indicator titration in details

iv. To analyze the catalytic activity and reusability of synthesized catalyst in transesterification reaction of the selected feedstocks for biodiesel production.

v. To analyze kinetic and thermodynamic parameters including green chemistry matrix calculation for production of biodiesel

vi. To characterize the produced biodiesel by NMR, GCMS and physicochemical properties as per American Society for Testing and Materials