iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 7 **Issue:** X **Month of publication:** October 2019

DOI: http://doi.org/10.22214/ijraset.2019.10017

Biofuels: Present Scenario, Challenges and Future Prospects in India

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Abstract: Biofuels are produced by biological materials like agriculture residues, fruit and vegetables waste, vegetable oils. Biofuels includes bioethanol, biodiesel, biobutanol, biogas and biohydrogen. 1st generation biofuels include the ones which are produced from food crops, 2nd generation biofuels are produced from lignocellulose materials and third generation biofuels are produced from algae. India is the 7th largest producer of biofuels, with the increase in production every year. India is currently working on biofuel policy 2018 to sustain in the field of biofuel and it is aiming to reduce the import of crude oil up to 10% by the year 2022. The sustainable production of biofuel is essential for country's economic growth and to reduce the impact of global warming.
Keywords: biohydrogen; 1st generation biofuel; second generation biofuel; third generation biofuel; fourth generation biofuel.

I. INTRODUCTION

In the current scenario, the natural resources of the crude oil and natural gas are depleting day by day. Along with this, the burning issues like the global warming & climate change are making it mandatory to search for sustainable sources for energy.

Biofuels are the fuels that are produced by the biological process such as fermentation, with the use of natural raw materials such as agriculture waste, vegetable oils and algae.

Biofuels are great alternative for the conventional petroleum fuels and are renewable, non-toxic and easily biodegradable. They put lesser impact on carbon emission and have a very low sulphur content which is indicator of good quality fuel [1].

The best quality of biofuels is that they can be blended with gasoline and can also be used as an individual fuel. This is responsible for the cost reduction and increased performance of the engines [2].

Biofuels are derived from biomass, which are considered as the renewable and biodegradable sources of energy. The biofuels are carbon neutral and their production has lesser impact on the environment as compared to conventional petroleum fuels [1].

The estimated production of biofuel in India was 500-600 million litres in 2017-18. India can fulfil their fuel demands totally by biofuels. India produced large amount of cellulosic material which can be converted into biofuels. In 2016, India achieved highest ever market penetration with a gasoline blend rate of 3.3 per cent across the country [49].

The estimated global production of biofuels in the year 2017-18 was 143 billion litres with an average growth of 2.5 per cent every year. The United State is the largest producer of biofuels followed by Brazil and Germany. The U.S. Accounts for about 43.5 per cent of global biofuel production [46].

Use of biofuels can reduce the dependence of the petroleum products, greenhouse gas emissions and other major pollutants. In other way it can strengthen the economy by utilization of agricultural waste products [3].

The potential raw materials for the biofuels are sugarcane, corn, soybean, sweet sorghum, molasses, and inedible oils like jatropha, cellulosic materials, municipal waste, industrial waste, microalgae and lipid producing microbes [1, 44].

By 2022, Government of India is expected to reduce the import of petroleum products by 10 per cent. This will help to ensure the energy security of the nation by producing biofuel in the country. [56].

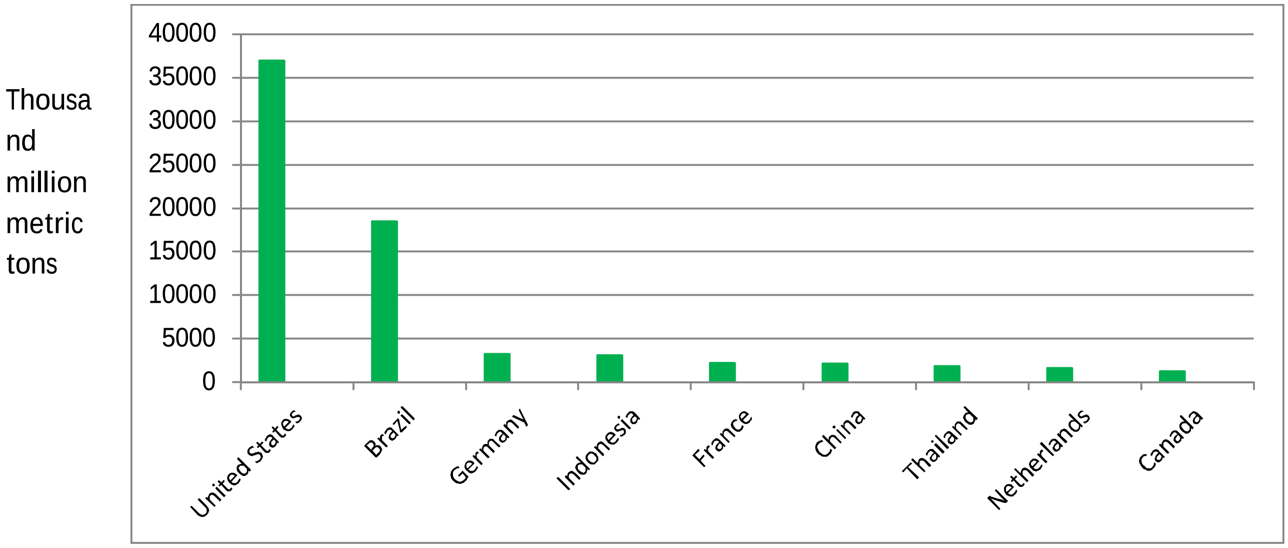
The downstream technology for is still a bottleneck for the production of due its high cost. Poor yield of biofuels is also a major setback in its production which needs more research to achieve maximum yield. The cellulosic materials are feasible choice for the substrate but the higher conversion efficiency within low cost is still a challenge [43].

Biofuels can replace the conventional petroleum fuels. They can help to fulfil the growing requirements of energy and combat the problem of global warming. To overcome the demand and supply of biofuels, the scale up of biofuel production is very important [1].

There are various socio-economic parameters that influence the industrial production of biofuels. Present technologies are not as effective to meet the present need of fuels. The application of genetic engineering can enhance the production of biofuels which can

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.177
Volume 7 Issue X, Oct 2019- Available at www.ijraset.com

fulfil the need of present energy requirements. Some challenges still exists in this technology, apart from that it holds a lot of potential to solve the problem related to production yield [1].



Top 10 Biofuel producing countries, [46]

II. BIOFUELS DERIVED FROM DIFFERENT SOURCES

A. First Generation Biofuels

First generation biofuels are produced from food crops like sugarcane, corn, Soybean and sweet sorghum etc. The first generation biofuels include bioethanol, biobutanol, biodiesel and biogas. They can help the in reduction of the CO_2 emissions. The annual production of first generation biofuels is about 50 billion litres. The producers of the first generation biofuels are developed countries like U.S. and Germany. The main problem with the production of first generation biofuels is their conflict with food security. As they are made from the food crops so there is an argument of using them for fuel production. There is also controversy over the use of farmlands (meant for agriculture purpose) for biofuel crops [4]. Therefore, the developing countries like India cannot rely on the first generation biofuels as they have a huge population to feed on daily basis. Use of food crops for biofuel production will increase the conflict of food vs. fuel. Again, the cost of the crop also remains as a considerable issue.

Table.1 1st Generation Biofuels yields, [44]

Raw Materials	Biofuel yield (Litres ha/a)
Cassava	6000
Corn Grain	3571
Sugarcane	5882
Sugar beet	5000
Sorghum	1235
Soybean	446
Oil palm	5906

B. Second Generation Biofuels

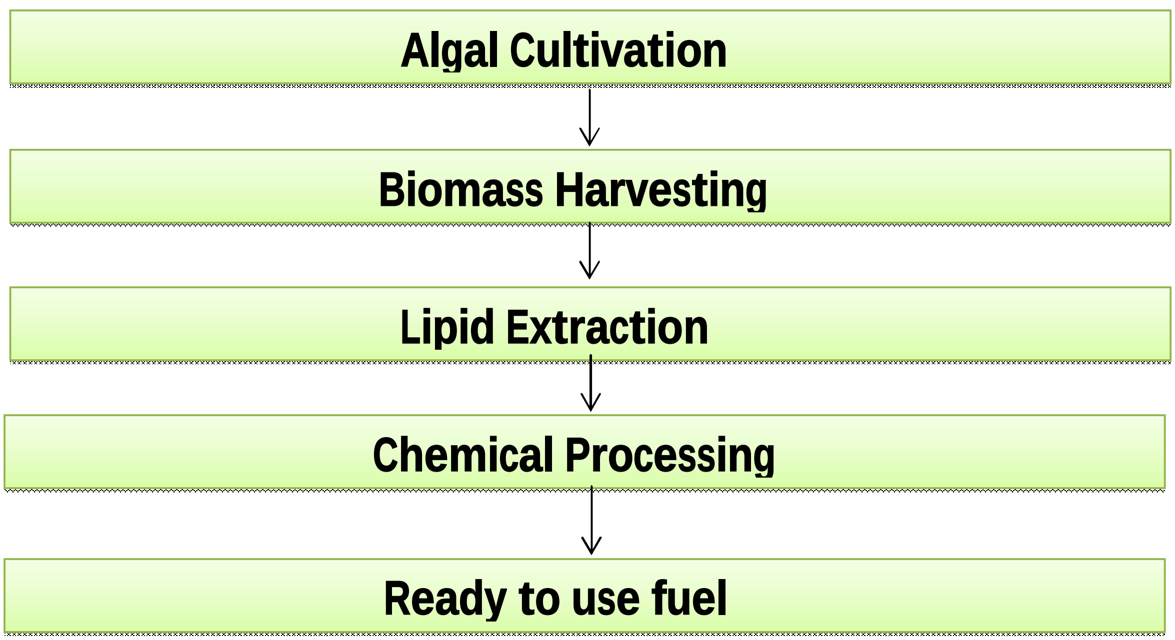
The fuels which are produced from the plant residue are known as second generation biofuels. The key component is lignocellulose, a part of plant cell wall which contains polysaccharide cellulose along with the lignin. As plant biomass is unutilized and easily available so they are the abundant and cost effective alternative for the production of biofuels. Cellulose is considered as the most abundant polysaccharide on earth having no food security issues therefore, use of lignocellulose is a best choice as a substrate for the biofuel production. The fuel that comes under this category is cellulosic ethanol. The best thing about the second generation biofuel is that they can reduce the CO_2 emissions and are abundantly available with no competition with food security [4]. In India, the unutilized agricultural residues are burned every year causing air pollution every year in the Northern parts of the country. The utilization of the plant biomass for the production of biofuels can be a game-changing step.

Table.2 Ethanol yields from Lignocellulose, [45]

Feedstock	Ethanol yield (L/metric tons biomass)
Cane Bagasse	314
Corn Stover	275-300
Wheat Straw	250-300
Soft Wood	420
Municipal Solid Waste	382

C. Third Generation Biofuels

Algae are a part of microbial world which can produce various lipids via photosynthesis in the presence of sunlight, water and carbon dioxide. They grow very fast as compared to plants and they do not require land for their cultivation. The yield of microalgae is 58700 litres per hectare [6]. They also grow in waste water because they do not need specific conditions for ontogenesis. This quality of algae makes them a potential source for biofuel. They can absorb and fix a huge amount of CO_2 thereby reducing the carbon emissions in the environment [5]. Algae synthesize fatty acids for the production of various lipids like sterols, carotenoids, quinones, terpenes and chlorophylls. They contain about 5-20% lipids, which include medium chain, long chain and very long chain fatty acids. Some algal species contain more than 80% oil. The biomass of algae can be converted into biofuel and biodiesel. Third generation biofuel i.e. algal biofuel has various advantages such as they grow in saline/waste water, they can be cultivated in the non-agriculture land, they utilize nutrients from the wastewater and can be cultivated in laboratory culture vessels [4].



Steps in the production of algal biofuel

Table.3 Lipid content in various species of algae, [44]

Algal Species	Lipid content (%db)
Chlorella protothecoides	57.9
Hormidium sp.	38
Sprirulina	6
Phaeodactylum tricornutum	20-30
Botycoccus braunii	25-80

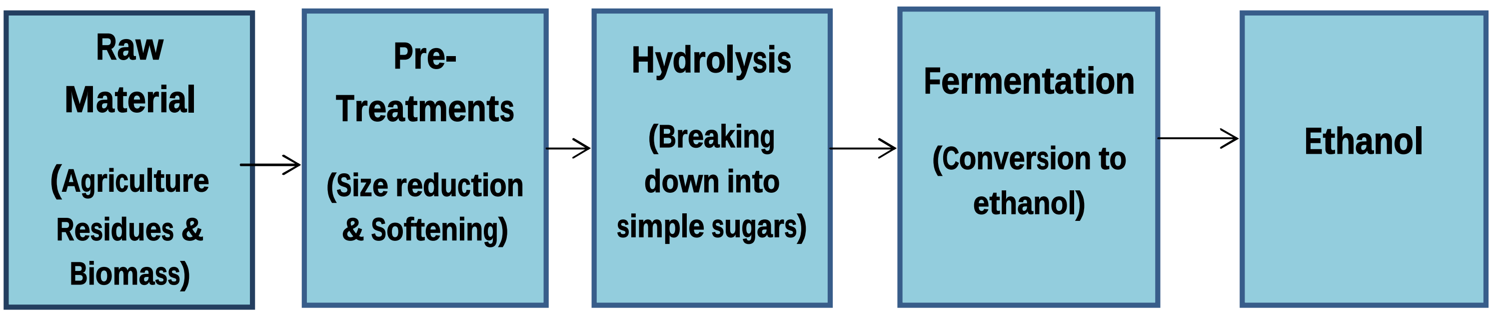
D. Fourth Generation Biofuels

They are the most advanced version of biofuels. Fourth generation biofuels are based on substrates which are unlimited, readily available and having low cost. Production of these fuels involves the application of synthetic biology in the cultivation of algae and cyanobacteria. Synthetic biology helps in the innovative designing and construction of existing natural biological systems. The system biology has potential to produce high quality biofuels by designing a photosynthetic/non-photosynthetic system [8]. Fourth generation biofuels are produced by various ways, (i) by genetically modified photosynthetic microbes to produce biofuels. (ii) By joint application of photovoltaic and microbes for the production of electro biofuels. (iii) By the synthesis of the special organelles which produce biofuel [7]. The bio resources are depleting day by day, so there is a current need of biofuels which need minimum raw material for their production [European commission 2012). Algae and Cyanobacteria are significant for production and research purposes. With genetic transformations cyanobacteria can produce various fuels and chemicals. Incorporation of specific fermentation pathways in cyanobacteria can produce biofuels straight from the solar energy [9].

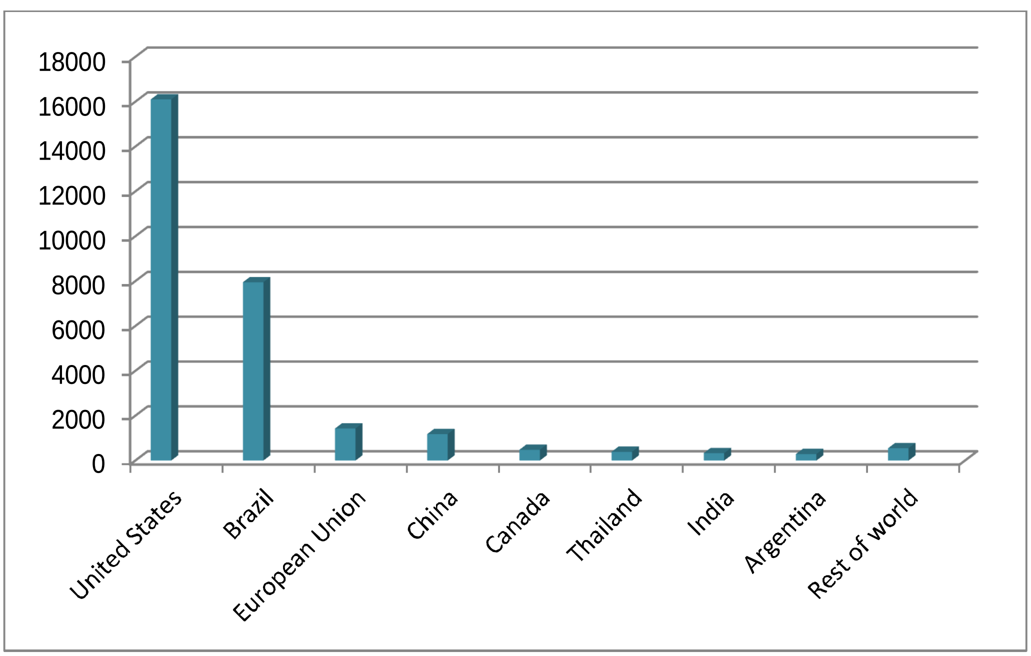
III. TYPES OF BIOFUELS

A. Bioethanol

Bioethanol made by microbial fermentation of carbohydrates. It can be directly used as fuel or can be blend with gasoline. It is the most produced biofuel in the world. Ethanol has higher octane number than gasoline [10]. It is made from a number of substrates like corn, sugarcane, sweet sorghum, barley etc. by yeast (*Sacchromyces cerevesiae*). Sugarcane has highest production efficiency per hectare than other crops [11] and India is the 7th largest producer of ethanol in the world [12]. Use of bioethanol will cause 70% reduction in the carbon emissions as compared to gasoline [13]. Incorporation of bioethanol as a fuel is cost-effective, sustainable and safer for the environment.



Ethanol production from agriculture residues [48]



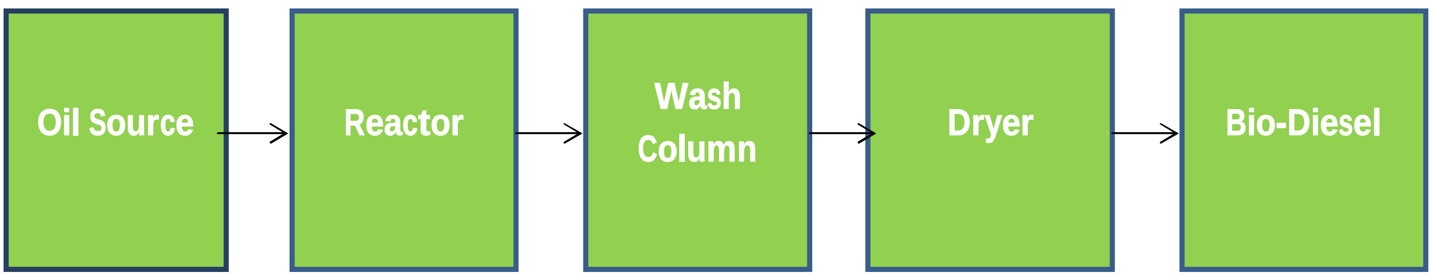
Ethanol production world scenario, [47]

B. Biobutanol

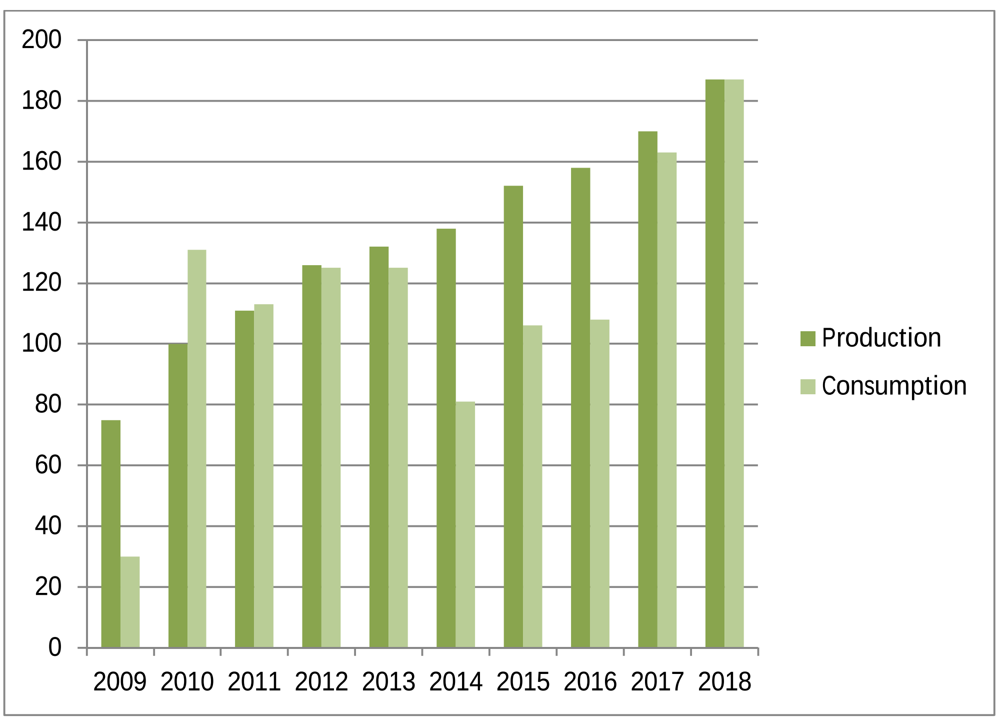
Butanol is four carbon long and non-polar alcohol which is less-corrosive, easy to transport and can be mixed with gasoline at any percentage. It has properties similar to gasoline. It can be directly used in the existing internal combustion engines without any modification [17]. Butanol synthesized by fermentation is called biobutanol. The biobutanol is produced by A.B.E. process. The organisms involved in the production of biobutanol are mainly *Clostridium acetobutylicum* and *Clostridium delberinckii*. Butanol is the co-product of the fermentation process along with acetone and ethanol. This process also produces by-products like hydrogen, isobutanol, acetic, lactic and propionic acid [14]. Butanol can also be produced by *Ralstoni Eutropha* H16 using an electro bioreactor [15]. The substrate for the production of butanol and ethanol are the same but the difference is only in the process of fermentation and distillation. Butanol produced from the biomass is more efficient because it provides more energy as compared to ethanol and butanol [16].

C. Biodiesel

Biodiesel is animal or plant based fuel having long chain alkyl esters. It is produced by the process of transesterification of the triglycerides. The raw materials used for the production of biodiesel are animal fats, vegetable oils like soybean, jatropha, rapeseed, mahua, mustard flaxseed, palm oil, sunflower and algae. Biodiesel reduces about 60% carbon emissions as compared to conventional diesel [18] and is non-toxic and biodegradable ensuring its safety for use. Biodisel is reported to have has higher flash point than petroleum diesel [19]. In India, Diesel consumption is five times more than gasoline. Production of biodiesel from edible oils is not feasible due to high cost; the use of non-edible oils reduces the cost to some extent [20].



Steps in biodiesel production [48]



Production and consumption of biodiesel in India, [49]

D. Biogas

Biogas is produced by anaerobic digestion of animal dungs, municipal and organic waste. It is a mixture of methane, carbon dioxide and hydrogen. Fertilizer is also produced as a by-product at the end of the biogas production. Municipal waste is a potential source for the production of biogas However, the pre-treatment of municipal waste is necessary to remove non-digestible matter [21]. Methane is also a greenhouse gas which cause global warming 25 times more than carbon dioxide [IPCC 2007]. The production of biogas seems to be a solution to this problem as it can utilize increasing municipal waste along with the energy security. Anaerobic digestion of solid wastes can solve the problem of landfilling which is hazardous for the environment. Production of Biogas is a promising area of research because it is renewable, cost-effective and environment friendly [22] Currently, Indian government has launched several biogas production programmes to increase the production and efficiency of the biogas. Various bottling plants are also established for the commercialization of biogas.

E. Biohydrogen

Hydrogen gas is a clean source of energy. This can also be used as feedstock for some industries. Water electrolysis, steam reforming of hydrocarbons and auto thermal method are some conventional procedure for the hydrogen production. However, these methods are not cost-effective. Biological methods have several advantages over these methods. Bio-photolysis of water by algae, dark and photo fermentation of carbohydrates by some bacteria (Anaerobic as well as Facultative) are some of the methods for the production of biohydrogen. Use of food industry waste materials like cheese whey, olive mill waste water and also carbohydrate rich agriculture waste aids in the utilization of waste materials, providing a feasible source for hydrogen production and solving the problem of waste treatment [23]. Germany is one of the leading hydrogen producers successfully running trains on hydrogen fuel. In India, hydrogen production is at very initial age, research is going on in various national laboratories. India has potential to produce biohydrogen on industrial level.

F. Syngas

Syngas is a mixture of hydrogen, carbon monoxide and sometimes carbon dioxide also. It is an intermediate in the production of natural gas, methanol and ammonia. Syngas is produced by gasification and mainly used in electricity generation. It is highly combustible so it is used as fuel in the internal combustion engines [25]. Syngas is produced by various sources like natural gas, coal, biomass, and hydrocarbons and also by steam reforming, dry reforming and partial oxidation [24]. Biomass can be converted into syngas by catalytic partial oxidation. For the reduction of char formation, catalyst can be operated at atmospheric pressure. The catalyst reduces the conversion time of biomass. Syngas can be produced by biomass gasification of agriculture and forest residue with the application of biomass gasification. Municipal waste can also be used for syngas synthesis after some pre-treatments. This will help to process and utilize the waste materials [26].

G. Solid Biomass Fuels

Solid biomass fuel can be a by-product, residue or waste product of various processes like farming, animal husbandry and forestry. Generally, this fuel does not compete with food production [Climate change, disasters and electricity generation, Dr. Frauk Urban and Tom Mitchell, 2011]. The drawback of the solid biomass fuel is that it emits high amount of pollutants. The pollutants include particulate matter, polycyclic aromatic polyphenols, dioxins and chlorophenols [27]. Biochar is produced from solid biomass like agriculture residues, it is produced through pyrolysis. Production of Biochar is helpful in reducing deforestation due to cutting off the need of charcoal obtained from forest [54].

IV. POTENTIAL RAW MATERIALS FOR BIOFUEL PRODUCTION

A. Agriculture Residues

In developed and a developing country, billion tons of agriculture waste is produced every year. The agriculture waste generally contains a high amount of cellulose t (~60-70%) which can be converted into biofuel. Agriculture waste includes straw, husks and leaves left after cultivation, husk and hull removed during milling and also animal dungs. The waste products that undergo burning are wheat residue, rice straw and hull. Sugarcane and cotton stalks also contribute to some amount of agriculture residue, which are used for biofuel production. Ethanol, hydrogen and butanol can be produced from agriculture waste using various technologies. In India, agriculture residue is used in numerous ways like cooking fuel, construction materials and feed for livestock animals. India produces million tons of grains per year therefore agriculture residue is also higher which are the potential substrate for production of biofuels because of low cost, abundance and no conflict with food security. High amount of cellulose can be easily converted into simple sugars for fermentation.

Use of the agricultural wastes for production of biofuels can be beneficial for the farmers as well as the industries as farmers can get the price for its waste products and the industries as well get their raw material at low cost [28].

Table.4 Biofuel Potential Crops, [48]

Crop	Residue type	Production (tons)
Rice	Stalk/husk	9.60
Wheat	Straw	8.70
Sorghum	Stalk	7.0
Sugarcane	Bagasse/leaves	3.42
Millet	Straw	1.04
Maize	Stalk/Cob	2.17
Gram	Waste	8.20
Pigeon Pea	Shell/stalk	2.90
Other Cereal	Waste	4.60

B. Fruit and Vegetable Waste

During processing, handling and supply of fruits and vegetables, a huge amount of waste is generated which accounts for a post-harvest loss of about 30% [29]. Globally about one third of harvested fruit and vegetable gets wasted. These wastes can be treated and successfully converted into bioenergy. Research has shown that the carbohydrate rich organic wastes are potential substrate for the biofuel production. Processing of fruits results in the generation of a large portion of organic residues and bioactive compounds like cellulose, hemicellulose, lignin, fats and oils. Conversion of these compounds into bioenergy can be the solution of energy crisis as well as waste utilization. Fruit wastes like banana peel, coconut shell, citrus peel, pineapple peel and sugar bagasse can be converted into biofuels [30]. Every year about 20 million tonnes greenhouse gas is emitted from food waste decomposition, which has more effect on global warming than CO_2 [31]. According to a report of FAO, globally about $750 billion food gets wasted every year [32]. Fruits and vegetable waste can be converted into any type of biofuel depending on the composition and the process applied. Enzymatic hydrolysis and fermentation can convert fruits and vegetables waste into bioethanol and biobutanol [33].

C. Plant Based Oils

Plant oils can be converted into biodiesel using trans-esterification. The potential oils used for biodiesel are soybean, sunflower, safflower, mahua, canola oil etc. Trans-esterification is the process of the conversion of vegetable oils into methyl esters of fatty acids, in the presence of short chain alcohol and catalysts [34]. However, vegetable oils are used in cooking process so they cannot be directly converted into biodiesel. The non-edible oils like jatropha, pongamia, mahua are the potential source for biodiesel production which does not conflict with food security and can be grown on non-agriculture lands. Biodiesel produced from plant based oils have low sulphur content hence they give lower greenhouse emissions than diesel. Biodiesel can be mixed in proportion with conventional diesel or it can be used directly but some modifications are needed [35].

Table.5 Various Oil Source for Biodiesel, [48]

S. No.	Crop Type	Oil yield (thousand liters/ha)
1.	Microalgae	47.5-142.5
2.	Palm oil	6.0
3.	Jatropha	2.0
4.	Canola	1.25
5.	Rapeseed	1.2
6.	Sunflower	1.0
7.	Soybean	0.5

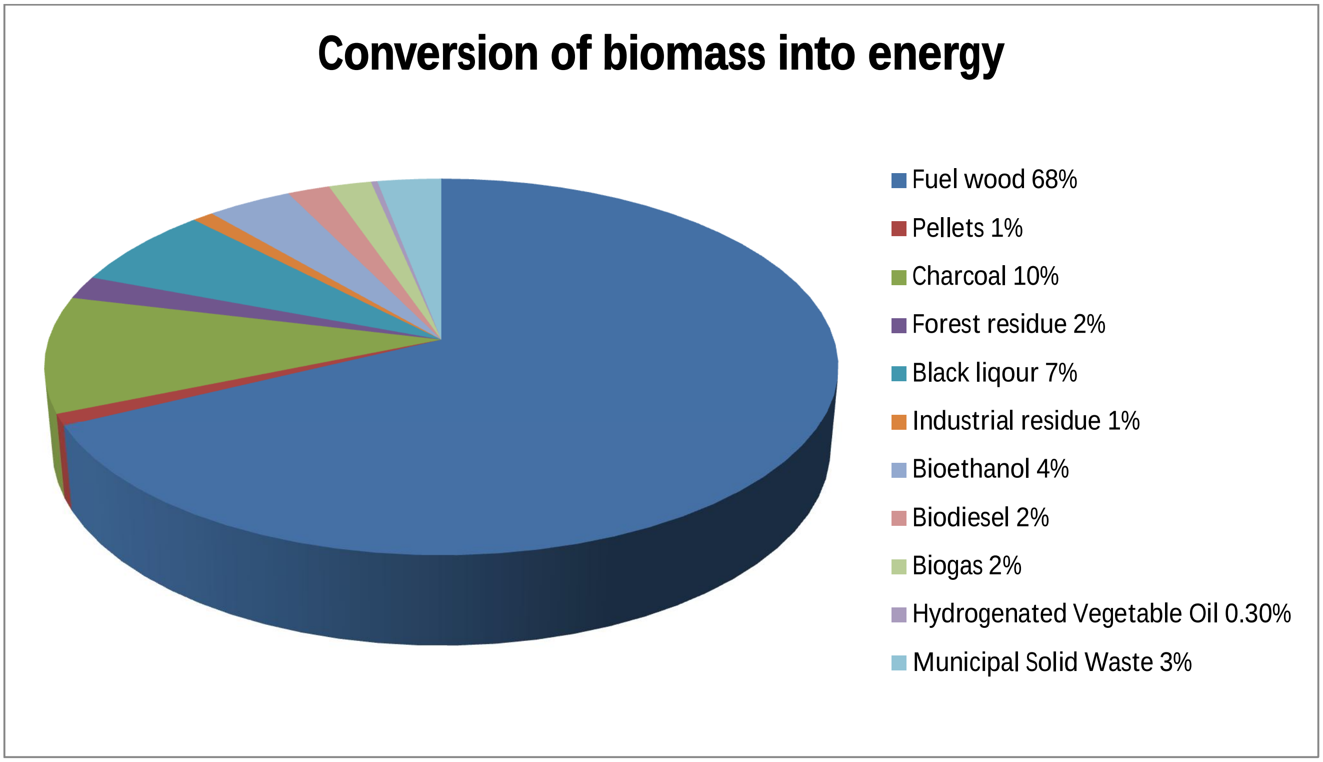
Plant based oils have lower viscosity which cause problems in the engines. Waste cooking oil is potential raw material for biodiesel production because it reduces the production cost up to 70-95% [36]. In India, FSSAI regulates the use of used cooking oil for the production of biodiesel as it contain high amount of trans fat which is not good for human health [2018]. There are various institutes in India like IISC Banglore, IIT Roorkee, IIP Dehradoon, Indian Oil Corporation limited Faridabad and many others who currently are engaged in research in the area of biodiesel.

D. Municipal Waste

Municipal organic waste is the most potential feedstock for the production of biofuel. As the maintenance of municipal organic waste is a problem for the urban cities, so the utilization of them is a problem solving step from the energy as well as waste management point of view. Use of solid municipal waste for the biofuel production leads to reduction in the landfills and greenhouse emissions. This process potentially follows the thumb rule of reuse, reduce and recycle. According to the study, when municipal waste derived biofuel is compared with petrol, the emission of greenhouse gas was reduced up to 92.5%. This makes municipal waste a potential raw material for the biofuel production [37].

E. Algae

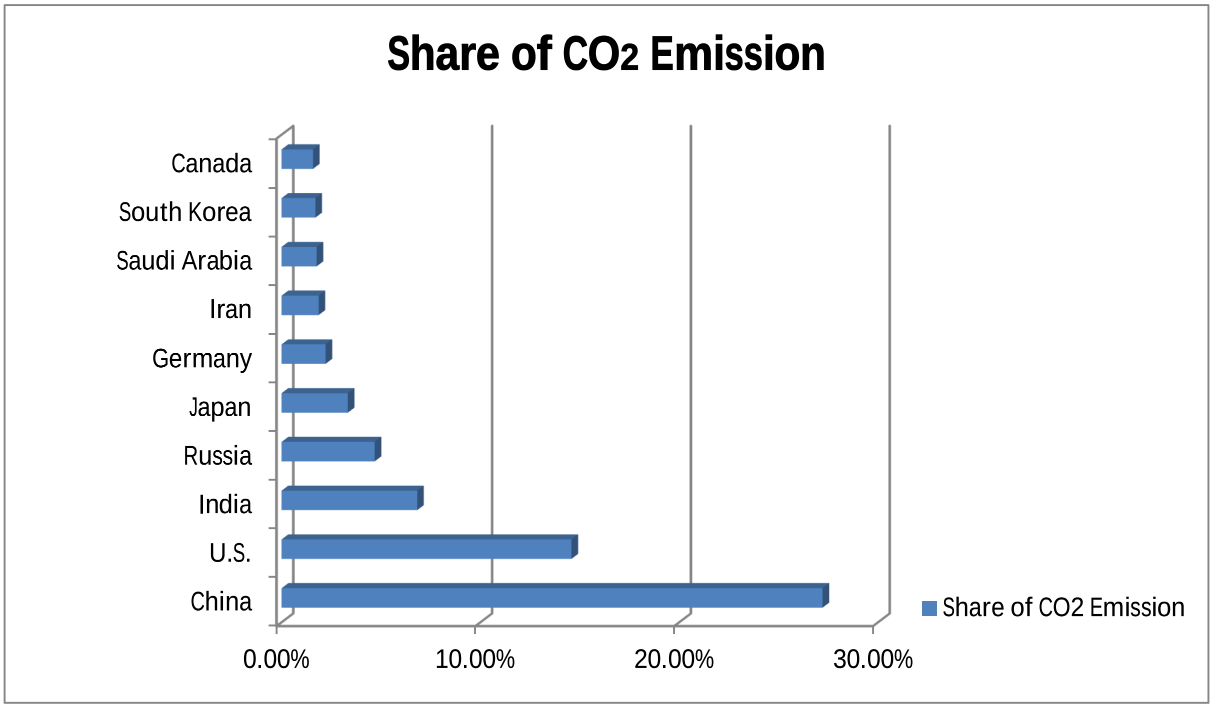
Algae are mainly photosynthetic microscopic organisms which are found in saline as well as fresh waters and are capable of converting sun energy, water and CO2 into biomass. Algae can be of two types filamentous and phytoplankton. They are considered as the renewable, sustainable and potential source of energy as they can be converted into different types of biofuels through different processes. High water content is the limitation in the application of different processes on algae for its conversion to biofuels. Oil and gas can be produced by thermochemical process while bioethanol, ethanol and biohydrogen can be produced by biochemical process. Algae can produce 30-100 times more energy per hectare as compared to energy crops. Algae can also grow into waste water, which reduces the amount of pollutants from the water. The advantages of algal fuels are high growth rate, no land requirements, CO2 absorption and cost-effectiveness.



Energy share of biomass resources, [50]

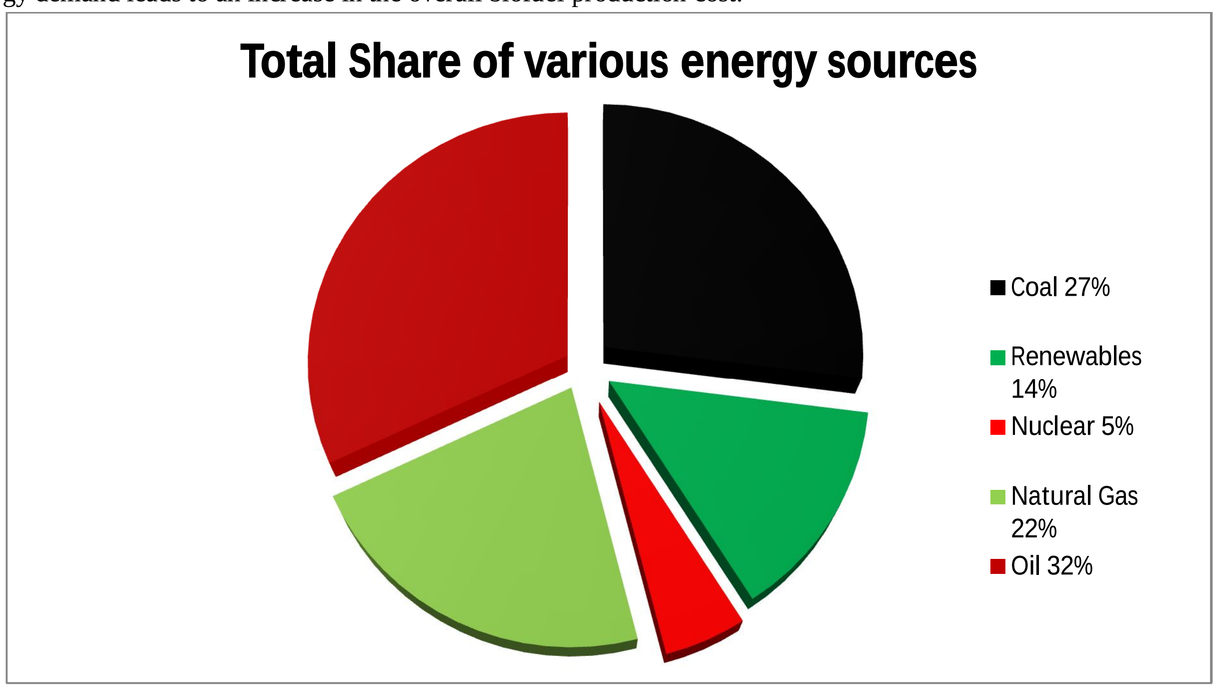
V. CHALLENGES

Global energy demand is increasing day by day while the fossil fuels are also depleting. The consumption of these fuels is increasing exponentially with the harmful effect of temperature increase on the environment. Therefore, renewable sources of energy are very crucial and vital to solve this energy crisis. Biofuels are the potential source of energy for future but the yield is still low, which needs to be increased to replace gasoline totally. Biofuel is still lying way behind fossil fuels in competition. The raw material cost is one of the major issue in overall biofuel production, use of municipal and agriculture waste can be feasible and more cost-effective [39]. Biofuel producing algae requires specific growth conditions like light, temperature, nutrients, salinity & pH, so this makes them difficult to grow in waste water in the open pound. Therefore the cultivation of the microalgae requires scientific and technical knowledge.



Share of CO2 Emissions by Major Countries, [55]

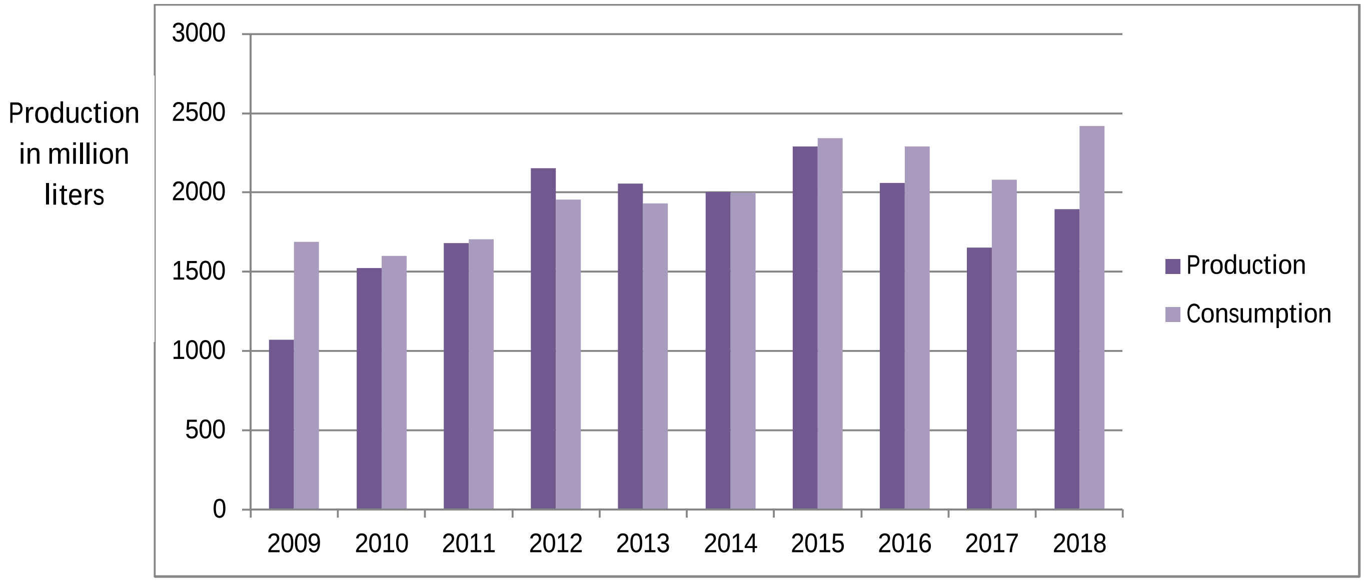
Genetic engineering is a key to increase the yield of the biofuel production. However, s it may also alter some important functions of genes which changes the behavioural pattern of the microbes. Therefore, it is advisable to combine multiple genetic engineering approach to optimize biofuel production. Also, genetic engineering leads to increase in the overall cost [41]. Apart from this, the downstream processing is also a cost limiting factor in the biofuel production. Purification is an essential step of bio refinery but high energy demand leads to an increase in the overall biofuel production cost.



Total Share of Various Energy Sources, [51]

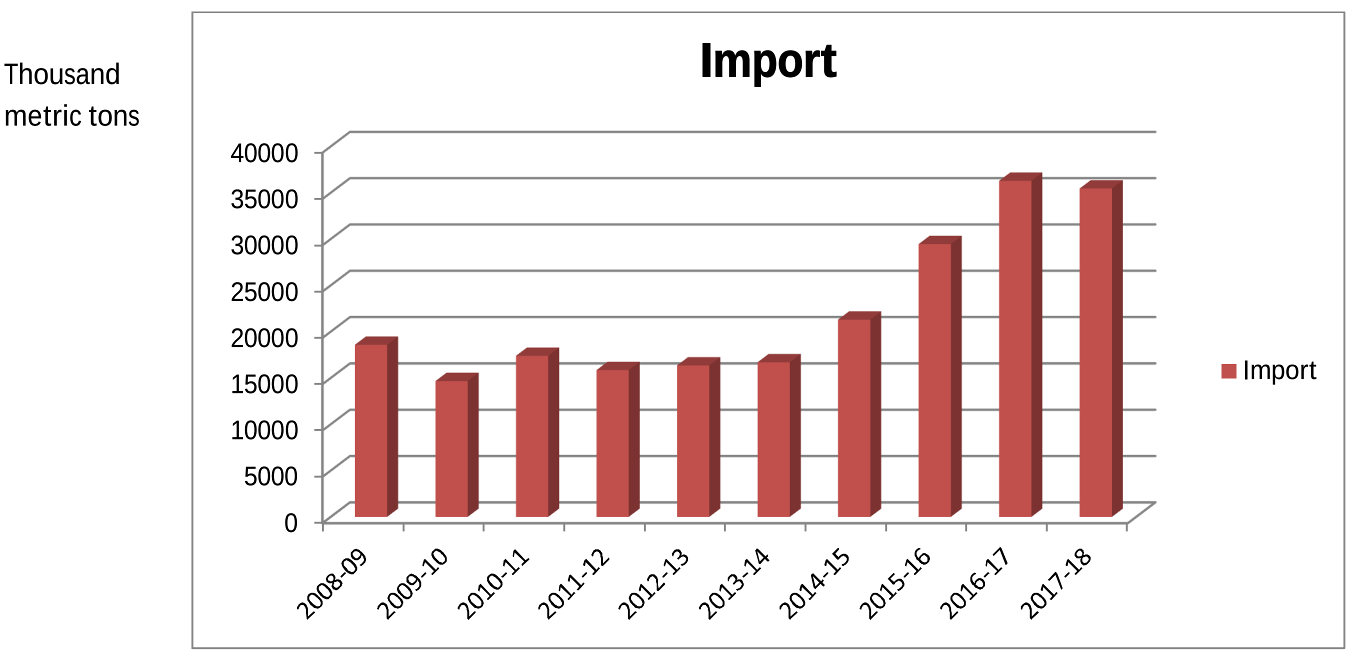
VI. BIOFUEL SCENARIO IN INDIA

India is the 7th largest ethanol producing country in the world. Indian government aims to reduce its 10% of crude oil import by 2022. India is currently producing ethanol and biodiesel at remarkable amount while biobutanol and biohydrogen production are at budding stage [56].



Production and Consumption of Ethanol in India, [49]

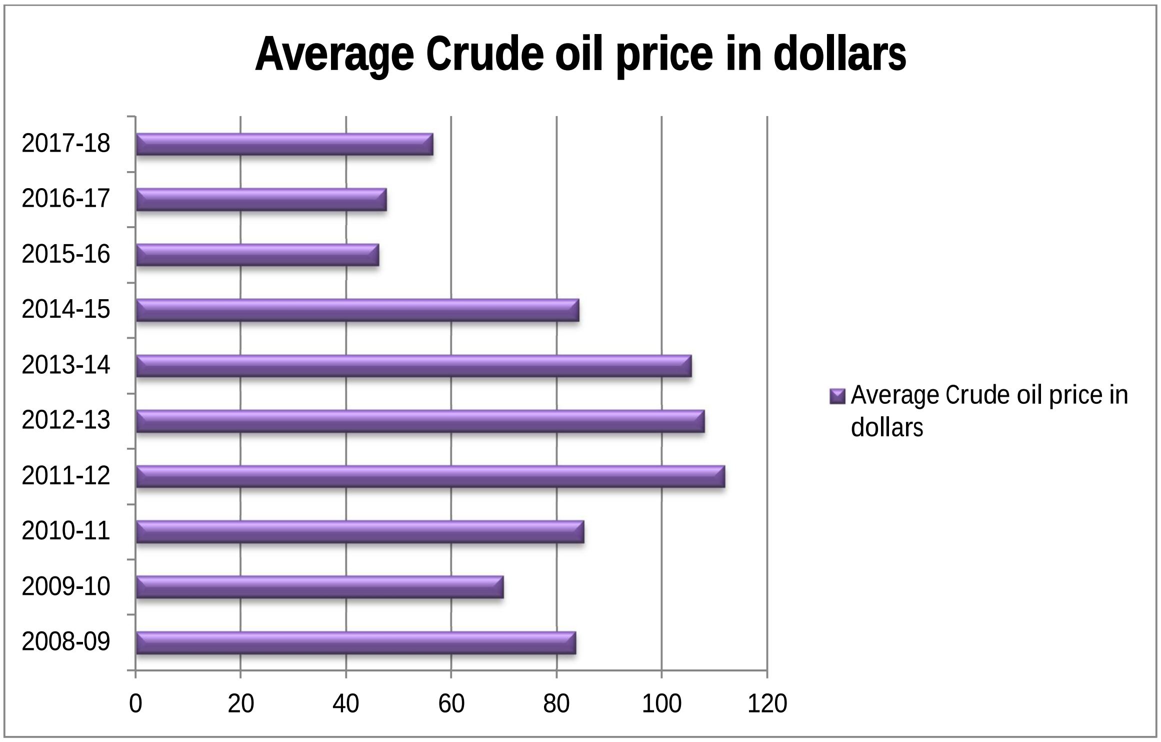
India has a number of biogas plants but still country is far away from the commercialization of biogas. India has implemented a biofuel policy in 2018, which mainly aims in the production of second generation biofuels. Energy requirements of the country are increasing day by day; the price of crude petroleum oil is unstable so the dependency on crude oil can influence economy when price hikes. In this scenario, it is important that India should be energy independent, to sustain in the world economy. Biofuel production will also increase farmer's income by giving value addition to the agricultural crop residues. Every year during winters in the northern region of the country, the environment is suffering from air pollution and citizens are becoming victims of respiratory diseases due to stable burning of the agricultural wastes, use of agriculture waste will save the people and environment's health.



Import of Crude oil in recent years, thousand metric tons, [52] Methane gas produced from the waste water is used as bio CNG in transport buses. Indian Railway is blending 5% biodiesel with diesel in its locomotives engines, which is cost saving as well as environment friendly. Many industries are also producing ethanol by using the sugarcane bagasse. Global warming and climate change is a burning issue to the world & every country is advised to reduce its carbon emissions and help in decreasing the global temperature rise [49]. The production and implementation of biofuel in the country will be the win-win situation for everyone.

VII. FUTURE PROSPECTS

Biofuels provide energy security, have less impact on environment and are sustainable in long run. According to the reports of IEA unstable price of fossil fuels, demand of energy security and climate change are the key reasons to adopt biofuel based economy. About 82% of the global energy demand is fulfilled by fossil fuels and 2.4% of the fuel need is accompanied by ethanol. In the transportation sector the interest toward bioenergy production is i increasing day by day. It is estimated that by 2030 about 7% of transportation fuel would be biofuel. By 2030, land requirement for the biofuel will be increased at a modest rate from 1% to 3.8% and more raw materials will be based on agriculture residue. This will lead to the reduction of the need of land for the fuel production. Developed countries like U.S. U.K. Germany, Brazil are increasing their bioenergy production every single year. Current growth of biofuel is driven by environmental concerns, energy security and increasing fuel prices. Some scientists questioned that biofuel generates as much as or more carbon that it captures. Also it takes tax payers money into the subsidies.



Price of Crude oil in recent years in India, [53]

In developing countries it maybe takes the land of edible crops which leads to increase in the price of food which will be problematic for poor consumers. The use of food crops for biofuel production leads to increase in the price of food products about more than 50%. Major question for the biofuel is also the overall environmental and economic impact versus output given. Even the 10% replacement with biofuel will reduce only 2.5% fossil fuel in the transport sector. The 1st generation biofuel alone could not substitute for fossil fuel. 2nd generation biofuel can be substitute for fossil fuels, with the techniques of plant breeding, genetic engineering and advanced downstream processing. Biofuel produced using these technologies could be more efficient and cost-effective. In the coming decades the production of 2nd generation biofuel will be increased up to 2-3 folds. Biofuel production still needs to reduce the use of food crops about 2-3%, as the population in 2050 will increased up to 9 billion which may lead to shortage of food causing major problem for the countries. The potential solution for this problem is the use of algal and lignocellulose biomass derived from crop waste or unutilized land [43].

VIII. CONCLUSION

The biofuels still needs to go long way, which is currently at the budding stage. The need of biofuel is at a high demand but effective technologies are needed to increase the productivity and meet the desired requirements. Currently, the developed countries are using the food crops for the biofuel production which may lead to a crisis as such countries have a large population to feed on daily basis. In India, the biofuel policy is new ray of hope for the biofuel industry; this can be a game changer in biofuel sector. Since the raw material cost is the major issue in the biofuel production, the use of non-food crops can be sustainable solution to this problem. This will reduce the competition over land for food vs. fuel. The use of agriculture residue and microalgae are potential substrates, because of their availability and higher growth rate, in addition to no conflict with food security. Pre-treatments of these substrates are also a cost limiting factor, the use of alternative feasible treatments can reduce the cost of production. The major challenge for the biofuel is still the lower yield and recovery, which can be overcome by using advance technologies like plant breeding, genetic engineering and recovery can be increased by using a set of downstream processing according to characteristics of the desired product.

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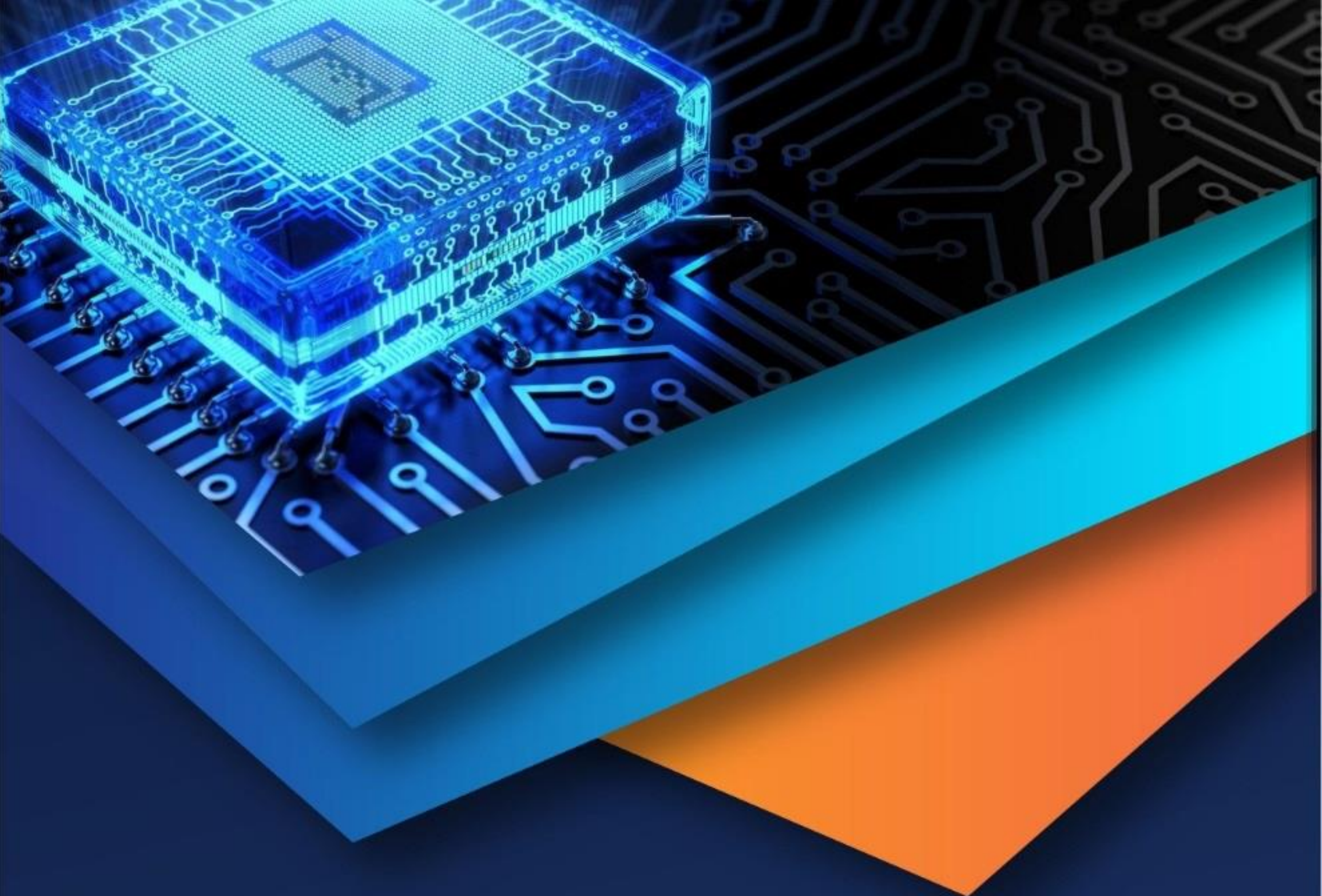

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