An Overview of Biofuel for Energy Security in India: Opportunities and challenges

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***Abstract*: Sustainable energy is crucial for sustainable development. India, being a responsible welfare nation, is trying to provide energy security by sustainable energy. Energy transition from conventional to renewables is on pace. Structured Policies, Programmes, R&D, coordinated efforts of stakeholders and strong government support has made an ecosystem for rapid growth in the biofuel sector and now India has become one of the leading markets in renewable energy. Biofuels have potential to meet the future energy demands as well as contributing to a reduction in greenhouse gas emission. The aim of this paper is to present an overview of biofuels in India including history, national policy, biofuel chemistry along with green chemistry, feedstock used, different generations and technologies, current status and future prospects. In Spite of the availability of ample feedstock, various challenges faced by the biofuel sector are also analysed and recommended different measures to overcome the obstacles so that the biofuel sector in India must be augmented in every possible way.**

***Keywords*: India, sustainable energy, energy security, biofuel chemistry, green chemistry, feedstock, generations, energy transition, stakeholders, ecosystem.**

INTRODUCTION:

Energy is a critical input for socio-economic development and fossil fuels have been contributing as a major source for fulfilment of this energy need since its discovery. India has a very limited reserve of fossil fuels whereas close to 74% of the energy demand is supplied by coal and oil [1]. The Indian economy is dependent on import of coal, oil and gas. Economic stride has been observed in recent years in India except the slowdown in the pandemic of Covid-19 along with the world's slowdown. The IMF has announced that over 50% of global growth in 2023 will come from India and China [2].

In the alignment of economic growth, the energy demand and consumption are also growing fast. According to the IEA (India Energy outlook 2021), primary energy demand is expected to grow nearly double to 1,123 million tonnes of oil equivalent, as India's Gross Domestic Product (GDP) is expected to increase to US $ 8.6 trillion by 2040 [3].

The size and growth of the human population of a country significantly affects the demand for energy. 1.4 billion people of India having population growth rate of 0.91% along with rapid industrialization and urbanization has made huge demand in the energy sector. Major energy demand sectors are building (residential and commercial), transportation and industries. But energy use on a per capita basis is still well under half of the global average and there are widespread differences in energy use and the quality of service across states and between rural and urban areas [3]. However, according to the India Energy Security Scenarios (IESS), 2047 developed by NITI Aayog, due to increased penetration of electrical technologies and appliances share of electricity in the energy demand increases from 15.6% in the base year 2011-12 to 24.8% in 2047 [4].

Energy is the requisite for the development of any economy. It is used in most of the activities of human beings. Life in the modern era became energy centric. In the context of India, rapid increase in population with energy intensive lifestyle, rise in income both in rural and urban areas, urbanization, industrialization, technological development has created pressure on energy. The energy supplied by fossil fuels is non-renewable in nature and has a limited amount on our planet. They take millions of years to form while we are depleting them every second. Conventional sources of energy are not only limited but contribute one third of global greenhouse gas emission and in turn responsible for climate change.

In the modern era, development is driven by energy. Development is natural and standard of living has to rise but not at the cost of our environment. As human beings are only one of the living components of a vast biodiversity and of course we are not an isolated system but continuously interacting with the rest of the part. So, by introducing greenhouse gases in our surroundings from generation of energy through fossil fuels, we became responsible for climate changes across the planet which has been adversely affecting the other components of the ecosystem along with human beings. Development has increased energy requirements and the gap between energy demand and availability has risen. India is, being a responsible welfare state, energy security is a must. Energy security is the continuous availability of

affordable energy. Therefore, due to environmental concern and dependency on import for fossil fuels, indigenous energy sources are explored and green energy becomes a ray of hope for energy security.

Focus on renewable energy is increased in India to achieve the goal of sustainable development with the wings of clean energy. For sustainable development sustainable energy is required. Sustainable energy is consistent availability of clean, affordable and reliable energy for different sectors of the economy. Government initiatives and strong support has created a good ecosystem for renewable energy in India and India became the world's topmost renewable energy market. Renewable energy comprises solar energy, wind energy, hydropower, nuclear energy, biomass energy, biohydrogen and energy from waste.

In the renewable energy basket biofuel is one of them. At present biofuel has a >2% contribution in the total renewable energy. But there is huge potential for its growth in India as 14% of GDP is from the agriculture sector. Fuel crop, agricultural waste, municipal wastes are important feedstock for biofuels. The aim of this paper is to present an overview of biofuels in India including history, national policy, feedstock used, different generations and technologies, biofuel chemistry, environment concern, current status and future prospects.

History of Biofuels in India

Biofuels are not a new concept but they have been used from the origin of our civilization. Initially they were mostly used in cooking and heating. It is the modern science which enabled us to extract bioenergy from the biofuels in that form which can easily be used in transportation, industries, electricity production etc. India is rich in biomass and traditionally India used them as a fuel but mostly in inefficient ways which led to air pollution and health issues. Gradually appropriate technologies for biofuels developed and it became an important input for economic growth with equity. Due to the experience of the oil crisis in 1973 and 1978, the potential of biofuels reappeared across the world. The modern history of biofuels in India also began in 1970's and launched several policy measures to promote biofuels then.

In 1975 feasibility of blending ethanol with petrol was examined. In 1980, the Indian Oil Corporation conducted trials on passenger cars and two & three wheelers using 10% and 20% anhydrous ethanol blends. In 2000, the ministry of petroleum and natural gas-initiated pilot projects in three oil depots covering 350 petrol stations to study related aspects of blending ethanol with petrol. In the light of successful blending results, the government of India launched Ethanol Blending Programme (EBP) in 2002 and mandated a 5% blending of ethanol in 9 States and 4 Union Territories. A committee on development of biofuels recommended strengthening the ongoing programme of blending of ethanol with petrol in 2003.

However, the 5% blending mandate in the case of ethanol could not be met due to shortage of bioethanol supply. In 2004, the mandate was amended "requiring E5 blends only when adequate ethanol supplies were available" [5]. National mission on biodiesel based on the Jatropha plantation was launched. Initially 5% biodiesel was blended to diesel and planned to extend the blending to 20%. This National mission on Biodiesel was launched by the recommendation of the Planning Commission in 2003 [6].

National Biofuel Policy-2009

In order to strengthen ethanol and biodiesel blending programmes, the National Biofuel policy of India was approved by the government in 2009. In this policy an indicative target of 20% blending of biofuels, both for biodiesel and bioethanol by 2017 was proposed.

Salient features:

1. Biofuels are based solely on non-food feedstock for avoiding conflict of food security Vs. Energy security.

2. Biodiesel production will be based on non-edible oil seeds which have to be cultivated in waste degraded and marginal land and will be encouraged through Minimum Support Price (MSP) and Minimum Purchase Price (MPP).

3. Financial Incentive for 2nd Generation biofuels and National Biofuel fund were considered.

4. Major thrust will be given to research, development and demonstration with focus on plantation, processing and production of biofuels.

5. The Ministry of new & renewable Energy has been designated as the coordination ministry of biofuels. A national biofuel coordination committee and biofuel steering committee will be set up.

Biofuels in India are of strategic importance as it augurs well with the ongoing initiatives of the government such as Make in India and Swachh Bharat Abhiyan. It offers a great opportunity to integrate with the ambitious targets of doubling the farmer income. Import reduction, employment generation, waste to wealth creation. Simultaneously, the existing biodiversity of the country can be put to optimum use [7]. Therefore, the National Policy on Biofuels-2018 was notified by the government in suppression of National Policy on Biofuels -2009 and further amended in 2022. This policy includes feedstock availability & development, blending biorefinery programme, financing, financial & fiscal incentives, research & development, demonstration, quality standards, pricing, distribution, marketing, import and export of biofuels. Also focused on institutional mechanisms with the role and responsibilities of stakeholders.

Salient features of National Policy on Biofuels-2018:

1. Biofuels are categorized into "Basic Biofuels" viz. First Generation (1G) bioethanol & biodiesel and "Advanced biofuels "; second Generation (2G) ethanol, municipal solid waste (MSW) to drop-in fuel, Industrial waste, plastic waste and third generation(3G) biofuels, bio-CNG etc.

2. The policy expands the scope of raw materials for ethanol production by allowing use of sugarcane juice, B-molasses, sugar containing materials like sugar beet, sweet sorghum, starch containing materials like corn, cassava damaged food grains like wheat, broken rice, rotten potatoes unfit for human consumption, biomass from grasses, agriculture residues like rice straw, cotton stalk, corn cobs, sawdust, bagasse, algal feedstock, sea weeds etc. For biodiesel production non-edible oilseeds used cooking oil, short gestation corps, animal tallow, acid oil, algal feedstocks are allowed.

3. Surplus food grains for production of ethanol is also allowed. For giving thrust on advanced biofuels, under viability gap feeding scheme for 2G ethanol biorefineries of Rs. 5000 crores in 6 years considered in additional tax incentive higher purchase price in compared to 1G biofuels.

4. The policy encourages setting up supply chair mechanisms for biodiesel production from non-edible oilseeds, used cooking oil and short gestation crops.

5. Roles and responsibilities of all the concerned ministries and departments with respect to biofuels have been defined to synergise efforts [7].

The amendment in National Policy on Biofuels-2018 made additional feedstocks; C-Heavy molasses, sugar, sugar syrup, agro-food/pulp industry waste, industrial waste off -gases for production of biofuels promoted Special Economic Zone (SEZ)/Export Oriented Unit (EOU) for the production of biofuels and allowed exports of biofuels in special situations. The amendment advanced the deadline to reach the blending target of 20% bioethanol in petrol from 2030 to 2025-26 [8].

Type of Biofuels

Biofuels are energy enriched chemicals produced from biomass which are abundant in nature. Usage of biofuels became more significant due to visions of decarbonizing societies, independence from imported oil and exploitation of local renewable energy sources [10].

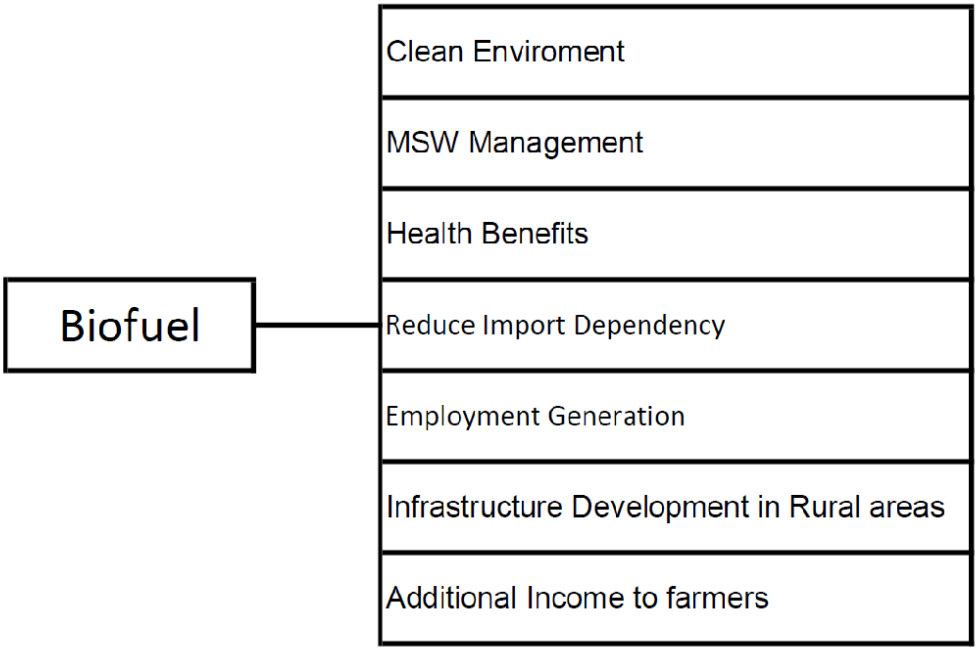

Fig 1. Advantages of Biofuels

Different biofuels are biodiesel, bioethanol, biobutanol, biogas, biomethane, biohydrogen, syngas etc.

Biodiesel

Biodiesel is an amber yellow liquid, non-flammable with viscosity like petroleum diesel. It is produced by the biomass of vegetable oil or animal fats, waste cooking oils, algal oil etc. The conventional method for production of biodiesel involves the transesterification of triglyceride from oil with short chain alcohols including methanol and ethanol to yield fatty acids methyl ester (FAME) or fatty acid ethyl ester (FAEE) and glycerol as a by – product.

Triglyceride + Alcohol ⇆ Biodiesel + Glycerol

Fig 2. Production of Biodiesel from Triglyceride

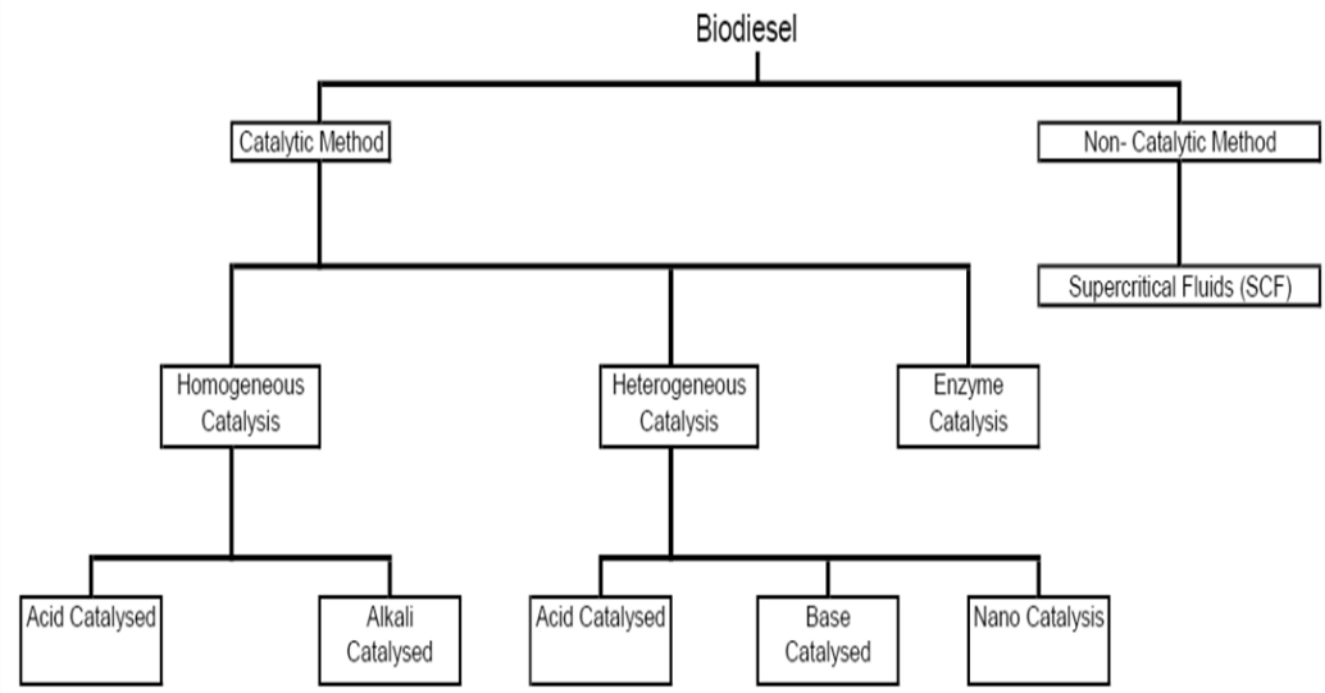

Fig 3. Methods of Biodiesel Production

Base catalyzed homogeneous transesterification is the conventional method for the production of biodiesel. This process involves transesterification of vegetable al with NAOH or KOH as catalyst at relatively mild temperature. The Common acids used in homogeneous acid catalysis transesterification are sulphuric acid, hydrochloric acid, phosphoric acid, boron trifluoride, sulphonic acid etc. Acid Catalysts have better tolerance levels in production of biodiesel from waste oil. However, homogeneous acid catalyzed reactions are not commercially preferred due to slower rate of reaction and higher temperature requirement. The heterogeneous catalysis for production of biodiesel is a green method. From the stand-point of green chemistry, catalysts may be recycled and subsequently employed in the reaction [II]. Some of the solid base catalysts involved in the production of biodiesel are zeolite, calcium oxide, magnesium oxide etc. However, heterogeneous catalysis reactions are not a preferred method for commercial production as the rate of reaction slow and saponification of glycerides and formation of methyl ester take place.

Biodiesel production by green methods: Green chemistry and green methods became pivotal in the production of chemicals in the present era of circular economy. In the context of green chemistry, during the process of production of chemicals twelve principles; atom economy, benign solvent, catalysis, use of renewable feedstocks, less hazardous synthesis, energy efficiency, prevention of waste etc. must be followed. Various green methods of production of biodiesel are in practice.

Heterogeneous Nanocatalysis has become promising method due to large surface area, efficiency and high specificity of nanocatalysts. Common heterogeneous nanocatalysts are calcium oxide nanocatalyst, zinc oxide nanocatalyst, magnesium oxide nanocatalyst, titanium oxide nanocatalyst, zirconium oxide nanocatalyst etc.

Enzyme catalysis for the production of biodiesel is a green method. Enzymes like lipase and immobilized lipase are used for conversion of biodiesel. The reaction is carried out at lower temperature with very good catalytic activities.

Supercritical fluids (SCF) are used as solvent in the non-catalytic process for the production of biodiesel. SCFs are green solvents in which the rate of reaction is high and also down processes are faster. Few important SCFs used in production of biodiesel are supercritical methanol, Supercritical methyl acetate etc.

Bioalcohols

Renewable biofuel market is dominated by bioethanol. Biobutanol or biogasoline is also gradually gaining attention due to superior qualities. Bioethanol is obtained by biological conversion of feedstocks. These are produced by sugar-based biomass, starch-based biomass and lignocellulose- based biomass. Hydrolysis and fermentation of feedstock followed by distillation and dehydration are the different steps in the production of bioethanol from sugar-based biomass.

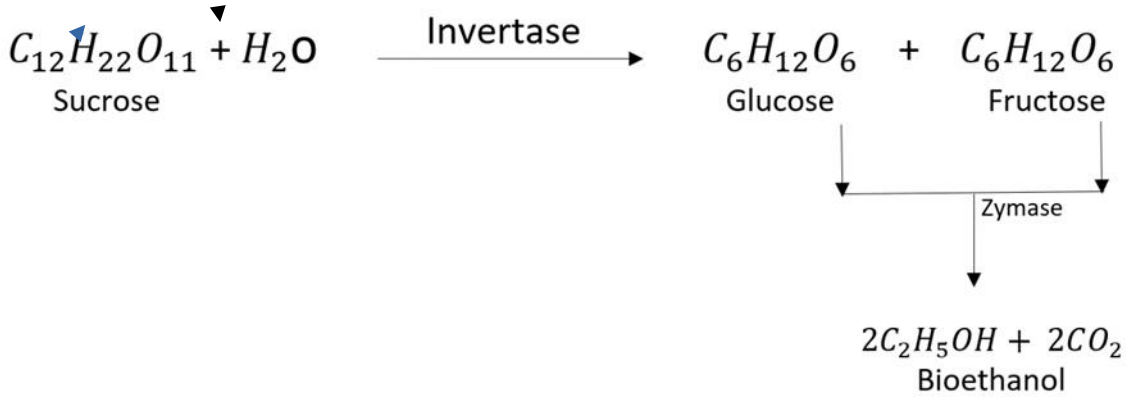

Fig 4. Production of bioethanol from sugar

Sugars are fermented to ethanol by using yeast like saccharomyces cerevisiae. The invertase enzyme present in the yeast converts sucrose into glucose and fructose and subsequently they are converted to bioethanol by zymase enzyme.
Starch based ethanol production depends on its structure comprised of amylose and amylopectin which has to break down for obtaining glucose syrup.
This is converted into D-glucose by the process of hydrolysis in the presence of glucoamylase enzymes.
Further fermentation, distillation and dehydration are followed to yield anhydrous ethanol.
Bioethanol can also be produced from lignocellulosic biomass. Such feedstock contains cellulose, hemicellulose and lignin. Cellulose is polysaccharide having monomeric units of D-glucose which are linked by β-1,4-glycosidic bonds.

Hemicellulose consists of a mixture of various C5 & C6 sugars. The different groups of molecules making up hemicellulose include xylans, mannans, galactans and arabinogalactans [12]. Lignin is a binding material which has an encrusting effect. Therefore, in order to extract cellulosic fibres from plant material lignin degradation is essential. Lignin is a complex amorphous aromatic polymer having monomeric unit phenylpropane. Pretreatment is the essential step for conversion of lignocellulosic material into bioethanol. This has to be done before enzymatic hydrolysis and fermentation. Pretreatment can be physical, chemical, biological or their combination. Pretreatment with dilute acid at mild temperature is considered as the most cost-effective method. In this process loosening of the cell wall matrix through degradation of hemicellulose takes place and high value products like furfural, hydroxy methyl furfural, phenols, aldehydes, aliphatic compounds are obtained [8]. Biobutanol can be obtained from sugar-based feedstocks, Lignocellulosic biomass or algal biomass. Biobutanol is prepared by the same process as that of bioethanol but with different microorganisms [9]. However, fuel yield is low but it has the advantage that it can be directly used without blending. So it is called Biogasoline.

Biogas, Biomethane and Syngas

Biogas is a mixture of combustible gases in which methane and carbon dioxide are major components. They can be produced by anaerobic digestion of organic substances present in waste. Waste materials are produced during the course of human activities. The Sources of waste are medical, industries, agriculture, forestry, municipalities etc. Waste contains natural materials like starch, lipid, glycogen, collagen, lignocellulose etc. as well as synthetic materials like polyethylene, Polyesters etc. Under anaerobic conditions, the organic materials are converted through microbiological processes into gases called biogas and organic fertilizer [13]. After removing carbon dioxide and minor gases from biogas, biomethane can be obtained by the process of biomethanation. Biomethane is composed of > 95% of methane. Biomethane on compressing is converted into Compressed Natural Gas called Bio-CNG. Biomethane can also be liquified and used as Liquified Natural Gas called Bio-LNG.

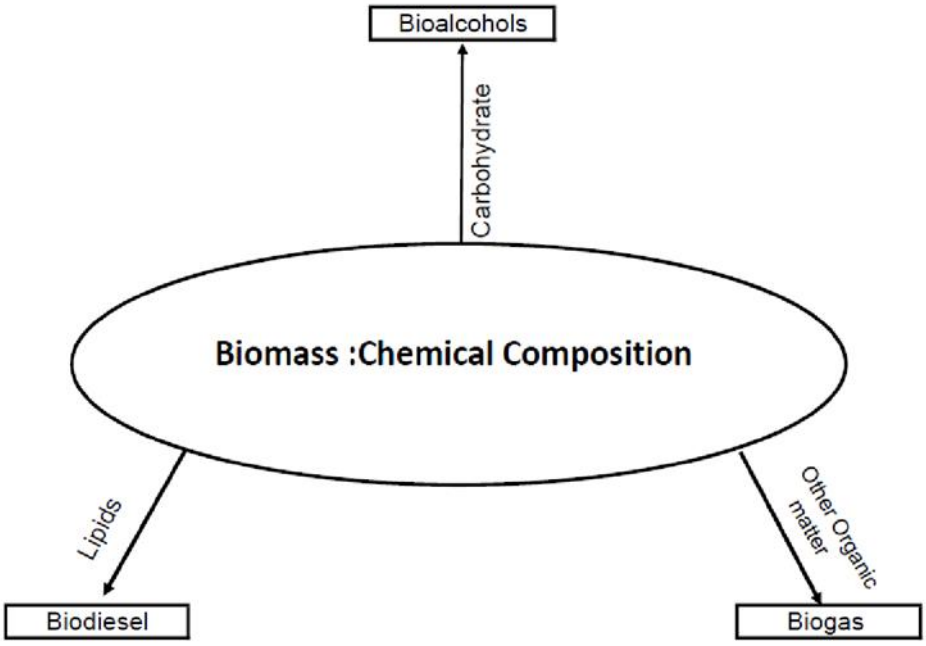

Fig 5. Chemical Composition of Biomass and produced Biofuels

Generations of Biofuels and feedstocks

Biofuels are mainly obtained from biological materials mostly from plants, animals, waste and microorganisms. The feedstock of biofuels is called biomass. Biomass is an organic substance derived directly or indirectly from the process of photosynthesis.

On the basis of feedstocks and accordingly used technologies in the production of biofuels, different generations of biofuels are considered.

First Generation (1G) biofuels

The feedstocks for First Generation (1G) biofuels are sugar, starch and oil-bearing food crops and sometimes animal fats. The technologies of production include fermentation, distillation and esterification which are well-settled. 1G biofuels are bioethanol, biodiesel and biogas. The production of 1G biofuels changed the role of farmers from grain producer to bioenergy producer. It opened the opportunities in rural areas including improvement in income of farmers, containment of rural-urban migrations as well as conservation of environment along with rural culture. But as the major

components of feedstock were food crops, conflict between food and energy started. Biomass for 1G biofuels required more land and water. So, natural resources were under stress. More fertilizers were used for increasing the production of food crops. Run off from the land caused eutrophication in the water bodies. Threatening on biodiversity became crucial. In Spite of these disadvantages, 1G biofuels provided small profit over fossil fuels in regard to greenhouse gases as they required a high amount of energy in the production process.

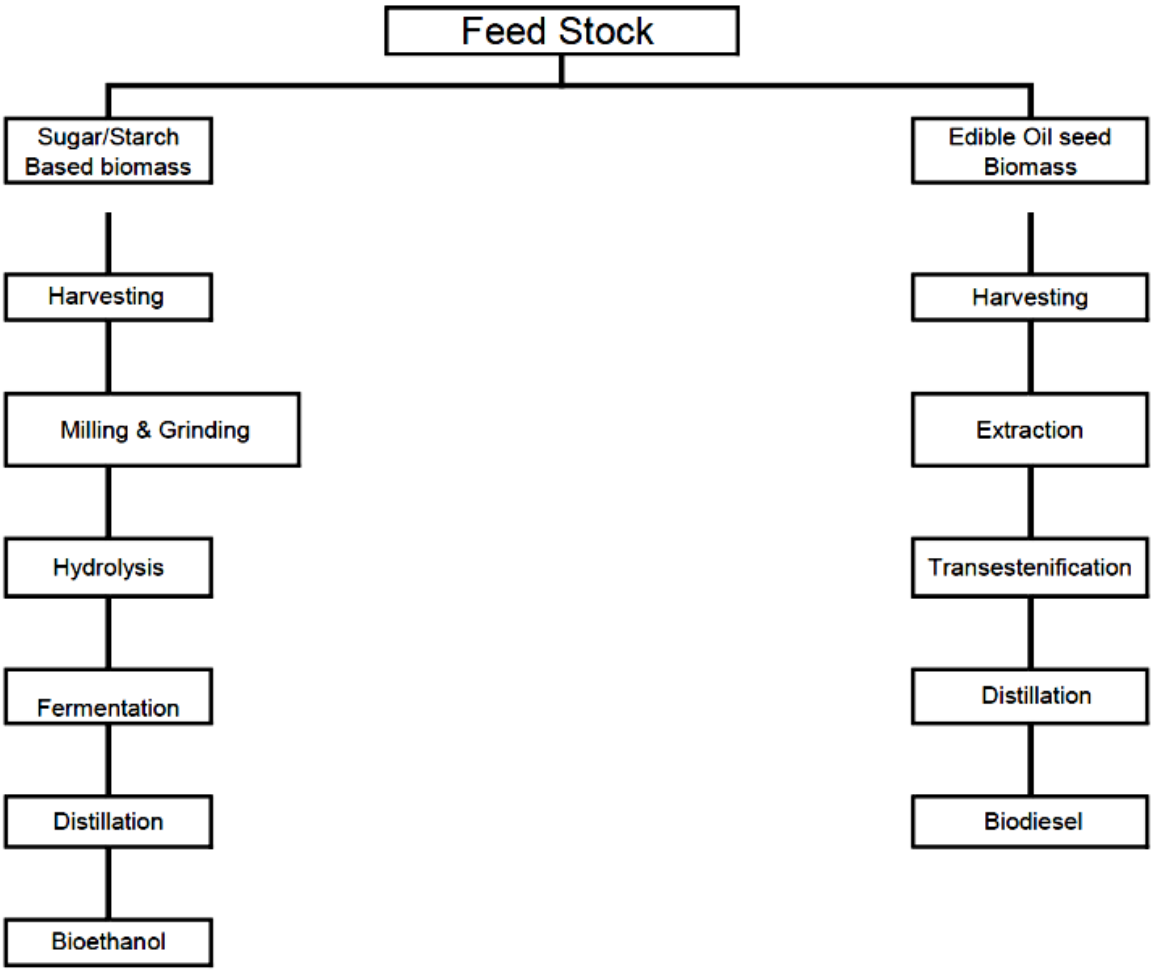

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Fig 6. 1G Biofuels Production Process

Second Generation (2G) Biofuels

Second Generation (2G) Biofuels are known as advanced biofuels. The feedstock of 2G biofuels are non-food crops, food unfit for human consumption, agriculture residues, grasses, waste vegetable oils, Industrial waste, municipal wastes etc. The basket of biomass became large and diversified in order to sustainable supply of feedstocks for production of biofuels. The 2G biofuels are bioethanol biobutanol, biodiesel, bio-SNG, bio-CNG, bio-LNG, bio-hydrogen etc.

Bio alcohols from starch and sugar as well as biodiesel can be produced by the same technology as in 1G biofuels. But pre-treatment is required for production of biofuels from lignocellulosic materials and followed by fermentation and distillation.

2G biofuels are better than 1G biofuels. As the feedstocks of 2G biofuels are non-food crops, conflict of food energy stopped. The requirement of land and water was reduced. 2G biofuels are more environmentally friendly and produce less greenhouse gases. However, the production cost of 2G biofuels is high. Agriculture and forestry have pressure to supply biomass. Supply chains of feedstocks are not developed.

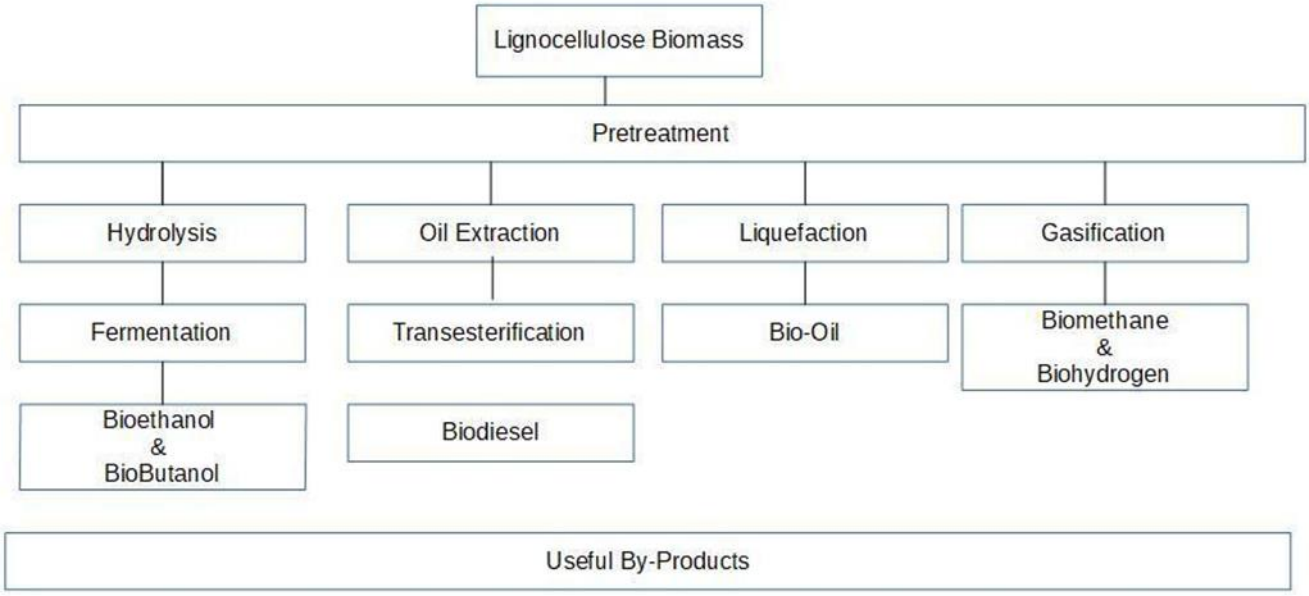


Fig 7. 2G biofuel production process from lignocellulosic biomass

Third Generation (3G) biofuels

The biofuels produced from algal biomass are called Third Generation (3G) biofuels. These biofuels include biodiesel, bioethanol, biobutanol, biomethane, jet biofuels etc. Algae are various groups of prokaryotic and eukaryotic organisms which are mainly composed of carbohydrates and lipids along with certain micronutrients such as nitrogen, phosphorus and potassium. These carbohydrates and lipids components are raw materials for the production of a range of biofuels and biomaterials. Algae may be autotrophic or heterotrophic. Autotrophic algae can be cultured easily by natural photosynthesis by only supplying carbon dioxide, salt and light energy sources while for the culture of heterotrophic algae organic nutrients are required.

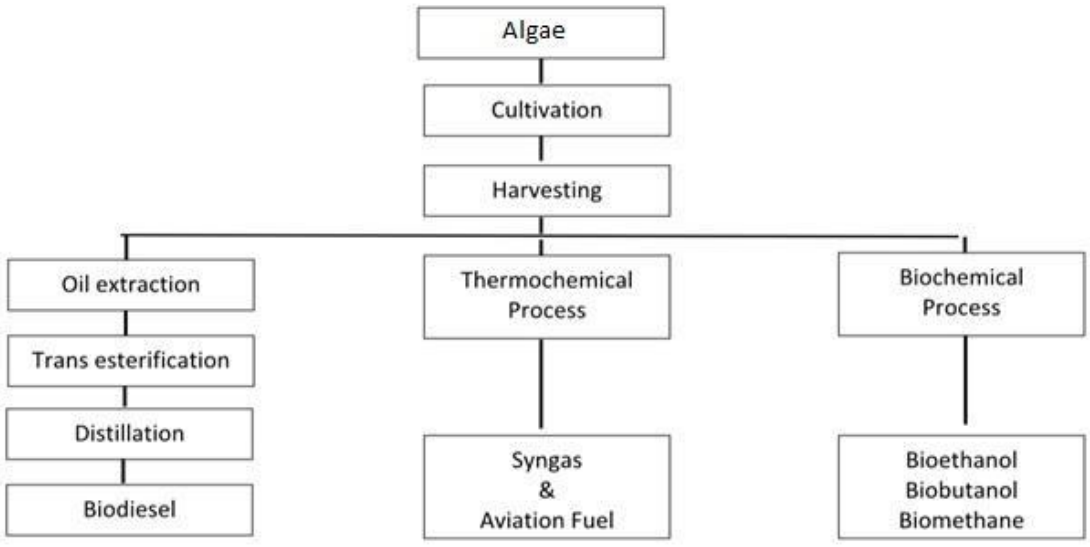


Fig 8. 3G biofuel production process.

Algae can be cultured in open ponds, close-loop systems and also in photo-bioreactors. The 3G feedstock is a sustainable feedstock as it can be grown throughout the year and has capability to grow under harsh conditions like brackish water, sea water, waste water which does not affect agriculture regarding land and water. It produces more than 30 times energy per acre than the land crops such as soybeans. A very important aspect regarding 3G biofuels is that the feedstock algae can be cultivated near power plant, industries where it can directly fix emitted carbon dioxide. However, the cost of biofuels production from algae is very high. More energy is required for producing biofuels as a large number of steps like flocculation, floatation, centrifugation, sedimentation and filtration are present.

Fourth Generation (4G) Biofuels

Metabolically engineered algae (MEA) are the feedstock of Fourth Generation (4G) biofuels. MEA has high yield along with high lipid content which is essential for cost effective and sustainable biofuels. The major disadvantage is that initial investment is very high. However, research in this field is at a preliminary stage.

Current status & Future prospects of Biofuels in India

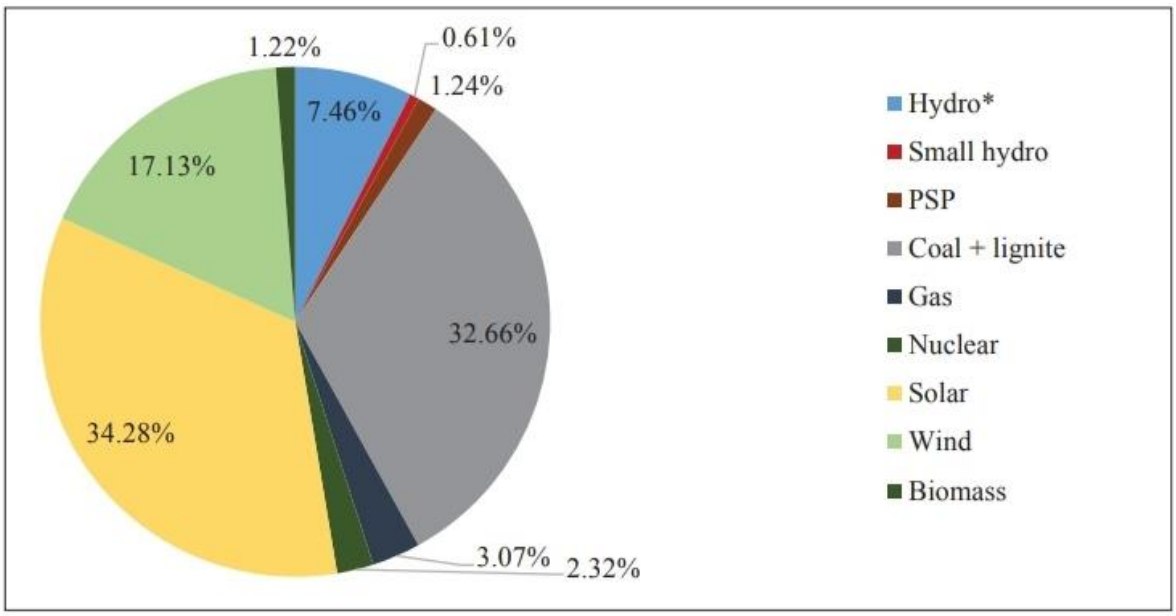
The significance of the biofuel sector to address the issues of energy security has been well established. Government has undertaken multiple interventions to provide biofuels in the country and now India has become the leading market in renewable energy. India ranked third position in Renewable Energy country Attractiveness Index, RECAI-2021 [20]. India has always shown its willingness in leadership to combat climate change. India has progressively decoupled economic growth from greenhouse gases emission. Even though India Supports the second largest population in the world, India's sustained efforts have ensured that its per capita CO_2 emissions are much lower than the global average. Government continuously promoting biofuel production from indigenous feedstocks. India is endowed with abundant and diversified biomass. Therefore, their maximum exploitation in an environmentally friendly and cost-effective manner is encouraged in every possible way.

Many Structured Programmes like Ethanol Blending Petrol Programme, National Biodiesel Mission, Biodiesel Blending Programme along with different schemes PM JI-VAN Yojana, GOBAR DHAN Scheme, RUCO Scheme etc. are implemented and now these are revamped by taking steps on pricing, opening alternate route for ethanol production, incentives, focus on R & D etc. Outcomes of these efforts are reflected in our achievements. Ethanol blending percentage in petrol rose sharply to10% in May, 2022. 20% ethanol blending started in 11 States and Union territories. In April ,2023 twelve Commercial plants and ten demonstration plants of 2G Biorefineries based on agricultural Waste as feedstock have been proposed to build under the Pradhan Mantri JI-VAN (Jaiv Indhan - vatavaran Anukool Fasal Awashesh Nivaran) Yojana with adequate biomass supply [16]. These biorefineries are based on diversified feedstock like rice Straw, cotton stalk, Wheat stalk, soy Stalk, maize, Corn Cob, Bamboo etc.

The 2G ethanol biorefinery at Panipat is already started in 2022 which is a rapid stride in biofuel production in the country. Biorefinery is parallel to petroleum refinery which is based on biomass feedstock and through environmentally benign greener methods biofuels along with many green products can be obtained. Actually, biorefinery is the sustainable processing unit of biomass into a spectrum of bio-based products and bio energy. It can provide a sustainable approach to valuable products that can also improve biomass processing economics as well as environmental footprint. (17)

India is developing a good ecosystem for greenpreneurs for greening India with growing India. Green credit Programme is initiated to incentivise environmentally sustainable and responsive actions by individual and local bodies. For maximum utilization of our rich biodiversity different schemes are implemented. GOBAR DHAN Scheme is managing and Converting cattle dung and solid waste in farms to useful compost, biogas and bio- CNG. RUCO (Repurpose Used cooking oil) scheme focuses on developing an ecosystem which can enable the collection and conversion of used cooking oil to biodiesel under SATAT (Sustainable Alternative Towards Affordable Transportation) scheme. CBG (Compressed Bio Gas) plants are being commissioned across the country. India is also launching the Global Alliance on biofuels along with big players of biofuels USA and Brazil during India's presidency of G 20.

India is one of the fastest growing economies having demographic dividends. Therefore, along with the growth in India energy demand will rise 3% annually from 2021 to 2030 [19]. Plenty of biomass is available ranging from peak of mountain to depth of ocean and currently they are partially utilized. Estimated biomass availability is 750 MMT per year while surplus biomass is 230 MMT per year. It is projected that the installed capacity of energy by the end of 2029-30 is more than 800 GW and of which non fossil fuel would be 500 GW [18].



Source: Central Electricity Authority

Figure 9. Projected optimal mix of installed capacity for 2029-30

Thus, bio-electricity and biofuels will be an efficient means of meeting some of the Sustainable Development Goals (SDGs); Affordable and clean energy by the year 2030. The aim of India is to achieve Net zero emission by 2070 with short term targets; reducing cumulative emissions by one billion tonnes, reducing emission intensity of India's Gross Domestic product (GDP) by 45% and increasing renewable capacity to 500 GW by 2030. So, biofuels have a greater role in reduction of emission along with energy security. However, many challenges are being faced by the biofuel sector in India.

Challenges

- The initial Installation cost of biofuel plants especially 2G, 3G and 4G are very high.
- Very few developers are interested in bio qual projects.
- The regulatory framework and procedure are different for different states and coordination among many states and the central government is not well. Inter- institutional Coordination is also poor.
- Biomass has diversification. Different states have different biomass and accordingly, different technologies are required.
- Infrastructure development for biofuel in rural areas, rural- Urban Continuum is crucial but the State government is not rapidly developing them.
- Well established research centres on biofuel are very few.
- Insufficient institutions and laboratories are present for certification and quality control.
- Trained and Skilled persons for demonstrating training operation and maintenance of plants are not enough.
- Biomass market is facing a demand and supply gap.
- Supply chains for biomass are not properly developed.
- Indigenous techniques are required but R&D is very slow.
- Life Cycle Assessment (LCA) is not done on a large scale while diversified feedstocks are there. So environmental benefits for technologies are not clearly understood.

Recommendations: -

Total installed capacity of bioenergy is 10.61 GW and India has potential to become a biofuel hub. The bottleneck in the development and production of biofuels are already analysed. India should work on these inhibitors. R&D on biogas from lignocellulosic biomass, pretreatment of paddy straw hybrid biorefinery, biomass-based biofuel cell, biohydrogen separation through membrane technology are in progress. India should strengthen its existing alliance and forgo new ones to harness globally available technology on biofuels. R&D should be in mission mode. Funding for R & D should be top priority because only technology can make clean energy sustainable.

- Enough green budgeting, green credit should be focused.
- Industry - academia partnership should be well developed.

- Vocational courses on biofuel technology should be designed and properly run in higher educational institutions.
- People should regularly be trained with regard to new technologies.
- Local bodies should be involved in campaigning and supply chain development.
- App based supply chain should be developed.
- For social recognition of renewable energy, continuous awareness programmes should be organized across the country.

With comprehensive policies, regulation framework, coordinated actions of stakeholders in mission mode the obstacles in the biofuel sector must be removed.

Conclusion

A sincere journey on the path of renewable energy across the world started after the first oil crisis in 1973. From the last 50 years, we all moved forward continuously in the field of renewable energy in order to reduce the import of oil & getting energy security, reducing greenhouse gases for combating climate change but we are far behind on our ambitious goals. India has the opportunity to become a leading country in the field of biofuel due to its geographical situation, economy, sincere workforce and overall good leadership and initiatives taken by the government. For sustainable development in the era of circular economy, energy security has to be provided without compromising the economies, society, culture and environment. So, adoption of green methods and green chemistry in technological advancements is required. India can rapidly grow in the field of biofuel. Significant research in 2G and 3G biofuels along with hybrid biorefinery plants development is urgent for the bioenergy economy. Proactive efforts of all of the stakeholders; policy makers, scientists, academicians, government and private companies, local bodies can establish biofuel a very significant position in the renewable energy mix for translating our climate pledge into action. The journey of India on the wing of biofuels has a lot of experience which will be valuable to other developing nations to undertake energy transitions towards a more sustainable future.

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