International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 07 Issue: 08 | Aug 2020 www.irjet.net p-ISSN: 2395-0072

Biofuels for Internal Combustion Engines: A review on Economically Sustainable Biofuel

Garvjeet Dahiya [1], Aman Deep Singh [1], Deepak Katiyar [1], Gaurav Thapliyal [1], Hemang Teotia [1], Ankur Dixit [2]

[1]Dept. of Mechanical Engineering, ABES Engineering College, Ghaziabad, U.P., India
[2]Professor Dept. of Mechanical Engineering, ABES Engineering College, Ghaziabad, U.P., India

---

Abstract - *Internal combustion engines are a major contributor to urban air pollution mainly in developing countries. Environmental degradation, climate change, and continuously increase in the number of pollution related health problems are the result of the rapid usage of fossil fuel mainly by the transportation sector. New technologies like electric vehicles, hybrid vehicles, electric propulsion are still under research and development stages, no doubt shifting to electric propulsion will result in a huge dip in harmful emission. To fill the gap between the internal combustion engines running on gasoline or petro diesel and electric propulsion which is under research, efforts have been made to utilize the bio-fuels blended with fossil fuels to reduce and to keep the emissions under check. The review is aimed at exploring different types of available biofuels, fuel additives, and the sustainability of these bio-fuels, challenges with bio-fuels and the possibility of improvement for their usage in different internal combustion engines.*

Key Words: **Internal Combustion Engine (ICE); Environment; Methanol; Ethanol; Butanol; Biodiesel; Sustainability; Biomass; Supply Chain.**

1. INTRODUCTION

Energy is the lifeline of scientific, technological and economic development of a country. The country's energy choice affects climatic changes, economic and political growth, foreign relations, and international alliances.

Over the time many developed Nations utilized the fossil fuels at that extent that now the developing countries are shown as the major culprit for the effect of increase in pollution, moreover, the developed Nations have shifted their production facilities overseas as to get rid of the increasing pollution, this has created pollution hotspot on the globe.

Still many developing Nations are completely dependent on the fossil fuels for their basic energy needs like generation of electricity and transportation through a lot of work is going on improving the engine efficiency for internal combustion engines and to reduce the emissions, but continuous dependency on conventional fuels not only result in harmful emissions but also in erosion of resources at a much faster pace that would ultimately result in an exhaustion of conventional resources.

Resolution adopted by the General Assembly of United Nations on 25th September 2015 stating about the immense challenges for sustainable adopted a firm resolution to shift on renewable energy for all the energy needs of All the Nations, as the research and development boosted significantly in the area of renewable energy for transportation sector by developing electric propulsion for automobile and still the research is going in the field of electric propulsion for aircrafts, but we need to understand that the shift it will take some time to emerge as fully reliable as well as economical for all the sections of the society, till then there is a need of an alternative source of fuel for transportation sector that is eco-friendly as well as produces less harmful emissions.

2. METHANOL

The utilization of alcoholic drink in IC Engine as fuel has been viewed as an alternative since the hour of advance of the inward combustion engine (ICE) since a component of the motor were intended to work with liquor as fuel with the distributor point of overhauling steam motors as the innovation of motor as the origination of motor architectural plan program improved. Methanol has been the fuel of decision for Indianapolis-type conclusion Capital of Hoosier State since the 1960s because of its predominant presentation demonstration just as security surety traits. Methanol, nonetheless, lost support keep as a significant fuel for the most part because of the disclosure of oil stores rock oil fund from which vitality could be determined that was progressively practical. Enthusiasm for the utilization of alcohol as fuel was revived during the 1973 oil emergency when the Organization Administration of Arab Petroleum Rock oil Exporting Countries Commonwealth Country (OAPEC) authorized some western nation's country for the help of Israel, which brought about an expansion in cost monetary value of oil inferred items. Subsequently, an investigation probe investigation was directed in 1973 through which a motor was created with entirely attractive gas mileages mileage and moderately lesser contamination when a methanol-gas mix wood spirit -gas mixing was utilized as a vitality source informant [1] [2].

Before long, in 1975, Volkswagen utilized a 15% mix of methanol-gasoline methanol-accelerator line. Strangely, the utilization use of methanol as a vitality source brought about a more noteworthy octane rating of the motor fuel and there was a greater amount quantity of motor power than with utilization of unadulterated gas. Correspondingly, 84 vehicles fomite were worked with absolute methanol in Ford and Volkswagen Motor organizations, and the motors of the vehicles motor of the fomite had more prominent effectiveness and toughness than the motors motor of gas controlled vehicles.

Utilization of methanol as transportation fluid fuel has a few difficulties and deficiencies. Without a doubt, doubtfulness, methanol has diverse physicochemical qualities, for example, a moderately more noteworthy dipole minute and dielectric consistent, and is miscible with water contrasted with fuel. Besides, when methanol fixation surpasses about 11% in gas methanol mixes, the fuel might be contradictory with a portion of the motor fomite segment. Dimethyl ether (DME), which was first presented as a petro diesel fuel during the 1990s. Methanol is ordinarily utilized for trans esterification of oils and fats got from vegetable issue, creature tissues, and microorganisms micro-organism. The nonappearance of carbon bonds, adherence , essentially encourages in situ steam change variety of methanol at 250 to 350 °C to high virtue hydrogen, with no NOX. Notwithstanding transportation and other portable applications, methanol can be utilized for static applications, for example, power magnate and warmth age. In such a manner, fashion, utilizing methanol as a vitality source can happen in gas turbines turbine of transport vehicles vehicle segments more effectively than gaseous petrol gasoline or light oil distillate divisions while there is less age of NOx and zero SO2 emissions. It is likewise simpler to utilize and more secure to ship than gaseous petrol [2].

When there is a fire and additionally blast, methanol gas focus methyl alcohol gun focusing in the air must be multiple times clock time s more prominent than that of fuel for head start to happen, though its velocity of consuming is right around multiple times less while there is an arrival of one-eighth the warmth, passion, contrasted with gas. The wood alcohol has a lesser brilliant warmth yield and, consequently, fire is less inclined to spread to close by combustible materials than is the circumstance with gas fuel. The general danger of combustibility with the utilization of gas and methanol-controlled vehicles burn ability with the exercise of gas and wood alcohol -controlled fomite was tried and it was uncovered that with gas controlled autos, automobile, the start of the fuel was progressively quick and completely inside interior minutes when the spilled fuel was exposed to open fire. Conversely, with methanol, wood spirit, there was no combustibility for a three-overlap longer thirstier time and the fire was limited to just the back binding of the vehicle. Because of this examination, testing, the Environmental Protection Agency inferred that substitution of gas with methanol wood spirit would diminish the fuel-related fire occurrences by 90%. Furthermore, methanol wood spirit consumes all the more neatly, decreasing the dangers danger of smoke inward breath related wounds, and all the more plainly, bringing about a light blue fire that is noticeable much of the time and is effectively discernable [1].

3. ETHANOL

Ethanol, a biofuel, is the main briny liquor that is utilized as human refreshment recreation diversion except if it is denatured. The utilization of ethanol grain fermentation alcohol caryopsis alcohol as an illuminant in light within oil visible radiation fossil crude oil just as a warming thawing source seed goes back rear backbone butt to the seventeenth century [16]. From there on, ethanol ethyl alcohol was utilized as a fuel in the main American ICE Glass model framework planned by Samuel Morey and that structured by the High German specialist, Nikolas August Otto, in 1826 and 1860, separately.

In 1896, Joseph Henry Ford and associates familiar fabricated their first quadricycle vehicle that had an ethanol-fueled grain alcohol -fuel motor. Since that time, prison term, different ethanol mixes have been utilized in various kinds of gas-fueled vehicles petrol -fueled fomite. Quantities of gas controlled autos that were constructed surpassed those of the liquor fueled partners better half one-half predominantly because of the divine revelation of oil stores stock that prompted gas being at a financially upper hand bridge player minus in nations with oil stores when contrasted with utilization of ethanol as a fuel source [1].

To be sure, interests pursuit in utilizing ethanol ethyl alcohol as a transportation fuel were restored during the 1970s because of an expansion in oil costs, price , because of global exchange commutation obstacles, straightforwardness, and accessibility availability availableness of ethanol generation and refining purification advancements, just as similarity of ethanol with ICE. All the more explicitly, ethanol accommodates a more prominent pressure insistency proportion, shorter consume time, time, and more noteworthy lean consume in ICE than gas. These favorable circumstances lot result solvent from the more extensive ethanol combustibility, burn ability , higher octane number, turn numeral , bit , more prominent fire speeds swiftness fastness and warms of vaporization [3].

It is worth to refer to that octane number is a standard turn is a banner proportion of value that demonstrates against thump properties of a given fuel. The higher the octane number, the less is the powerlessness impotency of the fuel to clap because of untimely consuming in the chamber. Ethanol, be that as it may, has just 65% of the vitality life force thickness of fuel (yet 25% more prominent vitality energy content than methanol), lesser smoke pressure qualification, low temperature ignition troublesome, and lesser fire blast attack radiance. Different impediments of ethanol incorporate destructiveness and boundless miscibility with water. While motor "cold turning over" can be significantly improved by mixing ethanol with fuel, the expansion in the instability unstableness of ethanol (fume pressure) can bring about increment growth in evaporative discharges after burning [3].

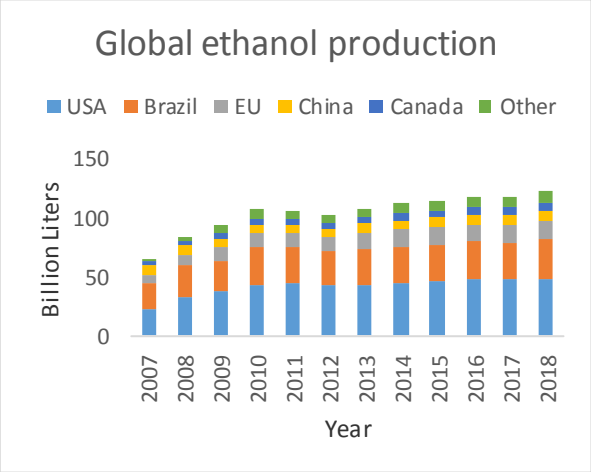

Chart -1: Global ethanol production from 2007 to 2018.

Around 80% of the worldwide generation of ethanol originates from maturations growth grain alcohol originates from festering ontogenesis while the staying 20% originates from a twenty % originates from a chemical substance chemical compound blend through hydration of C2H4 quaternary from gaseous petrol and oil colour . In 2018, absolute worldwide ethanol generation was roughly 108.14 billion trillion 108.1quaternity billion gazillion L for the most part from corn whiskey and sugarcane maturations that was about a 118% expansion underway when contrasted with the sum essence kernel created in 2007. The aggregate sum 200septenary. The totality inwardness of biofuel generation arrived at 143 billion litres in 2017 (~9 times meter expanded contrasted with its creation in 2000) with the ethanol as the biggest biofuel (representing about 95% of worldwide biofuel creation in 2008). The world driving fuel bioethanol makers U.S.A. and Brazil creating over 85% of the aggregate sum of bioethanol delivered all around from 2007 to 2018. China is the fourth quarter twenty-five percent largest ethanol maker with the sum created being just 2.7% of the worldwide ethanol generation in a similar period. Notwithstanding, China improved its creation share in 2018 coming to 4% of worldwide fuel ethanol while the USA United States of America and Brazil generally kept the comparative worldwide offer as 2007- 2018 (i.e., 84%).This stamped distinction in profitability between USA-Brazil and China might be because of feedstock accessibility handiness and cost. The bounty of sugarcane and corn in Brazil and the

USA, separately, seem to encourage the creation of bioethanol in the two nations [5].

Production of Ethanol from different microbes are listed in the table, below

Table -1: Sources of production of Ethanol

Microorganism	Advantages	Limitations	Reference
Yeast *Saccharomyces cerevisiae*	-High production of bio ethanol -Animal feed supplements from remaining of cells. -Use in commercial feed stocks -High alcohol yield (typically 90%)	-lignocellulosic hydrolysates produce less volumes of ethanol	[6]
Bacteria *Zymomonas mobilis*	-Very fast ethanol production up to 96% and 122 g/L -Presence of hopanoids-containing plasma Produce high tolerance to ethanol (vol/vol, ≥13%) -Higher ethanol yield (up to 10 % or more ethanol per fermented glucose) -No controlling of oxygen is required -Successful industrial scaled trials	-Difficulty in recombination of ethanol -Narrow pH range -No commercial plant	[7]
Escherichia coli	-Fermentation in all lignocellulose-derived sugars - -High temperature for fermentation -No requirements	-Small temperature and pH (6.2-8.1) growth ranges -Acetic and succinic acids are	[8]

	for complex growth factors	byproducts	
Klebsiella oxytoca	-Theoretical maxima reached in terms of production of ethanol	-Non availability of commercial production	[9]
	-Compatible with low pH ~5.2 at temperatures around 32°C -Minimization of waste by products		

4. BUTANOL

Butyl alcohol is a four-carbon alcohol with a trademark banana-like scent. The high vitality substance smell. The high school animation meaning gear vital force gist of butanol, butyl alcoholic beverage, its hydrophobicity and glimmer point, distributor point, make it a potential substitute fill-in backup for gas and petro diesel motor as fuel sources. The other alluring characteristics of this C4-fluid vitality source incorporates low instability, Low unstableness, miscibility, and octane-improvement property [38]. The moderately more prominent warmth affectionateness of vanishing for butanol butyl alcohol brings about a lesser burning at the stake temperature and diminished NOX outflows comparative with numerous other vitality sources [39]. The fanned structures isomers of butyl alcohol, for example, 2-methyl-1-butanol, 2-methyl radical group -I -butanol, 2-methyl-single -butanol, 3-methyl-1-butanol, and isobutanol likewise have high octane numbers and attractive fuel and fuel added substance properties [1] [10].

A significant restricting constituent for the utilization exercise of biobutanol as biofuel, nonetheless, is its low fixation regression in the bioreactor during (CH3)2CO butanol ethanol (ABE) maturation, which is 8 to multiple multiplication not as much as that of ethanol created by berm senescence . The low butanol fixation in the aging endless provision of ABE aging is because of butanol deadliness lethality to the aging microorganisms at low focal point.

Table -2: Methods of preparation of Butanol

Technique	Extraction process	Recovery process	Achievements	Limitations
Gas stripping	Fermentation by using oxygen or nitrogen gas	Enriched ABE gases cooled down in condenser for recirculation	Relative increase in production and decrease in toxicity	Reduced stripping rate for Butanol
Liquid-liquid extraction	Organic solvents are used in extraction	Recovery of solvents by fractional distillation	Relative increase in production and decrease in toxicity	Fermentation rate decreases gradually
Perstraction	Membrane contactor provides larger surface area for immiscible phases to exchange the butanol	Diffusion of Butanol across the membrane	Relative increase in production and decrease in toxicity	Reduced extraction volume. Fermentation losses. Expensive process.
Pervaporation	ABE solvents individually get to adsorbed onto the surface of either hydrophobic or hydrophilic membranes	Solvents in dissolved phase get absorbed into the down side of membrane surface	Relative increase in production and decrease in toxicity	Reduced extraction volume. Fermentation losses. Membrane deterioration.

5. BIODIESEL

The literature review provides an idea of biofuels, and their current and future usage along with the sustainability of biofuel in internal combustion burning engines as well as the

future perspective in the emerging field of biofuel energy [12].

From the literature review, it becomes clear then the biofuel is still a minor source of energy generator of free DOE worldwide, as till today, fossil fuel caters to about 80% of the world's energy needs. Biodiesel is one of the promising alternatives to the conventional fuel of internal combustion engines. Biodiesel can be produced by combining any natural A blend of biodiesel can be produced by mixing soybean and methanol by trans esterification in the presence of an acid catalyst to boost the rate of reaction [13].

Table -3: Fuel Properties

Fuel Properties	Biodiesel	Petro diesel
Density at 15°C, g/cm^3	**0.8833**	**0.8338**
Viscosity at 40°C, mm^2/s	**4.46**	**2.84**
Sulphur content, %	**<0.006**	**0.033**
Carbon content, %	**76.2**	**86.3**
Hydrogen content, %	**11.9**	**13.7**
Oxygen content, %	**12.2**	**--**
Flash point, °C	**176**	**63**
Cetane number	**54**	**47**
Net Calorie value, kJ/kg	**37242**	**42588**

Biodiesel presented itself as the most promising renewable and sustainable fuel for internal combustion engines for automobiles. Biodiesel from soil crops like soybean, rapeseed, jatropha palm oil, sunflower, waste food oil, canola oil, cottonseed, coconut and animal fat.

The feedstock depends on geographical conditions, soil and climatic condition of the region for visible growth of plants Lipase catalyst, an acid catalyst, and an alkali catalyst.

Table -4: Production of Biodiesel

Catalyst	Sources	Remarks
Lipase	Microalgae-fats, Marine Algae	Cost effective, less purification steps involved, improves separation of bio diesel, 80-85% extraction, re-usable
		anzyme.
Alkali	Sodium Hydroxide, Potassium Hydroxide, Carbonates, Alkoxides	Higher catalyzing speed, good corrosive resistance properties, sensitive to water content, separation of biodiesel via Saponification reaction, alkali catalyst need to be

oil with an alcohol crude with an inebriant such as methanol or ethanol, chemically.

Vegetable oil can be easily combined with the methanol for commercial use. Research has shown that the energy density of biodiesel and Petrol diesel is quite close.

Similarities between combustion properties of a regular petro diesel and biodiesel are listed in the table below:

from which their oil has to be extracted. Conventional mixing buy directly mixing tends to lower down the viscosity of arid vegetable oil but it isn't in Problem of carbon deposition in the combustion chamber and it lowers the mean effective pressure and hence, the engine tends to lose the power. In some cases the engine exhaust is reported to have black soot along with particulate matter, generally, at higher temperatures, the pyrolysis cracking is difficult to control, when running the engine on biodiesel, provided the condition favorable for conventional petro diesel fuel. The Ester exchange method utilizes triglycerides which are then transformed into monoester, which in turn reduces the viscosity of vegetable oil even at higher operating temperatures for compression ignition engines.

Due to the formation of monoesters, the molecular chain of blend breaks to one-third of the initial size which further increases the cetane number in compressed ignition engines. To break the long Chain of vegetable oils, certain commonly available alcohol groups are utilized, methanol, ethanol, propanol, and butanol proves efficient to further shorten the long chain of hydrocarbons.

Due to the reversibility of trans esterification reaction, the output of biodiesel is influenced by the proportion of reactants, by the type and amount of catalyst and activator and the reaction conditions. Generally, the catalyst used in esterification includes:

		neutralized, water cannot be reused after processing.

The above problem can be significantly reduced by using heterogeneous trans esterification catalysts it provides easy and cost-effective refining of the production of biodiesel and glycerol. Catalyst is reusable and is less toxic. Biodiesel is certainly the cleanest source of energy with a reduced amount of carbon dioxide, sulfur dioxide, carbon monoxide, hydrocarbons and particulate matter as compared to conventional petro diesel fuel. The carbon dioxide reduction can be understood as, the plant would have a considerable amount of carbon dioxide in its life cycle, hence maintaining the carbon cycle and thus, leaving a very less carbon footprint behind and maintaining the logical balance. Due to lower sulfur content in biodiesel as compared to mineralized petrol diesel, it reduces the problem of acid rain hence, it would prevent the water sources, aquatic life, animals and ground vegetation from harmful effects of acid rain.

For the more, it would prevent the corrosion due to acid rain to sculptures and monuments made of calcium stones. It would lead to low particulate matter discharge as the combustion exhaust is much cleaner and extra oxygen molecules present in the ester provides clean burning of fuel. Hence, the use of biodiesel in conventional petro diesel engine when blended in manufacturers allowable blending Ranges not only reduces the pollution by reducing hydrocarbons, aromatic hydrocarbons, sulfur dioxide, carbon monoxide, carbon dioxide footprints, alkenes, aldehydes, ketones, and particulate matter but also is more economical than conventional petro diesel. Though nitrogen oxide emissions are slightly e hire if the engine configuration and operating condition are maintained same as that of conventional petro diesel fuel engines, these nitrogen oxide emissions can be taken care of by optimizing engine using soft wares and biodiesel sensors. Biodiesel works well with new catalyst Technologies, particulate trapping, and recirculation of exhaust gases. Biodiesel extracted from soy plant reduces carbon dioxide by 78% on a life cycle basis, hence, biodiesel possesses more potential than conventional fuel.

Advantages that biodiesel have over conventional petro diesel fuel are higher cetane number, higher flammability, higher flashpoint, easy and safer transportation, higher viscosity, provides better lubrication effect. Most of the leading United States automobile manufacturers and doors the usage of biodiesel, up to a percentage ratio of 10%. A higher percentage of biodiesel blend may cause exercise soot formation. Higher percentages, it can clog engine and fuel filter due to its low viscosity. At high concentrations, it may react with a certain type of rubbers and degrade them.

6. SUSTAINABILITY AND SUPPLY CHAIN

There has always been a dilemma between food production and fuel generation. And also it is a matter of subject that there is always a contradiction between fuel and food prices. In the efforts to decarbonize the transportation industry and vehicles, there is rapid growth in the development of biofuels. It is so because the problems increasing such as greenhouse gas emissions, air pollution and also affected human health very badly. As a result of which there is an increase in the production of biofuels in recent years. Some assets like a maze, sugar cane, and vegetable oils are not only used for the food, feed but also in the making of biofuels and all these are 1st generation biofuels.

Although biofuel production is a small part in comparison to total energy production it is very necessary after seeing the environmental problems. The paper concluded that biofuels produced from grains have raised food prices. As corn and sugarcane are used as feed for livestock and also used in biofuel production so the rate of such type of commodities is increasing. For example, corn is used to make ethanol. Now the demand for fuel in rich countries is contending the food in poor countries.

6.1 Uncertainties and sustainability concepts in biofuel supply chain management:

Biofuels supply chain provides a link between raw materials, refineries, storage facilities, blending users and the end-user. The supply chain helps in the management of biofuels at 3 different levels, i.e., strategic, tactical, and operational. Right now we have 3 generation biofuels and 4th generation biofuel is still in the research stage. The general structure of the biofuels supply chain contains farms, storage facilities, bio refineries, blending facilities, retail outlets, transportation. When all these elements work together the biofuels production and its use can increase in the society.

Decision making in biofuel supply chain:

GP (goal programming) - is used to analyze the efficiency and energy balance of supply chain sustainability. AHP (analytic hierarchy process) is used for decision making, evaluate the priorities of goals.

Strategic decision- it is a long term decision which usually taken in 5 or more than 5 years depending upon the company. When it comes to biofuels its technology is changing according to the biofuels requirement and its application, usually, technology for biofuels is selected based on material availability, sustainability issue, and cost.

Tactical decision- this type of decision is taken for midterm because it contains production decisions, scheduling, and transportation of the goods. This leads to better functioning of strategically decisions.

Operational decision- these are short term decisions (made in daily or weekly) because it contains logistic scheduling, forecasting of demand so that company can analyze its production rate to control their efficiency and material flow.

6.2 Uncertainties in biofuel supply chain:

Uncertainties leads to affect decision making and supply chain performance by creating doubt or uncertainty regarding biomass supply (quality or quantity of biomass), transportation (delivery of raw material), production (production doesn't occur according to the plan or machine breakdown), demand and price (unexpected variation in demand of delivery or change in price of product) of the product.

6.3 Sustainability concepts and models in the biofuel supply chain:

Environmental- some policies have been introduced to decrease CHG and another environmental issue. With an increase in demand for biofuels will encourage more and more farmers to grow crops for biofuel. Biofuels are blending with fossil fuel with different percentages so that they can make a biofuel according to the requirement which causes less damage to the environment but the problem with biofuel is their GEP (global ecological performance) which is worse than fossil fuel and also their large scale production which is difficult to do. At this market share of biofuel in the market rages from 15-20% in 2050. (According to OECD's Energy technology perspective)

The concept of sustainability and its application to biofuels:

Biofuels production around the globe has increased rapidly. In 2008, the production of bioethanol is 69 billion liters in which the US and Brazil are major countries to produce bioethanol (around 90%).reason for an increase in biofuel production is the subsidies and other initiatives provided from government to the farmers. Even when the same material and process are used there is still a difference in biofuel properties. Therefore there are 127 different criteria (made by Delzeit and Holm-Muller) to certify biofuels according to their filtration process.

Initiatives for certification or labeling of biofuels:

Many countries have established their certification criteria for biofuels, for example, Netherland, UK (using renewable fuel obligation), Germany (using international sustainability and carbon certification). Due to the different criteria for sustainability in every country suffer from general adverse perception. Sustainability of biofuels depends upon 4 dimensions: technical, environmental, social, and economic.

6.4 Conclusion

Although biofuel production is a small part in comparison to total energy production it is very necessary after seeing the environmental problems. The paper concluded that biofuel produced from grains have raised food prices. As corn and sugarcane are used as feed for livestock and also used in biofuel production so the rate of such type of commodities is increasing. For example, corn is used to make ethanol. Now the demand for fuel in rich countries is contending the food in poor countries.

REFERENCES

[1] Hamed Kazemi Shariat Panahi1,2, Mona Dehhaghi1,2, James E. Kinder 3, Thaddeus Chukwuemeka Ezeji3, "A review on green liquid fuels for the transportation sector: a prospect of microbial solutions to climate change"

[2] T. B. Reed, R. M. Lerner, "Ethanol: A Versatile Fuel for Immediate Use"

[3] HamedKazemi Shariat Panahi, Meisam Tabatabaei, Mortaza Aghbashlo, Mona Dehhaghia, Mohammad Rehang Abdul-SattarNizami, "Recent updates on the production and upgrading of bio-crude oil from microalgae"

[4] Global ethanol production (billion liters) from 2007 to 2018. Source: AFDC (2018) and RFA (2019).

[5] 2019 ETHANOL INDUSTRY OUTLOOK, https://ethanolrfa.org/

[6] Kazemi Shariat Panahi, H., Dehhaghi, M., Aghbashlo, M., Karimi, K. & Tabatabaei, "Conversion of residues from agro-food industry into bioethanol in Iran: an under-valued biofuel additive to phase out MTBE in gasoline"

[7] KORI LYNN DUNN, "ENGINEERING ZYMOMONAS MOBILIS FOR THE PRODUCTION OF BIOFUELS AND OTHER VALUE-ADDED PRODUCTS"

[8] Hamed Kazemi Shariat Panahi 1, 2 Mona Dehhaghi 1, 2 James E. Kinder 3 Thaddeus Chukwuemeka Ezeji, "A review on green liquid fuels for the transportation sector: a prospect of microbial solutions to climate change"

[9] Bhatia L, Johri S, Rumana Ahmad, "An economic and ecological perspective of ethanol production from renewable agro waste: a review."

[10] D.C.Rakopoulos, C.D.Rakopoulos, E.G.Giakoumis, A.M.Dimaratosa, D.C.Kyritsis, "Effects of butanol–diesel fuel blends on the performance and emissions of a high-speed DI diesel engine"

[11] N.Qureshi, V.Singh, S.Liu, T.C.Ezeji, B.C.Saha, M.A.Cottaa, "Process integration for simultaneous saccharification, fermentation, and recovery (SSFR)"

[12] Prof. Dr. George A. Olah Dr. Alain Goeppert Prof. Dr. G. K. Surya Prakash, "Beyond Oil and Gas: The Methanol Economy, Second Edition"

[13] Daming Huang, Haining Zhou, Lin Lin , "Biodiesel: an Alternative to Conventional Fuel"