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# Sustainable Biofuel Production Process: Sources, Prospects and Challenges

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**ABSTRACT:**A **biofuel** is a fuel that is produced through contemporary processes from biomass, rather than a fuel produced by the very slow geological processes involved in the formation of fossil fuels, such as oil. Since biomass technically can be used as a fuel directly, some people use the terms biomass and biofuel interchangeably. More often than not, however, the word biomass simply denotes the biological raw material the fuel is made of. The word biofuel is usually reserved for liquid or gaseous fuels, used for transportation.Biofuels can be classified into two categories: primary and secondary biofuels. The primary biofuels are directly produced from burning woody or cellulosic plant material and dry animal waste. The secondary biofuels can be classified into three generations that are each indirectly generated from plant and animal material**.** The incessant increase in world population growth leading to increased human activities in the form of transportation, industrialization and other economic activities results into high energy demand to satisfy the human socio-economic development. Fossil fuel (Coal, Oil and Gas) based energy generation has been in usefor years which brings about carbon dioxide emission, causing health issues for man and the environment. This study evaluates the impacts of fossil fuels and readily available opportunities in biofuel as an alternative source of energy for sustainable economic development. The continuous consumption of fossil fuel as a major source of energy has contributed adversely to the emission of Green House Gases (GHG) and eventually lead to Climate change. Biomass can be obtained from the following resources wood and agricultural products, landfill and biogas, livestock residues, ethanol/biodiesel and solid waste. Biofuel produced from biomass which can replenish itself quickly after consumption is called Renewable energy. This study focuses on biomass and their various sources.In this research we describe the economic benefit of biofuel for cleaner environment and economic development. Recommendations was made on how to improve on current biofuel production for sustainable energy.

**Keywords:** Biomass, Bioethanol, Biofuel, Renewable energy, Transportation

## I. INTRODUCTION

The dominance of fossil fuel-based power generation (Coal, Oil and Gas) and an exponential increase in population for the past decades have led to a growing demand for energy (fossil based) resulting in global challenges associated with a rapid growth in carbon dioxide (CO2) emissions, poor health service, decline in economic growth, and socio-economic imbalance (Asumadu-Sarkodie & Owusu, 2016a). A significant climate change has become one of the greatest challenges of the twenty-first century. Its impacts may still be avoided if efforts are made to transform current systems. Renewable energy sources hold the key potential to displace greenhouse gas emissions from fossil fuel-based power generating and thereby mitigating climate change (Edenhofer et al., 2011)

Biofuel is a Renewable energy thatisgenerally produced from biomass.Biomass is any organic matter e.g. wood, crops, seaweed, animal wastes that can be used as an energy source. Biomass is probably the oldest source ofenergy after the sun. For thousands of years, people have burned wood to heattheir homes and cook their food.Biomass gets its energy from the sun. During a process called photosynthesis, sunlight gives plants theenergy they need to convert water and carbon dioxide into oxygen and sugars.Ayoub and Abdullah **(2012).** These sugars, called carbohydrates, supply plants and the animals that eatplants with energy. Foods rich in carbohydrates are a good source of energy forthe human body.Biomass is a renewable energy source because its supplies are not limited. Wecan always grow trees and crops, and waste will always exist, hence biofuel is a renewable energy.

**Photosynthesis** :This is the process by which green plants, algae, diatoms, and certain forms of bacteria make carbohydrates from carbon dioxide and water in the presence of chlorophyll, using energy captured from sunlight by chlorophyll, and releasing excess oxygen as a byproduct.

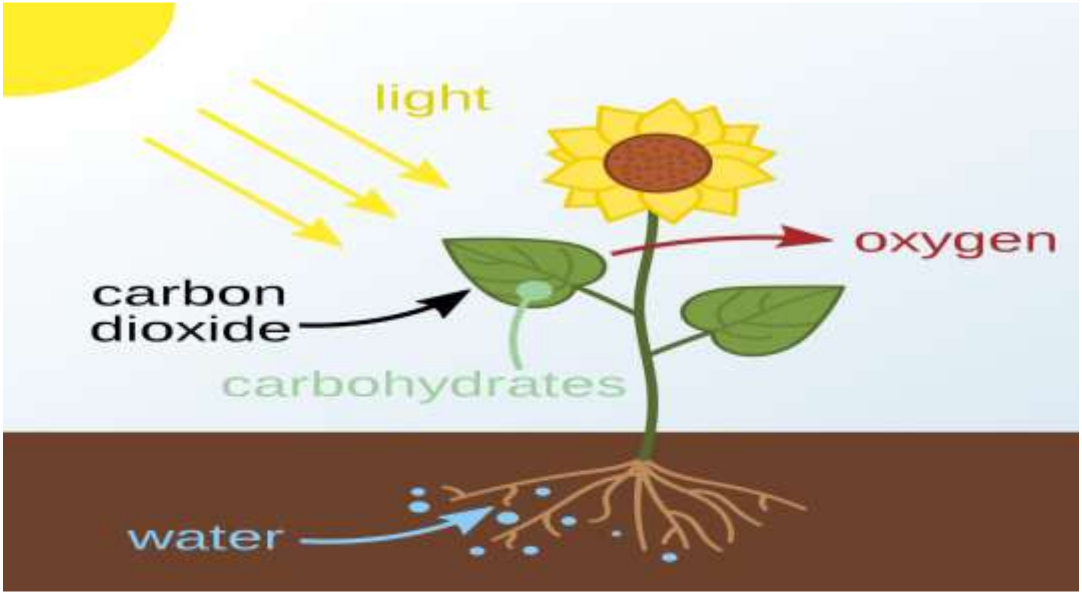


**Fig 1** PHOTOSYNTHESIS DIAGRAM

Biofuel production has enjoyed tremendous growth in recent years due to the prevailing environmental and climatic challenges associated with fossil fuel production.Biofuel growth, however, is not without controversy. There are at least three major ongoing debates concerning biofuels. The first concerns the true environmental impacts of biofuels. Comparing fossil fuel and biofuel emissions only during the end-use stage is shortsighted; what really matters are the emissions over the entire life cycle of the fuel. Thus, emissions at the farm level (for example, due to land use and cultivation of feedstock) and emissions associated with the processing and transportation of biofuels should also be considered. Some of these emissions may be offset as carbon is captured by plant biomass grown as biofuel feedstock, and hence many life-cycle analyses show that biofuels reduce greenhouse gases. Chilakpu (2013).Furthermore, these life-cycle analyses reveal that certain feedstocks are more efficient; for example, a United Nations study shows that Brazil's sugarcane ethanol process has net negative emissions, while America's corn ethanol can sometimes be more polluting than gasoline, depending on how the feedstock is grown and processed (UNEP 2009). Greenhouse effects and global climate change are controversial and critical issues that impact on the energy industry, government policy making, and society. In order to ensure long-term economic sustainability of the energy, transportation, and manufacturing sectors, there is need to look in the direction of renewable and sustainable fuels (Wilk, 2002). These are energy sources with high energy contents and minimal emission of greenhouse gases. Importantly, the resource development and production processes of these fuels should have minimal impact on the food chain, water supply, land use, and environment. Nuclear, solar, geothermal, wind, and biomass are all excellent fuel sources, since they are nearly carbon-neutral.The human race is already, directly and indirectly, exploiting a large fraction, almost half of the total primary production of the planet - through agriculture, fisheries, forestry, and other activities.

Indeed, few productive ecosystems around the world remain in their natural state, not diminished by the actions of mankind. As global ecosystem exploitation and destruction reaches its end-point sometime in the first half of the next century, and natural environments cease to exist outside a few more-or-less protected enclaves, our reliance on the bounties of nature will end. We will then depend entirely on how well we can manage the remaining biological and physical assets of our planet, to sustain the existence of a human population whose current growth rate is only exceeded by its accelerating consumption of natural resources. Asumadu-Sarkodie et al (2015). In addition, we will need to manage these resources within the context of a rapidly changing global environment, with unpredictable climate, ever scarcer raw materials, and diminishing productive land, which is being covered by settlements or devastated by exploitative practices.

If - economic and population collapse - is to be avoided, we must not only curb populations and, but must also develop and implement more efficient and environmentally benign technologies, more available to the large populations currently not enjoying the benefits of our technological economy. Biological energy systems can play an important role in this transformation of the human economy and condition, necessary for our survival through the 21st Century.Our road travel, flights, and shipping account for nearly a quarter of the world's greenhouse gas emissions, and transportation today remains heavily dependent on fossil fuels. The idea behind biofuel is to replace traditional fuels with those made from plant material or other feedstock that are renewable.Biological energy production begins with the photosynthetic fixation of $CO_2$ into biomass (starches, lignocellulosics, etc.) and is followed by conversion of biomass via various microbial processes to fuels (ethanol, methane, hydrogen, oils). Banos et al (2011). In the case of algal production of hydrogen and vegetable oils, both processes are conducted by a single organism. Even in these cases there is a clear differentiation between the photosynthetic processes of $CO_2$ fixation (and oxygen production) and the subsequent conversion of the fixation products to renewable fuels. The production of the waste biomass is of little concern in the conversion of waste materials, such as in methane fermentations. Still, ultimately, the source of all biological fuels is photosynthesis, carried out by plants and algae. The efficiency of photosynthesis is thus, a central issue in the future development of these renewable biological energy sources.

**Table 1; Fossil fuel Energy sources in Nigeria**

| S/N | RESOURCES | RESERVES |
|---|---|---|
| 1 | Crude oil | 36.2 billion barrel |
| 2 | Natural gas | 187 trillion SCF |
| 3 | Coal and lignite | 2.7 billion tones |
| 4 | Tar sand | 31 billion barrels of oil equivalent |

**Source; (Sambo, 2010)**

## 1.2 BIOFUEL AS A RENEWABLE ENERGY AND THEIR SOURCES

Reliable energy supply is essential in all economies for heating, lighting, industrial equipment, transport etc, etc. (International Energy Agency, 2014). Renewable energy supplies reduce the emission of greenhouse gases significantly if replaced with fossil fuels. Biofuel are sustainable in the sense that they will not increase the net $CO_2$ emissions, they should not affect food security nor threaten biodiversity. Brew-Hammond (2010)Renewable energy naturally replenish themselves without being depleted in the earth; they include bioenergy, hydropower, geothermal energy, solar energy, wind energy and ocean (tide and wave). The main renewable energy forms and their uses are shown below.

**Table2; Renewable energy sources and their uses**

| Energy sources | Energy conversion and usage options |
|---|---|
| Hydropower | Power generation |
| Morden biomass | Heat and power generation, pyrolysis, gasification, digestion. |
| Geothermal | Urban heating, power generation, hydrothermal, hot dry rock. |
| Solar | Solar home systems, solar dryers, solar cookers |

| | |
|---|---|
| Direct solar | Photovoltaic, thermal power generation, water heaters. |
| Wind | Power generation, wind generators, windmills, water pump. |
| Wave and tide | Numerous design, tidal steam. |
| Microbial fuel cells | Power generation, street light, lamps |

Source: Central Bank of Nigeria (2007)

**Table 3 Resources and their capacities**

| Source | Capacity | Remark |
|---|---|---|
| Big hydro power | 11,500 MW | Only 1972 MW exploited |
| Small hydro power | 3,500 MW | Only about64.MW exploited |
| Solar | 3.5KW/m/day to 7 KW/m/day | |
| Sunshine hours | 4 to 7.5 hrs. per day | |
| Wind | 2 to 4m/s at10m height mainland | |
| Biomass | Fuel wood | 11milion hectares of forest/woodland |
| do | Animal waste | 245 million assorted |
| do | Energy drops & agric. residue | 72 million hectares of Agric. Land |

Source: Central Bank of Nigeria (2007)

**Table 4: Projected Sectorial Energy Demand in Nigeria**

| S/N | Sector % | Base year 2005 | 2010 | 2015 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|---|---|
| 1 | Industry | 13.81 | 28.92 | 37.01 | 40.75 | 44.69 | 48.78 |
| 2 | Transport | 30.80 | 27.62 | 24.56 | 22.92 | 22.27 | 21.62 |
| 3 | Household | 49.29 | 38.16 | 33.05 | 30.62 | 27.27 | 24.12 |
| 4 | Service | 6.13 | 5.30 | 5.39 | 5.72 | 5.78 | 5.49 |
| | Total Mtoe. | 32.14 | 49.92 | 76.45 | 112.67 | 158.95 | 224.54 |

**Table 5: Energy Production in Nigeria**

| S/N | Type | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|
| 1 | Coal (million tons) | 0 | 0 | 0 | 0 | 0 |
| 2 | Oil (million barrels/day) | 2.3 | 2.5 | 2.5 | 2.2 | 2.2 |
| 3 | Natural gas (billion $M^3$)<br>Flared % | 52.75<br>44.1 | 5976<br>40.4 | 58.35<br>39.4 | 61.80<br>36.1 | 70.1<br>31.1 |
| 4 | Electricity generation(billion $M^3$ | 22.03 | 22.92 | 24.22 | 23.47 | 16.94 |

### 1.3 BIOFUEL PRODUCTION AND CLIMATE CHANGE

Since 1850, the global use of fossil fuels has increased to dominate energy supply, leading to a rapid growth in carbon dioxide emissions. Data by the end of 2010 confirmed that consumption of fossil fuels accounted for the majority of global anthropogenic greenhouse gas (GHG) emissions, where concentrations had increased to over 390 ppm (39%) above preindustrial levels (Edenhofer et al., 2011).Biofuel as an alternative source of energy are clean sources of energy which decreases environmental impacts, produces minimum secondary waste and are sustainable based on the current and future economic social needs. Biofuel technologies provide an exceptional opportunity for mitigation of greenhouse gas emission and reducing global warming through substituting fossil fuel based energy sources Barbier (2002)

## II. METHODOLOGY

### 2.1 SOME BIOFUEL SOURCES AND TECHNOLOGY

Biofuel is a form of energy source from natural and persistent flow of energy widely available in our immediate and everyday environment in the form of biomass. The biomass from which biofuel are produced are highlighted. They include wood and agricultural product, solid waste, landfill gas and biogas, ethanol and/or biodiesel.

**2.1WOOD AND AGRICULTURAL PRODUCT**

Most biomass used today is home grown energy. Wood logs, chips, bark, and sawdust accounts for about 44 percent of biomass energy. But any organic matter can produce biomass energy. Other biomass sources can include agricultural waste products like fruit pits and corncobs. Wood and wood waste are used to generate electricity. Much of the electricity is used by the industries generating the waste; it is not distributed by utilities, it is a process called cogeneration. Paper mills and saw mills use much of their waste products to generate steam and electricity for their use. However, since they use so much energy, they need to buy additional electricity.

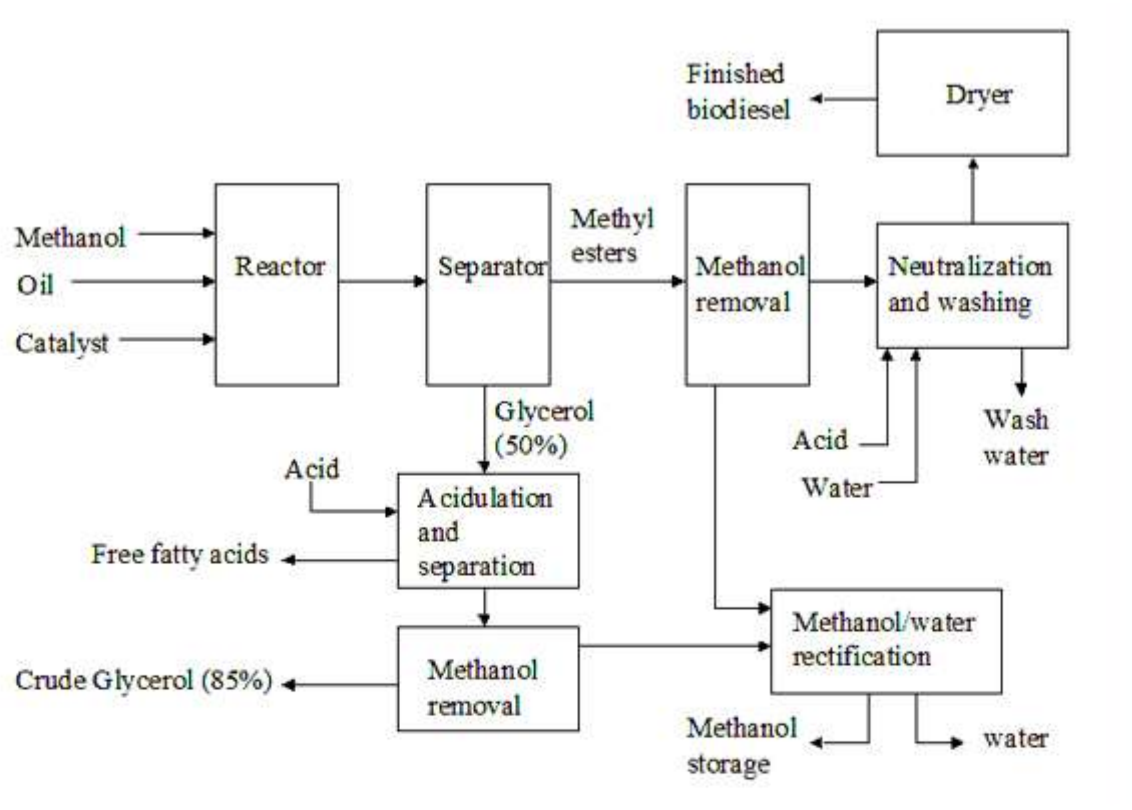


**Fig 2 process flow schematic for biodiesel production**

**2.2 SOLID WASTE**

Burning trash turns waste into a usable form of energy. One ton (2,000 pounds) of garbage contains about as much heat energy as half of coal. Garbage is not all biomass; perhaps half of its energy content comes from plastics, which are made from petroleum and natural gas. Power plants that burn garbage for energy are called waste-to-energy plants. These plants generate electricity much as coal-red plants do, except that combustible garbage not coal is the fuel used to fire their boilers.

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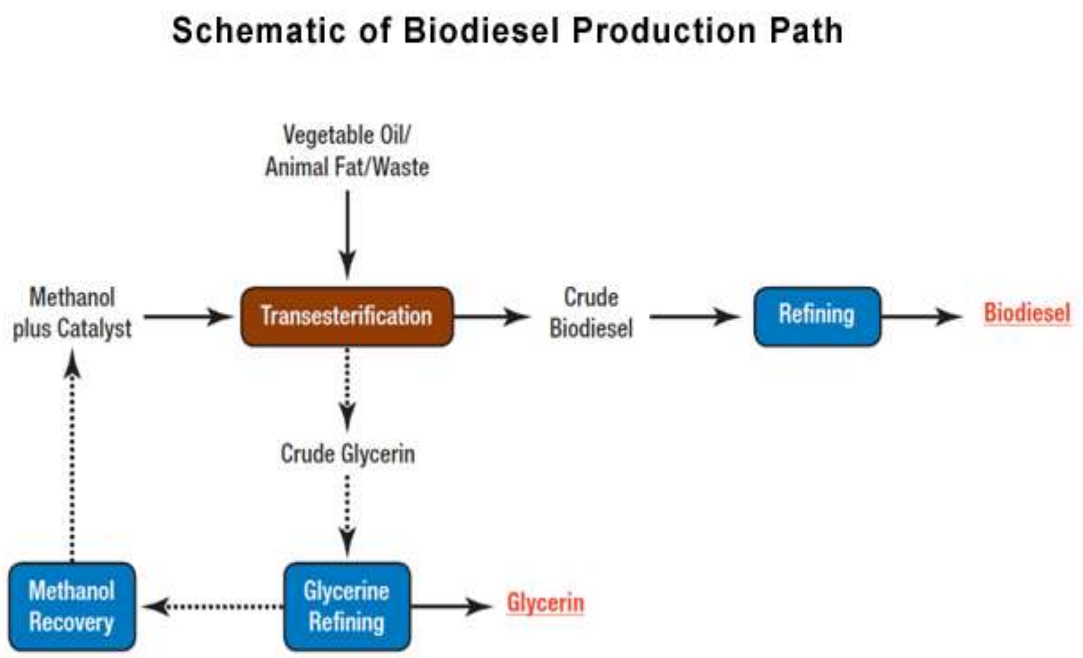


**Fig 3 Schematic of Biodiesel Production Path**

**2.3 LANDFILL AND BIOGAS**

Bacteria and fungi are not picky eaters. They eat dead plants and animals, causing them to rot or decay. A fungus on a rotting log is converting cellulose to sugars to feed itself. Although this process is slowed in a landfill, a substance called methane gas is still produced as the waste decays. New regulations require landfills to collect methane gas for safety and environmental reasons. Methane gas is colorless and odorless, but it is not harmless. Korbitz (1999). The gas can cause fires or explosions if it seeps into nearby homes and is ignited. Landfills can collect the methane gas, purify it, and use it as fuel. Methane can also be produced using energy from agricultural and human wastes. Biogas digesters are airtight containers or pits lined with steel or bricks. Waste put into the containers is fermented without oxygen to produce a methane-rich gas. This gas can be used to produce electricity, or for cooking

2.4 **ETHANOL AND BIODIESEL**

Bioenergy is a renewable energy sources derived from biological sources. Bioenergy is an important source of energy, which can be used for transport using biodiesel, electricity generation, cooking and heating. The annual biodiesel consumption in the United States was 15 billion litres in 2006. It has been growing at a rate of 30-50% per year to achieve an annual target of 30 billion litres at the end of year 2012 (Ayoub & Abdullah 2012). Electricity from bioenergy attracts a large range of different sources, including forest by-products such as wood residues, agricultural residues such as sugar cane waste; and animal husbandry residue such as cow dung. One advantage of biomass energy-based electricity is that fuel is often a by-product, residue orwaste product from the above sources. Presently, global production of biofuels is comparatively low, but continuously increasing. Sambo (2010). Ethanol is an alcohol fuel (ethyl alcohol) made by fermenting the sugars and starches foundin plants and then distilling them. Any organic material containing cellulose, starch, or sugarcan be made into ethanol. The majority of the ethanol produced in the United States comesfrom corn. New technologies are producing ethanol from cellulose in woody fibers fromtrees, grasses, and crop residues.Today nearly all of the gasoline sold in the U.S. contains around 10 percent ethanol and isknown as E10. In 2011, the U.S. Environmental Protection Agency (EPA) approved theintroduction of E15 (15 percent ethanol, 85 percent gasoline) for use in passenger vehiclesfrom model year 2001 and newer. Fuel containing 85 percent ethanol and 15

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percentgasoline (E85) qualifies as an alternative fuel. There are more than 10 million flexible fuelvehicles (FFV) on the road that can run efficiently on E85 or E10. However, just under 10percent of these vehicles use E85 regularly. Palligamai et al (2008). Biodiesel is a fuel made by chemically reacting alcohol with vegetable oils, animal fats, orgreases, such as recycled restaurant grease. Most biodiesel today is made from soybean oil. Biodiesel is most often blended with petroleum diesel in ratios of two percent (B2), fivepercent (B5), or 20 percent (B20). It can also be used as neat (pure) biodiesel (B100).Biodiesel fuels are compatible with and can be used in unmodified diesel engines with theexisting fueling infrastructure. It is one of the fastest growing transportation fuels in the U.S.Biodiesel contains virtually no sulfur, so it can reduce sulfur levels in the nation's diesel fuelsupply, even compared with today's low sulfur fuels. While removing sulfur from petroleum based diesel results in poor lubrication, biodiesel is a superior lubricant and canreduce the friction of diesel fuel in blends of only one or two percent. This is an importantcharacteristic because the Environmental Protection Agency now requires that sulfur levelsin diesel fuel be 97 percent lower than they were prior to 2006.

## 2.5 ETHANOL PRODUCTION METHODS

The production method of ethanol depends on the type of feedstock used. The process is shorter for starch- or sugar-based feedstocks than with cellulosic feedstocks.

### Starch- and Sugar-Based Ethanol Production

Most ethanol in the United States is produced from starch-based crops by dry- or wet-mill processing. Nearly 90% of ethanol plants are dry mills due to lower capital costs. Dry-milling is a process that grinds corn into flour and ferments it into ethanol with co-products of distillers grains and carbon dioxide. Wet-mill plants primarily produce corn sweeteners, along with ethanol and several other co-products (such as corn oil and starch). Wet mills separate starch, protein, and fiber in corn prior to processing these components into products, such as ethanol.

### Cellulosic Production

Making ethanol from cellulosic feedstock's such as grass, wood, and crop residues is a more involved process than using starch-based crops. There are two primary pathways to produce cellulosic ethanol: biochemical and thermochemical. The biochemical process involves a pretreatment to release hemicellulose sugars followed by hydrolysis to break cellulose into sugars. Sugars are fermented into ethanol and lignin is recovered and used to produce energy to power the process. The thermochemical conversion process involves adding heat and chemicals to a biomass feedstock to produce syngas, which is a mixture of carbon monoxide and hydrogen. Syngas is mixed with a catalyst and reformed into ethanol and other liquid co-products. Ogbonna et al (2006)

Photosynthetic efficiencies are the ultimate limiting factor in biological energy production. Currently agricultural and forestry efficiencies seldom exceed 1% of total solar energy input converted to a recoverable product. However, even with current productivity's, the potential for photosynthesis to produce food, fiber, fuel, and forest products is truly enormous. Total primary productivity exceeds current fossil fuel consumption by an order of magnitude. Recently a group of experts projected the potential of improved forest preservation and management and agricultural practices to mitigate the greenhouse effect by sequestering $CO_2$ into long-term biomass and soil carbon and by replacing fossil fuels with biofuels. They concluded that the entire fossil fuel $CO_2$ emissions could be balanced with biological systems (2). In addition, this could be accomplished without diminishing the production of food, fiber, and forest products. Even conservative projections by this group indicated that biological processes could generate greenhouse gas off-sets equivalent to almost half the current annual atmospheric $CO_2$ rise, and at relatively low costs. These actions do not even require the heroic measures of "planetary management" suggested by some, such as increasing primary productivity through trace nutrient fertilization of oceanic and terrestrial environments

## 2.6 PRODUCTION OF BIOFUEL FROM CASSAVA

Cassava (Manihot esculenta), sometimes also called manioc, is the third largest source of carbohydrates for human consumption in the world, with an estimated annual world production of 208 million tons. In Africa, which is the largest center of cassava production, it is grown on 7.5 million ha and produces about 60 million tons per year. It is a major source of low cost carbohydrates and a staple food for 500 million people in the humid tropics. Fresh roots of cassava contain about 30% starch. Cassava starch is one of the best fermentable substances for the production of ethanol. At the moment sugar cane is the most widely used crop for bio-ethanol in the Tropics, but sugar cane requires a lot of water. There are various ways of making biofuels, but they generally use chemical reactions, fermentation, and heat to break down the starches, sugars, and other molecules in plants. The resulting products are then refined to produce a fuel that cars or other vehicles can use.Douglas (2013).Much of the gasoline in the United States contains one of the most common biofuels: ethanol. Made by fermenting the sugars from plants such as corn or sugarcane, ethanol contains oxygen that helps a car's engine burn fuel more efficiently, reducing air pollution. In the U.S.,

Alternatives to diesel fuel include biodiesel and renewable diesel. Biodiesel, derived from fats such as vegetable oil, animal fat, and recycled cooking grease, can be blended with petroleum-based diesel. Some buses, trucks, and military vehicles in the U.S. run on fuel blends with up to 20 percent biodiesel, but pure biodiesel can be compromised by cold weather and may cause problems in older vehicles. Renewable diesel, a chemically different product that can be derived from fats or plant-based waste, is considered a "drop-in" fuel that does not need to be blended with conventional diesel.Other types of plant-based fuel have been created for aviation and shipping. More than 150,000 flights have used biofuel, but the amount of aviation biofuel produced in 2018 accounted for less than 0.1 percent of total consumption. In shipping, too, adoption of biofuel is at levels far below the 2030 targets set by the International Energy Agency. Renewable natural gas, or bio methane is another fuel that potentially could be used not only for transportation but also heat and electricity generation. Gas can be captured from landfills, livestock operations, wastewater, or other sources. This captured biogas then must be refined further to remove water, carbon dioxide, and other elements so that it meets the standard needed to fuel natural-gas-powered vehicles.

## III. DISCUSSION

So-called "drop-in" biofuels can be defined as "liquid bio-hydrocarbons that are functionally equivalent to petroleum fuels and are fully compatible with existing petroleum infrastructure". Drop-in biofuels require no (engine) modification of the vehicle. Some examples of drop-in biofuels include biobutanol, biodiesel, synthetic paraffinic kerosene, and other synthetic fuels.In 2018, worldwide biofuel production reached 152 billion liters, up 7% from 2017 and biofuels provided 3% of the world's fuels for road transport. The International Energy Agency want biofuels to meet more than a quarter of world demand for transportation fuels by 2050, in order to reduce dependency on petroleum.However, the production and consumption of biofuels are not on track to meet the IEA's sustainable development scenario. From 2020 to 2030 global biofuel output has to increase by 10% each year to reach IEA's goal.

Ethanol fuel is the most common biofuel worldwide, particularly in Brazil. Alcohol fuels are produced by fermentation of sugars derived from wheat, corn, sugar beets, sugar cane, molasses and any sugar or starch from which alcoholic beverages such as whiskey, can be made. The ethanol production methods used are enzyme digestion, fermentation of the sugars, distillation and drying. The distillation process requires significant energy input for heat.

Ethanol has roughly one-third lower energy content per unit of volume compared to gasoline. This is partly counteracted by the better efficiency when using ethanol

## IV. CONCLUSION AND RECOMMENDATION

From 1978 to 1996, the US NREL experimented with using algae as a biofuels source in the Aquatic Species Program. A self-published article by Michael Briggs, at the UNH Biofuels Group, offers estimates for the realistic replacement of all vehicular fuel with biofuels by using algae that have a natural oil content greater than 50%, which Briggs suggests can be grown on algae ponds at wastewater treatment plants. These oil-rich algae can then be extracted from the system and processed into biofuels, with the dried remainder further reprocessed to create ethanol. The production of algae to harvest oil for biofuels has not yet been undertaken on a commercial scale, but feasibility studies have been conducted to arrive at the above yield estimate.

Biogas is methane produced by the process of anaerobic digestion of organic material by anaerobes. It can be produced either from biodegradable waste materials or by the use of energy crops fed into anaerobic digesters to supplement gas yields. The solid byproduct, digestate, can be used as a biofuel or a fertilizer. Biogas can be recovered from mechanical biological treatment waste processing systems. Landfill gas, a less clean form of biogas, is produced in landfills through naturally occurring anaerobic digestion. If it escapes into the atmosphere, it is a potential greenhouse gas

Biodiesel can be used in any diesel engine when mixed with mineral diesel. It can also be used in its pure form (B100) in diesel engines, but some maintenance and performance problems may then occur during wintertime utilization, since the fuel becomes somewhat more viscous at lower temperatures, depending on the feedstock used. In some countries, manufacturers cover their diesel engines under warranty for B100 use, although Volkswagen of Germany, for example, asks drivers to check by telephone with the VW environmental services department before switching to B100. There are various social, economic, environmental and technical issues with biofuel production and use, which have been discussed in the popular media and scientific journals. These include: the effect of moderating oil prices, the "food vs fuel" debate, food prices, poverty reduction potential, energy ratio, energy requirements, carbon emissions levels, sustainable

biofuel production, deforestation and soil erosion, loss of biodiversity, impact on water resources, the possible modifications necessary to run the engine on biofuel, as well as energy balance and efficiency. However the process of conversion or chemical transformation, could be very expensive. This might not be worth-while to use for an economical large-scale commercial supply of biofuels. Consequently, there is still the need for much research to be carried out for an effective, economical and efficient conversion process. In other words, this article is written as a broad overview of the subject and includes information based on the research conducted globally by scientists according to their local socio-cultural and economic situations. Douglas (2012)

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