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RESEARCH ARTICLE

HARNESSING BIOTECHNOLOGY FOR SUSTAINABLE BIOFUEL PRODUCTION; CHALLENGES AND SOLUTIONS

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Abstract

Bioenergy is a versatile energy system. A multitude of feedstock, technology pathways, and end products encompass biomass-energy conversion. Amongst the renewable energy options, bioenergy has the unique potential to deliver significant benefits to society and the environment. Considering its prominence in the overall energy mix, the bioenergy sector has not received the desired attention. Its impacts on economic, social, environmental and greener energy factors are numerous. Due to the informal and local nature of most of the feedstock and technology used for biofuel production, it is very challenging to gather, analyze and report accurate and updated information on bioenergy developments. Moreso, it is important to note that there is a lack of reliable and updated data on bioenergy globally and locally. This paper, therefore explored available information on different biomass sources; current statistics on global and national bioenergy demand and utilization, its benefits and challenges; technologies for improving bioenergy production and yield from biomass; current climate challenges, and emerging biotechnology techniques relevant for sustainable biofuel production to meet energy demand and climate challenge.

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Introduction:-

Biofuel is derived from organic material or biomass such as crops, organic wastes, and forest residues. Biomass is a naturally occurring carbonaceous material that is of biological origin and is a complex renewable material with enormous chemical variability. It is considered to be the major source of domestic energy in Nigeria contributing up to 78% of the Nigerian energy supply (Edirin and Nosa, 2012). The poor masses depend heavily on biomass for energy mainly in the form of wood and agricultural residues, with attendant negative impacts such as indoor air pollution and immense pressure on natural resources (Akande and Olorunfemi, 2009). Since trees and crops are natural CO_2 absorbers and storage units, there needs to be a balance between the quantity of biomass harvested for bioenergy and the growth of trees and other plants in forests and fields.

Currently, bioenergy is the largest renewable energy source globally. The realization of the need to urgently change the course of global energy production and consumption, cannot be more glaring than in the most recent occurrences of extreme weather conditions being experienced in different regions of the world. Starting with the huge and devastating wild forest fires to the deluge of water floods in otherwise drought-prone areas; the Ukraine-Russia war and its effect on the global politics and economics of energy demand and supply are all pointers on the need for self-sufficiency in renewable energy production for any sovereign nation.

Classes And Sources Of Biofuels

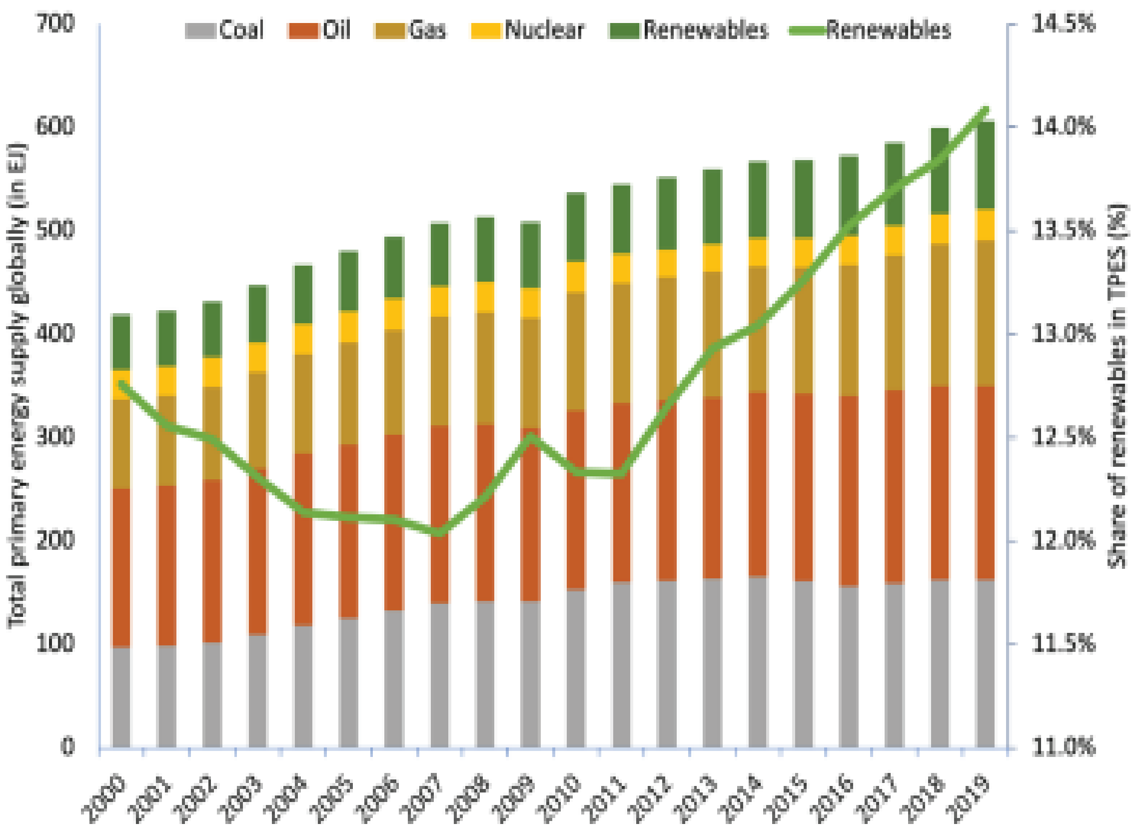
Based on different raw materials, biofuels are categorized into four:

a. First-generation biofuels: produced from agricultural feedstock, vegetable oil, animal fat, sugar, starch, and cereals such as maize and sugar cane among others.First-generation biofuel feedstocks are unsustainable due to food security and landuse.(Kumar, 2015)

b. Second-generation biofuels:produced from non-food sources such as lignocellulose (Graeme, 2011). Lignocellulose is divided into either bio-waste (straws, corn residues, woody wastes, old paper/cardboard, bagasse, spent grains, municipal solid waste, agricultural residues like oilseed pulp, sugar beet pulp) or energy crops such as short rotation coppice (basket willow - Salix viminalis) and energy grasses like Miscanthusgiganteus(Graeme, 2011). The use of lignocellulosic biomass is more sustainable and ethically acceptable and therefore must be promoted

c. Third-generation biofuels: also referred to as advanced biofuels, are producedfrom microalgae and cyanobacteria.

d. Fourth generation biofuel: produced by the photosynthetic generation of biohydrogen and bioelectricity.



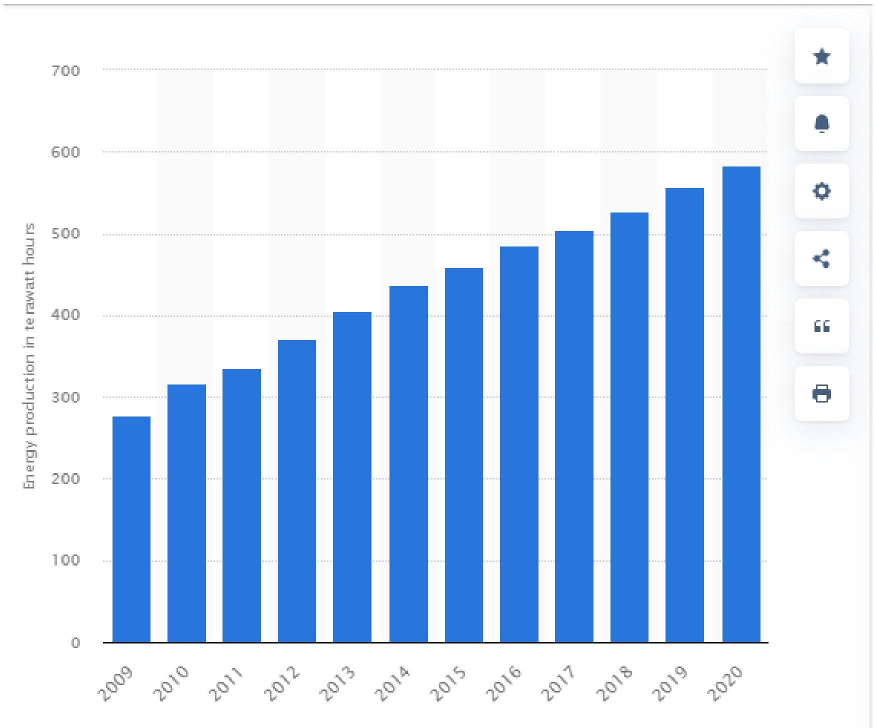
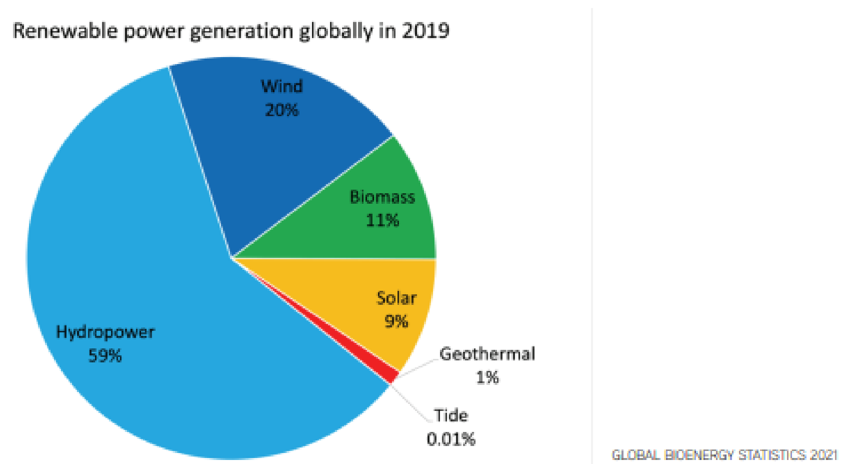


Figure 1:- Total primary energy supply globally and the sources from 2000 – 2019.



Source: Global Bioenergy Statistics 2021

Figure 2:- Pre-COVID Data on Renewable Power Generation.

Types Of Biofuels And Their Mode Of Production

Biofuels, as an alternative tofossil fuels, is attracting global attention, they are liquid or gaseous renewable products that are produced from biomass and are used for either transportation or burningpurposes (Annie, 2006; Segun, 2012).Among these biobutanol, biodiesel, bioethanol, and biogas are predominant which can be produced either using chemical catalysts or biocatalysts from biomassand can greatly replace petroleum fuels.

Biobutanol:

An organic alcohol produced through Acetone-Butanolfermentations using Clostridium acetobutylicum from molasses and cereal grains (C_4H_9 OH) (Manish and Kalyan, 2012; Ruth et al., 2018). It has manyadvantages such as high energy content, high hydrophobicity, good blending ability, does not require modifications in internal combustion engines and is less corrosive than other biofuels (Manish and Kalyan, 2012).

Biodiesel:

A fatty acid methyl ester produced from edible, non-edible oil crops (jatropha, and rape seed), and waste frying oil (Olusegun et al., 2019). is a clean burning alternative to fossil fuel produced by transesterification reaction of fat or oil with an alcohol to give mono-alkyl esters and glycerol (Daniyan et. al., 2014). As glycerol is separated, the fatty acid methyl esters are used as biodiesel. It can be used either in its pure form or as blends with fossil diesel in diesel engines without any engine modifications, it is sustainable, biodegradable, environmentally friendly, non-toxic, and has better combustion characteristics compared to fossil diesel (Annie, 2006; Daniyan et al., 2014). It is also a clean alternative for diesel-running vehicles like trucks and big farm equipment (Rosen, 2021) .

Bioethanol:

This is a promising biofuel produced by fermenting sugars and cereal crops (C_2H_5OH) (Annie, 2006; Ibrahim et al., 2011). The liquid wash from the yeast fermentation of biomass-derived sugars is distilled and used as liquidfuel (Graeme, 2011; Annie, 2006). Bioethanol is produced from sugar cane, maize, and lignocellulose. Bioethanol from lignocellulose is sustainable and has the potential to become a substitute for or replace gasoline (Annie, 2006). Bioethanol can be used in pure form in special engines or blended with gasoline in any proportion up to 10% without the need for engine modification (Annie, 2006).

Biogas:

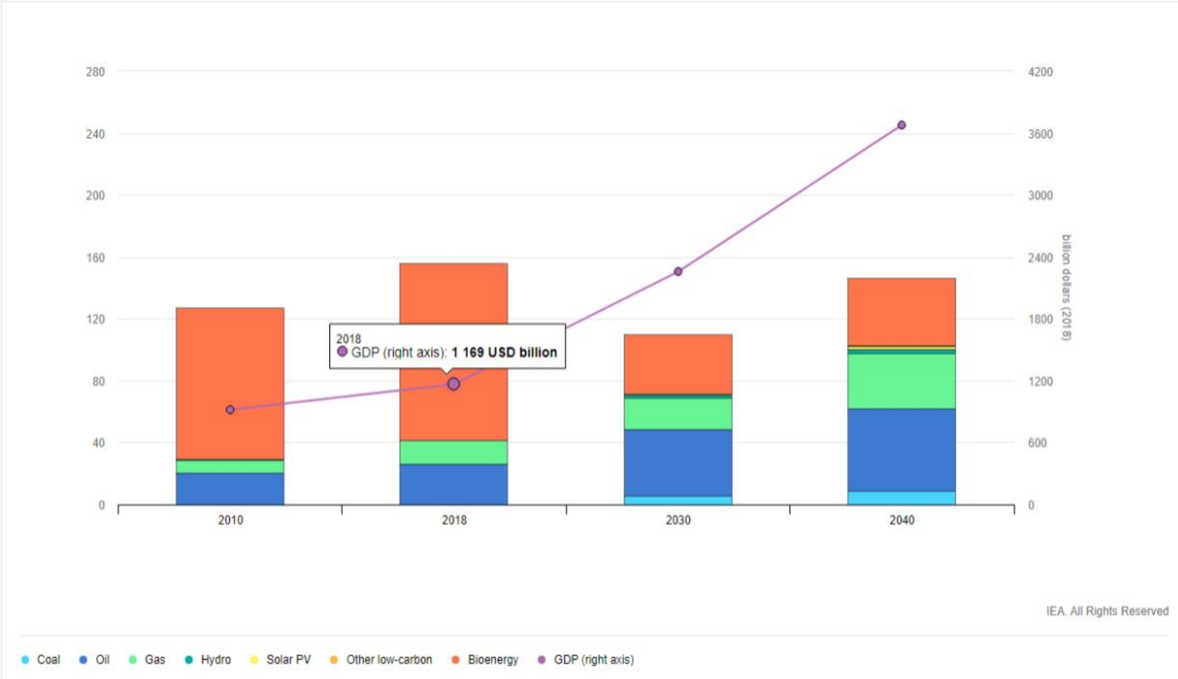
This is a mixture of gases mainlymethane (CH_4) and carbon dioxide (CO_2),produced through anaerobic fermentation of household, agricultural and industrial waste(Juliet et al., 2016). It is mostly used for cooking purposes and can also be used to generate electricity (Edirinand Nosa, 2012; Thomas and Emmanuel 2012). After removal of CO2, biogas can offer more options when upgraded to natural gas quality it could serve as autogas, or distant utilization by using the existing natural gas grid (Guan and Irini, 2012).

Other biofuels include bio-synthetic gas (bio-syngas), bio-oil, bio-char, Fischer-Tropsch liquids, and biohydrogen. The production of energy from biomass requiresthe application of various technologies such as solid combustion, gasification, and fermentation which results in various liquid and gaseous fuels from many biological resources (Akande and Olorunfemi, 2009; Abubakar et al., 2017). The shift towards increased production and use of biofuels is now a global effort and the government of many countries such as Brazil, China, the USA, and Germany has set up many biofuel programs and initiatives, this shows biofuels are important to all nations including African countries (Oshewolo, 2012).

Biofuel Demand And Food Production

The annual global demand for biofuels is set to reach 186 billion liters representing 28% growth by 2026. The United States leads in volume increases, with much of this growth a rebound from the drop caused by the pandemic. Asia accounts for almost 30% of new products over the forecast period, overtaking European biofuel production by 2026. This is due to strong domestic policies, growing liquid fuel demand, and export-driven production. Recent Indian ethanol policies and blending targets for biodiesel in Indonesia and Malaysia are responsible for most of the growth in Asia. India is set to become the third largest market for ethanol demand worldwide by 2026. (IEA, 2022)

On the other hand, biofuels produced from wastes, residues, and dedicated crops that do not compete with food crops (such as crops grown on marginal land) make up 45% of biofuels estimated to be consumed in 2030 in the Net Zero Scenario, up from an estimated 7% in 2020. Today, used cooking oil and waste animal fats provide the majority of non-food-crop feedstocks for biofuel production. Given that these feedstocks are limited, however, new technologies will need to be commercialized to expand non-food-crop biofuel production. For instance, cellulosic ethanol and biomass-to-liquids technologies use non-food feedstocks to produce low-carbon biofuels for use in the transport sector. While the average production cost is still double to triple that of fossil fuel equivalents, it could decline by as much as 27% over the next decade.



Source: IEA, 2020

Fig 3:- Nigeria primary energy demand and GDP in the Africa Case (AC) 2010-2040

Nigeria remains Africa's largest economy: in the AC scenario above, supplying an economy three times larger than today would require less energy demand if the energy mix were to be diversified.In the AC, gas meets a growing share of energy demand, supported by the implementation of the government's gas master plan. This scenario projects that fossil fuels (coal, oil, and gas) will increasingly play a significant role in meeting local energy demands in Nigeria from now to 2040 while bioenergy declines; contrary to the trend in other regions of the world; and this can only change if we harness local bioenergy capacities and appropriate technologies such as biotechnology in a sustainable manner. The IEA Africa energy outlook 2019 in presenting Nigeria's energy opportunities outlook suggests that "reducing bioenergy use across all sectors would bring several benefits, not least because its use is strongly linked to deforestation and air pollution".

Current Climate Challenges and Available Bio-solutions

Climate change is accelerating and its impacts increasing. Human actions are estimated to be causing the planet's climate to change 170 times faster than natural forces. Catastrophic climate change has been associated with an increase in the global average temperature of >3 °C. This level of global warming would probably imply a serious shift in global climate patterns, unprecedented loss of landmass creating large flows of climate refugees, significant risks to regional and global food security, a combination of high temperature and humidity jeopardizing normal human activities, and massive species extinctions having adverse cascading effects on ecosystem functioning and services critical for sustaining humanity.

Limiting the earth's temperature rise to 1.5 °C is thus not only crucial for saving the majority of the world's plant and animal species as well as safeguarding low-lying island states from sea level rise and the poorest countries from climate extremes but also a precautionary step to prevent triggering climate tipping points. According to the 2018 special report by the Intergovernmental Panel on Climate Change of the United Nations, the remaining carbon budget to stand a reasonable chance (66%) of limiting warming to 1.5 °C would be depleted by around 2030.

'Within the broad context of sustainable development, climate change is an issue for which renewable energies can, may or even must play a key role' (Waller-Hunter, 2004). Integration of renewable energy in energy systems is the key measure to meeting the climate challenge, and it plays a vital role in the transition of energy consumption from fossil energy to renewable energy. Biofuels help reduce the carbon footprint of transportation and other industries by efficiently utilizing the planet's carbon cycle. Every gallon of biofuel that replaces a gallon of fossil fuel helps reduce greenhouse-gas emissions.

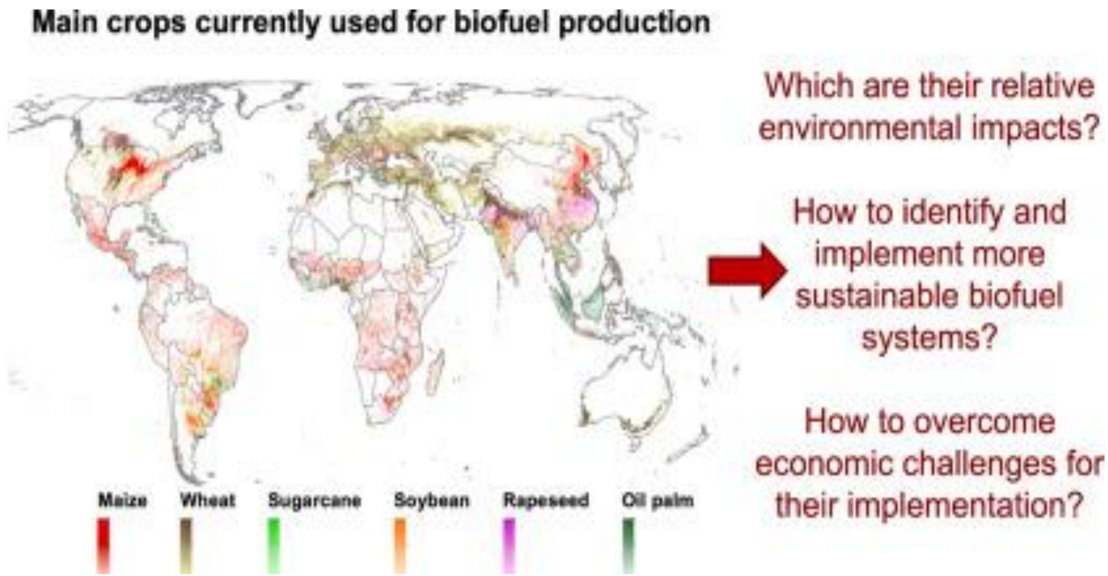
Renewables could supply four-fifths of the world's electricity by 2050, massively cutting carbon emissions and helping to mitigate climate change. Sustainable bioenergy should form a key part of the energy mix alongside solar and wind power for optimum results. Currently, the integration of renewable energy is facing new challenges, associated with the renewable energy access capacity to the power grid, electrical energy storage, renewable energy technology innovation, and policy designs involving market-based mechanisms and administrative policies. The key driving forces are energy transition, renewable energy investment, technology innovation, and related policies. Therefore, it is pertinent to speed up innovation in business and technology toward this goal. This can be achieved by taking possible action to promote renewable energy today.

Several companies are harnessing the natural ability of some microorganisms to break down agricultural or forestry waste to produce fuels. This is one of the goals of the French company Global Bioenergies, which is working with Audi to produce gasoline from sustainable sources such as wheat straw and wood chips. The Swiss firm Clariant is also developing methods to turn agricultural waste into biodiesel in collaboration with ExxonMobil. Other companies such as Solaga in Germany and AlgaEnergy in Spain are researching how to produce fuels from sunlight and carbon dioxide using algae. In Nigeria, the National Biotechnology Development Agency has fabricated mobile biodigesters for the production of biogas (from indigenous biomass and animal wastes) and recently developed optimized systems for methane production (accessed online https://nabda.gov.ng).

Sustainable Production of Bioenergy, Challenges, and Solutions

The current biomass capacity of Nigeria is over 200 billion kg of biomass per year. Since biofuels make use of waste to supply energy, it helps in waste management. It also has the potential to supply more energy (10 times) than the one produced by the sun and wind. Wood fuel and charcoal account for over 80% of the energy that is consumed in households in Nigeria for cooking and heating. Wood fuel accounts for about 94% of traditional biomass that is utilized for household cooking in Nigeria. 46 million tonnes of wood fuel were used in 2014 for domestic cooking in the country. The nation's total energy consumption in 2015 was 121 Mtoe. It was reported that Nigeria has the potential to generate about 62 Mtoe (2.6 billion GJ) of energy from its biomass resources (about 51% of the nation's energy consumption in 2015). The largest resource by far is agricultural crop residue, much of which is currently burnt in the fields. The estimated bioenergy potential of Nigeria's forest residue (8.7 Mtoe equivalent to 363 PJ) is 1.04 times greater than the energy consumed for transportation and four times greater than the nation's electricity consumption in 2015. The costs of transportation energy (pump price of oil products) and electricity in Nigeria are still high despite the huge amount of biomass that is available in the country, from which clean and renewable fuels or energy can be produced.

Lignocellulosic biomass—the fibrous, non-edible part of plants—is an abundant domestic resource that can potentially provide a renewable feedstock for advanced biofuels. A key component to producing market-competitive lignocellulosic biofuels lies in developing more efficient and cost-effective ways to break down the tough, complex structures of the cell walls in cellulose into sugar and efficiently convert the resulting biomass sugars into biofuels.In recent years, biofuels produced from crops have become an increasingly common alternative. However, these crops are starting to compete for agricultural land, which can contribute to deforestation and rising food prices. Here again, the application of biotechnology in the development of non-food high-yielding oil-producing crops like jatropha can be explored.



Advances in synthetic biology—which involves engineering biological systems for new uses—can offer innovative solutions to improve these processes. This, in turn, can speed up the development and commercialization of biofuels, making them attractive and affordable to industrial manufacturers. Advances in biotechnology can help overcome critical bottlenecks in biofuel production, leading to improved process efficiency and reduced operating costs. Ultimately, these breakthroughs will help drive the emerging bioeconomy, and reduce the world's dependence on crude oil and greenhouse gas emissions from the transportation sector, while encouraging the creation of a new domestic bioenergy industry.

Synthetic biology (SynBio) can be applied to biofuel production by either developing more efficient enzymes to break down solid biomass or engineering robust microbes that produce useable biofuel directly. Microbes are being engineered with synthetic DNA to produce novel enzymes—special proteins that accelerate chemical reactions—that can increase the rate at which biomass is broken down. Microorganisms can also be modified to produce renewable hydrocarbon fuels that are identical to petroleum-based gasoline, diesel, or jet fuel. These technological breakthroughs can lead to improved biomass conversion efficiency and reduced production costs.

Conclusion:-

1. Africa's most populous country needs more than 10 times its current electricity output to guarantee supply for its over 198 million people – nearly half of whom have no access. The biomass energy potential in Nigeria is promising, as shown in the above statistics, and it would require heavy investment, stakeholder cooperation, and the development of indigenous technologies.
2. If the abundant bio-resources of Nigeria are harnessed to produce bioenergy, transportation fuels, and electricity, then energy will become more affordable and accessible to the general populace. The deployment of large-scale biomass energy systems will not only significantly increase Nigeria's electricity capacity but also ease power shortages in the country. The power sector of the country will also be stabilized, and electricity supplies provided for rural areas, where agricultural waste biomass occurs.
3. An increase in energy generation will yield more productivity for industries and the rate at which they are shutting down because they spend more on power will be reduced to minimal. Many local factories/companies will spring up and foreign investors will be eager to invest in Nigeria with little concern about power. The establishment of biopower plants will surely create more jobs and indirectly reduce the number of people living in poverty which is increasing every day at an alarming rate.
4. A myriad of technologies exist that have been reported for bioenergy production, and the most sustainable utilization of biomass to energy conversion will be a mix of the following; identifying lignocellulosic biomass for biofuel production,microbial platforms for enzyme production and biofuels, high substrate utilization ability, good tolerance to inhibitors and end products, bioprospecting for native strains with the gene of interest, bioinformatics tools for DNA/protein sequence analysis, genome editing, enzyme immobilization techniques amongst others.

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