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BIOFUEL: A SUSTAINABLE APPROACH TO CLEAN ENERGY SOLUTIONS, TRANSITION, CARBON NEUTRALITY AND GREEN ECONOMY

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ABSTRACT

Fossil fuels contribute to environmental deterioration through carbon emissions, air pollution and resource depletion. Biofuels offer a sustainable alternative, mitigating these impacts by providing a renewable, cleaner energy source. Biofuels, derived from renewable organic materials, serve as an essential component in fostering a green economy by providing an alternative to traditional fossil fuels. The utilization of biofuels supports sustainable practices, contributing to reduced greenhouse gas emissions and mitigating climate change. In the context of a green economy, biofuels play a pivotal role in fuel blending, as they can be seamlessly integrated with conventional fuels to create environmentally-friendly blends. Various crops, such as corn, sugarcane and soybeans, are extensively employed in biofuel production, showcasing the versatility of feedstock sources. This diversification minimizes dependence on a single crop, promoting agricultural sustainability. Despite its potential benefits, careful consideration must be given to the environmental impact of biofuel production, ensuring responsible land use and avoiding deforestation. Additionally, the blending percentage of biofuels in conventional fuels needs to be optimized to strike a balance between environmental benefits and technical feasibility, aligning with global efforts to achieve a more sustainable and carbon-neutral energy landscape.

Key words : Biofuel, Blending, Energy, Environment, Mitigation.

Introduction

Fossil fuels have been the primary source of energy for centuries, but their use has come at a great cost to our planet. The burning of fossil fuels releases harmful greenhouse gases into the atmosphere, contributing to climate change and global warming. In addition, the extraction and transportation of these fuels can have devastating effects on local ecosystems and communities. It is clear that we need to find alternative sources of energy that are sustainable and environmentally friendly. Conventional sources of energy, such as coal, oil, and natural gas, are not only harmful to the environment but also finite resources that will eventually run out. This is where biofuels come in as a promising alternative. Biofuels are derived from renewable sources such as plants, algae and organic waste, making them a sustainable and eco-friendly option. They also have the potential to reduce our dependence on fossil fuels and mitigate the effects of climate change. In 2020, global ethanol production experienced a reduction of approximately 15%, while biodiesel production saw a decrease of around 5%. The International Energy Agency (IEA) anticipates that the global output of transportation biofuels will rebound in 2021 to reach a level of approximately 162 billion liters, similar to that of 2019 (Biodiesel Magazine, 2021).

It is estimated that biofuels will contribute approximately 5.4% of the energy needed for road

transportation (IEA, 2021).

The use of biofuels aligns with the United Nations' Sustainable Development Goals (SDGs), particularly SDG 7, which aims to ensure access to affordable, reliable, sustainable, and modern energy for all. By promoting the use of biofuels, we can reduce greenhouse gas emissions, improve air quality and create new economic opportunities in the renewable energy sector. India has been at the forefront of promoting biofuels through its Biofuel Blending Programme. The programme aims to blend biofuels with conventional fuels to reduce the country's dependence on imported oil and promote sustainable development. The government has set a target of achieving 20% ethanol blending and 5% biodiesel blending by 2030. This initiative has the potential to create new jobs, reduce greenhouse gas emissions, and improve the country's energy security. In conclusion, the use of fossil fuels has had a detrimental impact on our planet, and it is time to explore alternative sources of energy. Biofuels offer a sustainable and eco-friendly option that aligns with the SDGs and can help mitigate the effects of climate change. India's Biofuel Blending Programme is a promising initiative that can serve as a model for other countries looking to promote sustainable development. First-generation biofuels are under scrutiny for two primary reasons. Firstly, they are directly competing with food crops for resources. Secondly, their expected energy, economic, and environmental benefits may not materialize as initially envisioned. Second-generation biofuels are believed to pose fewer risks to biodiversity compared to their first-generation counterparts, potentially even offering positive benefits (IEA, 2010). Many researchers suggest that if biofuel production continues to impact food prices to a similar degree, the population facing food insecurity in developed nations could rise to nearly 1.2 billion by 2025 (Senauer, 2008)

Generations of biofuel

There are four generations of biofuels, each with its own unique feedstock and potential benefits and drawbacks.

- **First Generation Biofuels:** These are derived from existing row crops such as corn ethanol or soy biodiesel. They are processed from vegetable oil, starch, or sucrose, and require simple biochemical treatments for conversion to transportation fuels. However, these crops require intensive agricultural input, limiting their sustainability.
- **Second Generation Biofuels:** These are derived from cellulosic biomass such as perennial grasses, crop residues and trees. They require additional treatment to break down cellulose for creating an end product such as a liquid fuel. Although these crops require little initial input, transporting high quantities of biomass can be a logistical and financial challenge for producers.
- **Third Generation Biofuels:** These are made from algae, which can be harvested for oil or biomass. Algae grow quickly and do not require pretreatment, but controlling the environment for optimal growth is challenging and expensive.
- **Fourth Generation Biofuels:** These are the latest biofuel generation, which encompasses the use of genetic engineering to increase desired traits of organisms used in biofuel production. This applies to a variety of traits from utilizing multiple types of sugars to higher lipid synthesis or increased photosynthesis and carbon fixation. Fourth-generation biofuels hold high promise for the biofuel industry, but further technological developments in up scaling and reduction of production costs are necessary for commercialization.

Despite biodiversity loss being recognized as a significant environmental issue, it is rarely incorporated as an impact category in life cycle assessment (LCA) studies of bioenergy systems (Mortimer, 2016). Each generation of biofuels has its own advantages, disadvantages and the choice of feedstock and conversion process depends on factors such as sustainability, cost, and availability.

Raw materials used for Biofuel production

Bioethanol Crops

Bioethanol is primarily produced from carbohydrate-

Fig. 1 : Different Generations of Biofuel.

rich crops containing significant amounts of sugar or starches. Key bioethanol crops include:

- **Corn:** A major feedstock for bioethanol worldwide, particularly in North America
- **Sugar cane:** Used extensively in Brazil and other tropical regions
- **Sweet sorghum:** An emerging feedstock, particularly in warmer regions
- **Miscanthus:** A cellulosic crop gaining importance for bioethanol production
- **Switchgrass:** A promising cellulosic crop for bioethanol

Biodiesel Crops

Biodiesel is typically produced from oil-bearing crops, although waste materials can also serve as feedstock. Important biodiesel crops include:

- **Rapeseed (Canola):** Dominant feedstock for biodiesel in Europe
- **Sunflower:** A widely cultivated oilseed crop
- **Soybeans:** Primary feedstock for biodiesel in the United States
- **Palm oil:** Commonly used in Southeast Asia
- **Mustard, Camphor, Jatropha:** Emerging biodiesel crops

Additionally, waste materials such as restaurant grease, animal fat and agricultural residue can be utilized for biodiesel production.

Other notable crops include:

- **White sweetclover:** Suitable for biofuel production, particularly in dry areas
- **Hemp:** Highly oil-containing seeds offer potential for biodiesel production

Algae

Algae are a promising feedstock for biofuel production due to their high lipid content and rapid growth rates. Algal lipids are often divided into neutral and polar lipids, with neutral triglycerides (TAGs) being the most significant type of lipid for biodiesel synthesis. Different species of microalgae have different types and quantities of lipids, but the basal levels can be altered by modifying lipid metabolism.

Algae are leading the way in third-generation biofuel production. When utilized for biofuel production, algae offer a significant reduction in CO_2 emissions compared to fossil fuel sources, thus mitigating the trend of increasing temperatures. The production of 1 kg of microalgae involves capturing and fixing up to 1.8 kg of CO_2 (Chisti, 2007).

Various strategies have been explored to enhance microalgal lipid production, including genetic modification, environmental manipulation and metabolic engineering. Some of the most promising microalgae species for biofuel production include *Chlorella*, *Crypthecodinium*, *Cylindrotheca*, *Dunaliella*, *Isochrysis*, *Nannochloris*, and *Scenedesmus*.

It should be noted that while biofuels offer numerous environmental benefits, they do pose challenges related to competition with food crops, land usage and resource requirements. Future research aims to develop advanced technologies and novel feedstocks to address these issues and improve overall efficiency and sustainability.

Types of Biofuels

1. **Ethanol:** Ethanol, a transparent and colorless alcohol, is generated by fermenting sugars sourced from biomass like corn, sugarcane and switchgrass. Its primary application involves serving as a fuel additive to gasoline, with the prevalent blend being E10 (10% ethanol and 90% gasoline) in the United States. Ethanol is also a viable standalone fuel for flex-fuel vehicles, offering a cleaner burn and contributing to the reduction of greenhouse gas emissions, despite having a lower energy density than gasoline.

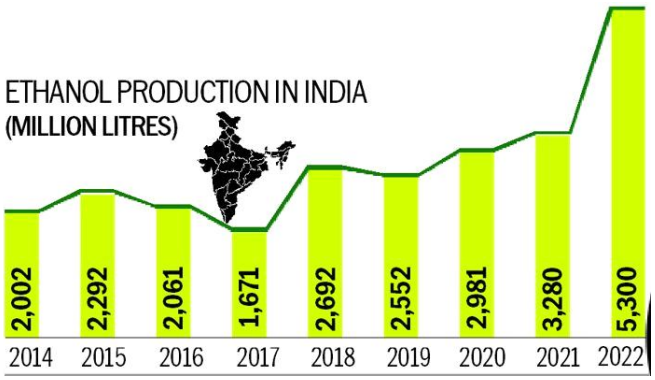

Fig. 2 : Ethanol Production graph in India.

2. **Biodiesel:** Derived from renewable sources such as vegetable oils, animal fats, or recycled cooking grease, biodiesel is a sustainable fuel produced through transterfication. This process separates glycerin from the fat or oil, resulting in a fuel that can replace or be blended with petroleum diesel. While having a similar energy content to petroleum diesel, biodiesel produces fewer emissions of particulate matter, carbon monoxide, and hydrocarbons.
3. **Biobutanol:** A four-carbon alcohol obtainable from biomass like corn, sugarcane, and switchgrass, biobutanol boasts a higher energy density than

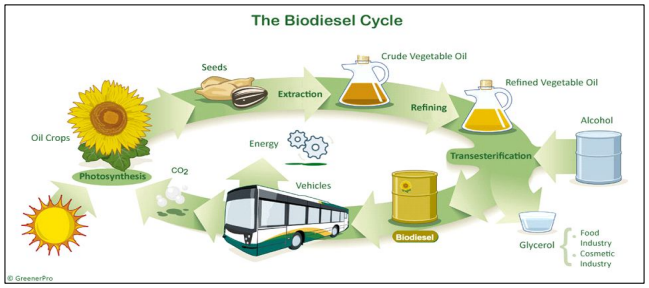

Fig. 3 : Biodiesel Cycle.

ethanol. It can be seamlessly used in standard gasoline engines without modification and its lower vapor pressure compared to ethanol makes it less volatile and more manageable for transport and storage.

4. **Biogas:** Produced through the anaerobic digestion of organic waste, such as food scraps, animal manure and waste water, biogas is a renewable fuel primarily composed of methane. Suitable for heating, electricity generation, or upgrading to biomethane for vehicle fuel, biogas contributes to emissions reduction by capturing methane that would otherwise be released into the atmosphere.
5. **Methanol:** A colorless and flammable liquid, methanol can be derived from biomass through gasification. It serves as a fuel in internal combustion engines with minor modifications. Despite a lower energy density than gasoline, methanol's cleaner burn results in fewer emissions of particulate matter and nitrogen oxides.
6. **Dimethyl ether (DME):** A colorless gas produced from biomass through gasification, DME is a clean-burning fuel replacing diesel and natural gas. With a higher cetane number than diesel, DME ignites more easily and burns more completely, leading to lower emissions of particulate matter and nitrogen oxides.
7. **Green Diesel:** Resulting from the hydrotreatment of vegetable oils and animal fats, green diesel is a renewable fuel compatible with conventional diesel engines. It significantly reduces particulate matter and nitrogen oxides compared to petroleum diesel and boasts a higher energy density than biodiesel, allowing for blending with petroleum diesel in any proportion.
8. **Renewable Jet Fuel (SAF):** A sustainable alternative to petroleum-derived jet fuel, SAF can be produced from various feedstocks, including waste streams from the aviation sector. With properties similar to petroleum jet fuel, SAF can be used in existing aircraft engines without modification, reducing greenhouse gas emissions and enhancing air quality around airports.

India's Contribution to Biofuel Production

National Policy on Biofuels – 2018

In order to promote biofuels in the country, a National Policy on Biofuels was made by Ministry of New and Renewable Energy during the year 2009. Globally, biofuels have caught the attention in last decade and it is imperative to keep up with the pace of developments in the field of biofuels. Biofuels in India are of strategic importance as it augers well with the ongoing initiatives of the Government such as Make in India, Swachh Bharat Abhiyan, Skill Development and offers great opportunity to integrate with the ambitious targets of doubling of Farmers Income, Import Reduction, Employment Generation, Waste to Wealth Creation. Biofuels programin India has been largely impacted due to the sustained and quantum non-availability of domestic feedstock for biofuel production which needs to be addressed.

Salient Features

1. The policy classifies biofuels into two main categories: "Basic Biofuels," including First Generation (1G) bioethanol and biodiesel and "Advanced Biofuels," encompassing Second Generation (2G) ethanol, Municipal Solid Waste (MSW) to drop-in fuels, Third Generation (3G) biofuels, bio-CNG, etc. This distinction enables the extension of suitable financial and fiscal incentives for each category.
2. The policy broadens the range of raw materials for ethanol production by permitting the use of Sugarcane Juice, Sugar-containing materials such as Sugar Beet, Sweet Sorghum, Starch-containing materials like Corn, Cassava and Damaged food grains like wheat, broken rice, Rotten Potatoes that are unfit for human consumption for ethanol production.
3. Recognizing the risk faced by farmers during surplus production phases, the policy allows the use of surplus food grains for ethanol production, subject to approval from the National Biofuel Coordination Committee, thereby addressing concerns related to appropriate pricing for agricultural produce.
4. Emphasizing Advanced Biofuels, the policy introduces a viability gap funding scheme of Rs. 5000 crore over six years for 2G ethanol biorefineries, along with additional tax incentives and a higher purchase price compared to 1G biofuels.
5. The policy fosters the establishment of supply chain mechanisms for biodiesel production from non-edible oilseeds, Used Cooking Oil, and short gestation crops.
6. Clearly outlining the roles and responsibilities of all

relevant Ministries/Departments concerning biofuels, the policy document aims to streamline efforts and promote synergies in the sector.

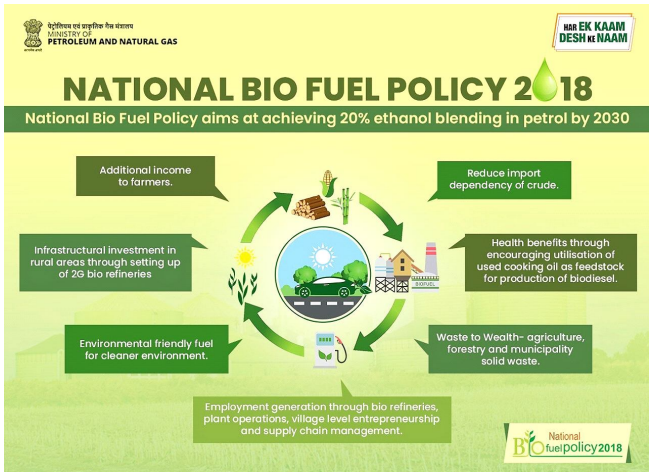

Fig. 4 : National Biofuel Policy 2018.

Amendments to National Biofuel Policy 2018

The National Policy on Biofuels has recently undergone significant amendments, aiming to enhance its impact and align with key national objectives. These approved changes include:

i. Expanding the range of feedstocks permissible for biofuel production.

ii. Accelerating the ethanol blending target, moving it to 20% by the Energy Security Year (ESY) 2025-26 from the initial goal set for 2030.

iii. Encouraging biofuel production within the country under the Make in India initiative, particularly by units situated in Special Economic Zones (SEZ) and Export Oriented Units (EOUs).

iv. Introducing additional members to the National Biofuel Coordination Committee (NBCC). v. Allowing the export of biofuels under specific circumstances.

v. Modifying or eliminating certain phrases in the policy to align with decisions made during the National Biofuel Coordination Committee meetings.

This proposed amendment is poised to stimulate the development of indigenous technologies, contributing to the Make in India initiative and fostering increased employment opportunities. The original National Policy on Biofuels, established in 2018, is set to undergo transformation with these amendments. The envisioned Make in India drive, bolstered by the production of more biofuels, holds the potential to curtail the import of petroleum products significantly. By expanding the range of permissible feedstocks, the amendment aligns with the principles of Atmanirbhar Bharat, reinforcing the vision of India achieving 'energy independence' by 2047 as envisioned by the Prime Minister.

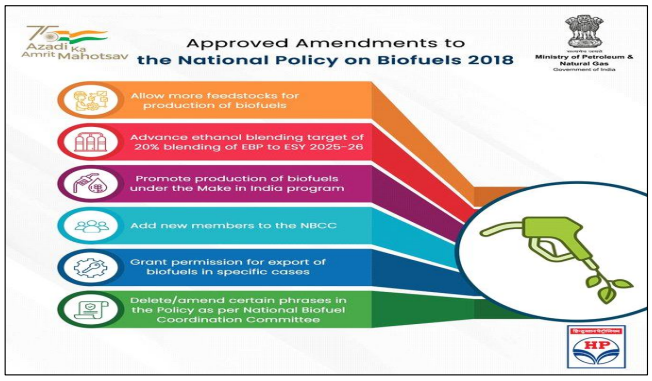

Fig. 5 : Amendments to the National Policy on Biofuels 2018.

Expected Benefits

- **Import dependency reduction:** Producing one crore liters of E10 can save Rs. 28 crore in foreign exchange at current rates. The anticipated supply of around 150 crore liters of ethanol in the 2017-18 ethanol supply year is expected to result in forex savings exceeding Rs. 4000 crores.
- **Environmental advantages:** One crore liters of E-10 can prevent approximately 20,000 tons of CO_2 emissions. For the 2017-18 ethanol supply year, there will be a substantial reduction of around 30 lakh tons of CO_2 emissions. The policy also aims to reduce greenhouse gas emissions by discouraging crop burning and promoting the conversion of agricultural residues and wastes into biofuels.
- **Health benefits:** Prolonged reuse of cooking oil, especially in deep-frying, poses potential health risks and can lead to various diseases. Using used cooking oil as a feedstock for biodiesel can prevent its diversion into the food industry, promoting health benefits.
- **MSW Management:** With an annual generation of 62 million metric tons of Municipal Solid Waste (MSW) in India, available technologies can convert waste, including plastic, into drop-in fuels. A single ton of such waste has the potential to yield approximately 20% of drop-in fuels.
- **Infrastructural Investment in Rural Areas:** A 100 kiloliters per day (klpd) bio-refinery is estimated to require around Rs. 800 crore in capital investment. With ongoing initiatives to set up twelve 2G bio-refineries with an investment of approximately Rs. 10,000 crore, the addition of more such refineries nationwide will stimulate infrastructural investment

in rural areas.

- **Employment Generation:** A 100 klpd 2G bio-refinery has the potential to create 1200 jobs in plant operations, village-level entrepreneurship, and supply chain management.
- **Additional Income to Farmers:** The adoption of 2G technologies allows the conversion of agricultural residues and waste, typically burned by farmers, into ethanol. This process could provide a valuable income source for farmers by creating a market for these waste products. Additionally, during surplus production phases, the conversion of surplus grains and agricultural biomass can contribute to price stabilization, addressing the risk of farmers not receiving appropriate prices for their produce.

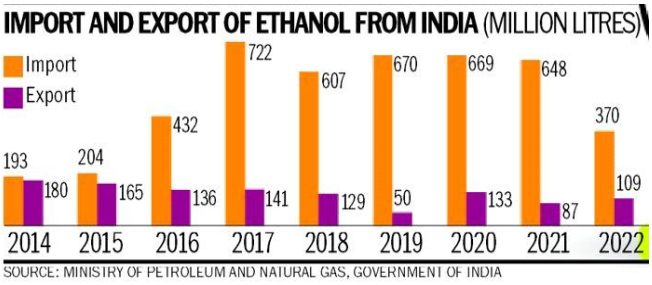

Fig. 6 : Ethanol trade of India (Import and Export).

Global Biofuel Alliance

The Global Biofuels Alliance (GBA) is a collaborative effort initiated by India during its tenure as the G20 Chair, aiming to unite governments, international organizations, and industries with vested interests in biofuel production and consumption. The primary objective of this alliance is to promote the development and adoption of biofuels as a crucial component of the global energy transition, while also fostering job creation and economic growth.

GBA seeks to accelerate the global adoption of biofuels by facilitating capacity-building activities throughout the entire biofuel value chain, offering technical assistance to national programs and encouraging the exchange of policy insights and technological advancements. Moreover, it aims to promote the use of sustainable biofuels by engaging a diverse range of stakeholders.

Additionally, GBA endeavours to establish and implement internationally recognized standards, codes, and sustainability principles to incentivize the adoption and trade of biofuels. It also plans to serve as a central repository of knowledge and expertise in the field, acting as a catalyst for global collaboration to drive the widespread adoption of biofuels.

The initiative holds significant benefits for India, enhancing its global standing and offering opportunities for its industries to export technology and equipment. Furthermore, GBA aims to support and accelerate India's existing biofuel programs, such as the PM-JIVAN Yojna, SATAT and GOBARdhan scheme, thereby contributing to increased farmers' income, job creation, and overall socio-economic development.

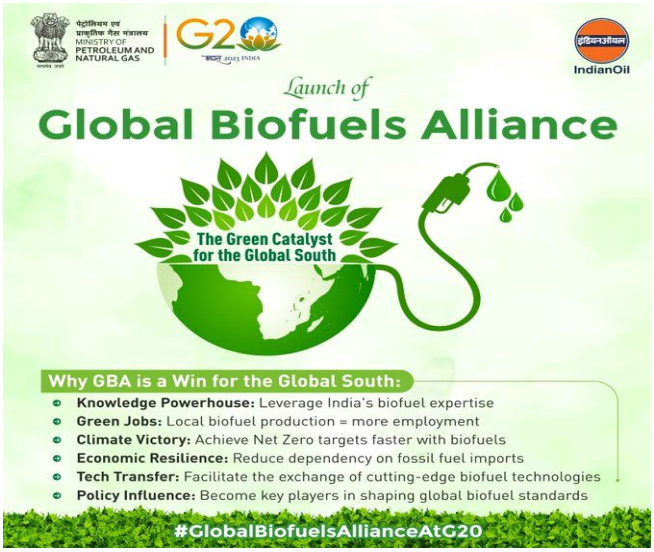

Fig. 7 : Global Biofuels Alliance (At G20 Event, 2023).

Currently, GBA boasts the participation of 22 countries and 12 international organizations, including eight G20 nations, four G20 invitee countries, ten non-G20 countries and twelve prominent international organizations, all committed to advancing the cause of biofuels on a global scale.

The Global Biofuels Alliance (GBA) has garnered membership from a total of 22 countries and 12 international organizations:

- Among the countries, there are eight G20 nations: Argentina, Brazil, Canada, India, Italy, Japan, South Africa and the USA.
- Additionally, four G20 Invitee Countries have joined: Bangladesh, Singapore, Mauritius and the UAE.
- Furthermore, ten non-G20 countries have become members: Iceland, Kenya, Guyana, Paraguay, Seychelles, Sri Lanka, Uganda, Finland, Tanzania and the Philippines.

In terms of international organizations, the following twelve entities have joined the alliance -

Asian Development Bank, World Economic Forum, World LPG Organization, UN Energy for All, UNIDO, Biofutures Platform, International Civil Aviation Organization, International Energy Agency, International

Energy Forum, International Renewable Energy Agency, World Biogas Association, and the World Bank.

Future Prospects

The potential of biofuels in shaping a sustainable alternative to conventional fossil fuels is significant, with technological advancements and efficiency improvements playing pivotal roles in this trajectory. Over the years, global biofuel production has witnessed a threefold increase from 2000 to 2007, although it still constitutes less than 3% of the total global transportation fuel supply. Second-generation biofuels, exemplified by cellulosic ethanol, hold promise in minimizing land requirements and maximizing yields per acre. Despite these advancements, challenges persist, including competition from unconventional fossil fuel alternatives and concerns about potential environmental tradeoffs. Notably, algae-based biofuels are emerging as a sustainable option, attributed to their high energy reserve properties. Ongoing investments in research and development are anticipated to yield enhanced biofuel products capable of replacing traditional fossil fuels, thereby contributing significantly to global efforts aimed at reducing greenhouse gas emissions and addressing climate change concerns.

Conclusion

Biofuels present a compelling opportunity to conserve nature by promoting sustainable energy solutions that minimize our reliance on nonrenewable resources. By leveraging diverse feedstocks, such as lignocellulosic biomass, algae and waste materials, we can produce biofuels with reduced impacts on ecosystems and agriculture. Moreover, biofuels contribute to greenhouse gas emission reductions, helping combat climate change and preserving habitats. As research continues to expand the capabilities of third- and fourth-generation biofuels, we can expect even greater conservation benefits, fostering a symbiotic relationship between human progress and ecological health**.**

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