**GREEN TECHNOLOGY FOR SUSTAINABLE ENERGY PROCUTION FROM AGRICULTURE SECTOR**

**Suhana Puri Goswami\*, Shailja Chauhan, Upasna Mishra, and Ajay Kumar Chauhan, Affiliation: Suhana Puri Goswami, Assistant Professor, Medi-caps University, Indore**

**Ajay Kumar Chauhan, Post Doctoral Research Fellow, ICGEB, New Delhi**

**Shailja Chauhan, Assistant Professor,Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior**

**Upasna Mishra, Assistant Professor, Medi-caps University, Indore Email:** [**suhana.goswami@medicaps.ac.in**](mailto:suhana.goswami@medicaps.ac.in)

**Abstract:**

Green technology, also known as sustainable technology, has emerged as a crucial driver for achieving sustainable development goals in various sectors including agriculture sector. This book chapter is about the significance of green technology in agriculture and promoting environmental conservation, resource efficiency, social well-being and energy generation. By integrating eco-friendly practices, renewable energy sources, advanced materials, and data-driven solutions, green technology contributes to mitigating climate change, preserving biodiversity, and enhancing the resilience of societies. Moreover, this chapter emphasizes the role of green technology in fostering a circular economy, reducing greenhouse gas emissions, and empowering communities, particularly in the context of urbanization and agriculture. In addition, agricultural sector contribution to energy is discussed in detail. The abstract concludes with a call to action for policymakers, researchers, and stakeholders to prioritize and invest in green technology solutions to address pressing global challenges and pave the way for a more sustainable and resilient world.

**Key Words:** Green technology, Sustainable development, Environment, Renewable Energy, Circular economy, Agriculture

# Introduction

Agriculture serves as a vital means of providing sustainable food for current and future generations both. In addition, it provides biomass in the form of agro waste and lignocellulose biomass (LCB) that can be used for energy production. This energy can be generated in the form of heat, fuel, and electricity. Presently, the world energy demand is fulfilled by the petroleum-based fossil fuel, which are limited. Therefore, an alternate non-exhaustive and sustainable route for energy generation is new research concern. Use of conventional fossil fuel, coal fired boiler, and gases emits high level of pollutants, and greenhouse gases (Li et al., 2022). These pollutants and greenhouse gases mainly includes carbon dioxide, carbon monoxide, SOx, NOx, and polyaromatic hydro-carbons (PAHs)(Majumdar, Chintada, Sahu, & Chalapati Rao, 2013). Data from IEA 2018 on CO2 emissions in 2018 were 33.2 Gt, and which will be get increased to 35.6 Gt. The contribution due to sustainable development policy scenarios is very far to achieve target (IEA, 2022). Therefore, overcome with existing problem with uses of fossil fuel an alternate solution is agriculture sector. Which has its great potential to produce biomass, which can be converted into renewable energy. As we know after land cultivation and harvesting enormous amount of agro waste is generated in the form of stubbles. Due to lack of awareness among farmers, these leftovers of paddy, wheat, and bagasse, etc. are directly burnt in to environment. Consequently, which severely imparts environment and health problems, and loss of lignocellulosic biomass. In the pursuit of environmental preservation and reducing our carbon footprint, green energy has emerged as a promising alternative to conventional energy sources. Nevertheless, a disparity exists between the potential of renewable energy and its practical implementation, often referred to as execution obstacles (White & Walsh, 2008). The fundamental rights to a healthy and productive life, ecological protection, as well as the promotion of sustainable agriculture and green technology. Through strategic partnerships and collaborations, we can harness natural resources effectively, while also ensuring farmers have a reliable and viable income source. To meet the needs of sustainable development goals and environmental protection, the utilization of agricultural wastes and microbial fermentation play an important role to convert it into energy (Chauhan & Kalyan, 2021). Therefore. In this context, to fulfill current demand of fossil fuel the Indian Government aimed to blend petrol with ethanol. As per the NITI Ayog report, they have successfully achieved 10% blending of the ethanol with petrol, and further aimed to increase it to 20% by the 2025. However, India is among the world’s major producer of sugarcane. Sugar from sugarcane (1G, first generation fuel) helps in generation of ethanol. However, the 1G biofuel production is limited due to debate on food vs fuel and land uses for food crop (Chauhan, 2020). Whereas, use of lignocellulose-based material can be used for 2G (2nd

generation) biofuel, while algal based 3G and 4G is still in developmental stage. Due to these development in the energy sector helps in increasing demand for green production for raising income of farmers and achieving sustainable agricultural development. Therefore, this chapter gives you the detail about with green technologies and its application for generation of agriculture-based bioenergy,

# Content of Green Technology

* 1. **Green Technology**

These technology commonly known as "environmentally-friendly technology" or "clean technology," its focus is on promoting sustainability and ecological preservation. Green technology (GT) encompasses a comprehensive array of scientific disciplines aimed at mitigating human impacts on the natural environment. It involves diverse fields such as energy, atmospheric science, agriculture, material science, and hydrology. GT is a broader term (**Fig 1**), which is closely related to environmental science, green chemistry, environmental monitoring, and electronic devices used for resource conservation and minimizing human-induced environmental harm, and convert waste into energy. Its primary objective is to reduce hazardous waste and pollutants generated during various mechanized processes and product utilization. Further, the waste generated from agriculture and industrial origin can be converted in to energy.

On the other hand, through extensive utilization of green technology, firms generate surplus derivatives that disrupt the Earth's ecosystem, leading to environmental hazards and depletion of natural resources. The introduction of pioneering technology raises ethical conundrums concerning its impact on morality and society. Common practice involves comparing the current societal configuration to a hypothetical system referred to as an "idyllic system." Scientists continually refine pragmatic gadget attributes over time to enhance performance while keeping these conceived devices in consideration. According to Ayub *et al*. (2016), ideal technology possesses renewable characteristics and emits no greenhouse gases into the atmosphere, earning its designation as "green technology"(Ayub et al., 2021).

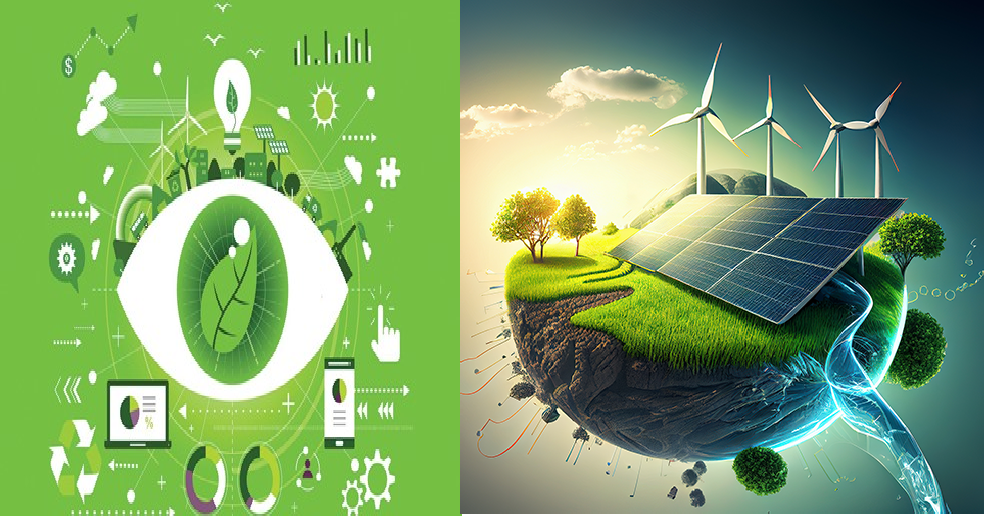


Figure 1: Green Technologies

# The Evolution of Green Technology

Scientists started to perceive the ecological effects of coal-burning industrialized plants in the early 19th century, and manufacturers have tried to diminish these effects by changing production techniques to create less grunge or waste byproducts. The Second World War marked a pivotal moment in American history, with over 400,000 volunteers assembling supplies to reduce consumption and waste. Rachel Carson warned about chemical pesticide dangers, whereas doctors described strange ailments linked to nuclear radiation. This epoch is considered the birthplace of the ecology movement, aiming to protect ecosystems and resources whilst educating the public about rogue technology. Through the conception of the Environmental Protection Agency in the 1970s, the government renowned, the value of the environment and promoted curbside recycling whereas setting stringent regulations for waste management and pollution.

# Objectives of Green Technology for Sustainable Development:

The objectives of green technology for sustainable development are aligned with promoting environmentally friendly and socially responsible practices while fostering economic growth and prosperity. These objectives aim to achieve a balance between meeting current needs and ensuring the

well-being of future generations. Some key objectives of green technology for sustainable development include:

1. **Environmental Protection:** The primary objective is to protect and preserve the natural environment, including air, water, land, and ecosystems, by reducing pollution, conserving resources, and mitigating climate change.
2. **Resource Efficiency:** Green technology aims to optimize the use of natural resources, such as energy, water, and materials, to minimize waste and increase resource sustainability.
3. **Renewable Energy Transition:** Promoting the widespread adoption of renewable energy sources, like solar, wind, and hydro, to replace fossil fuels and reduce greenhouse gas emissions.
4. **Energy and Waste Management:** Implementing energy-efficient technologies and waste management strategies to reduce energy consumption and minimize waste generation.
5. **Sustainable Agriculture and Food Security:** Advancing sustainable agricultural practices that promote soil health, biodiversity conservation, and food security for present and future generations.
6. **Green Building and Infrastructure:** Developing sustainable buildings and infrastructure that are energy-efficient, environmentally friendly, and contribute to the overall well-being of occupants
7. **Circular Economy:** Encouraging a circular economy model, where resources are reused, recycled, and repurposed, reducing waste and extending the life cycle of products.
8. **Economic Growth and Green Jobs:** Green technology aims to drive economic growth and create green job opportunities in sectors such as renewable energy, energy efficiency, and sustainable agriculture.
9. **Climate Change Mitigation:** Green technology plays a crucial role in mitigating climate change by reducing greenhouse gas emissions and promoting climate-resilient practices.
10. **Biodiversity Conservation:** Green technology supports efforts to protect and conserve biodiversity, essential for maintaining ecological balance and ecosystem services.
11. **Innovation and Research:** Supporting research and development of new and innovative green technologies to continually improve sustainability efforts.

# Pillars of Green Technology:

The pillars of green technology delineate fundamental principles and targeted domains directing the conception and application of ecologically sound and sustainable technologies. These pillars are indispensable for tackling environmental predicaments, mitigating ecological footprints, and fostering a more sustainable and environmentally-conscious future. The primary pillars of green technology encompass the following:

1. **Renewable Energy:** Advocating the utilization of renewable energy sources such as solar, wind, hydro, geothermal, and biomass, which possess low environmental impact and perpetually replenish, as alternatives to finite fossil fuels.
2. **Energy Efficiency:** Enhancing energy efficiency across diverse sectors, including buildings, transportation, and industrial processes, to minimize energy consumption and curb greenhouse gas emissions.
3. **Sustainable Materials:** Encouraging the adoption of eco-friendly and sustainable materials in product design and construction to curtail resource depletion and waste generation.
4. **Waste Reduction and Recycling:** Implementing strategies for waste reduction and fostering recycling and up cycling practices to alleviate pressure on landfills and foster a circular economy.
5. **Green Infrastructure:** Integrating green infrastructure solutions into urban planning and construction, such as green buildings, green spaces, and sustainable transportation systems, to foster environmentally friendly and resilient cities.
6. **Water Management:** Emphasizing sustainable water management practices, including water conservation, water recycling, and efficient irrigation systems, to preserve this invaluable natural resource.
7. **Sustainable Agriculture:** Promoting agricultural practices that minimize the use of harmful chemicals, conserve soil health, and support biodiversity preservation.
8. **Environmental Monitoring and Conservation:** Utilizing advanced monitoring technologies to assess environmental impacts and support conservation endeavors aimed at safeguarding natural resources and ecosystems
9. **Green Transportation:** Advancing green transportation options, such as electric vehicles, public transportation systems, and alternative fuel technologies, to reduce emissions from the transportation sector.
10. **Eco-friendly Products and Services:** Encouraging the development and adoption of products and services that exhibit minimal environmental impacts throughout their life cycles.

# 7R concept in Green Technology in energy generation

The 7 R concepts in green technology **(Fig 2**) comprise a series of principles that advocate for sustainable practices and resource efficiency. Each "R" denotes a distinct action or approach, targeting waste reduction, resource conservation, and the mitigation of technology and human activities' environmental impact. As we know the agricultural products are renewable and which can be suitably use and re-use for the benefits of societies and helps in green technologies development.

**Rethink:** This involves questioning and reevaluating traditional practices and methods to identify more sustainable alternatives. It encourages a shift in mindset towards adopting greener and more eco- friendly approaches.

**Reduce:** The principle of reducing emphasizes the need to decrease the consumption of resources and materials to the minimum necessary. By using less, we can reduce waste and environmental burdens.





**Rethink**

**Recycle**

**Reduce**

**7 R**

**Remake**

**Reuse**

**Refurbish**

**Repair**

**Figure 2:** 7 R concept for sustainable technology (if you copied this figure then please make it using PPT and other tool and give proper citation)

**Reuse:** The reuse principle encourages finding ways to extend the life cycle of products or materials by using them again for the same or different purposes. This helps reduce the demand for new resources and minimizes waste generation.

**Repair:** Repairing products instead of discarding them and buying new ones can extend their useful life, reducing the need for additional resource extraction and production.

**Refurbish:** Similar to repair, refurbishing involves restoring products to a like-new condition, ensuring they remain functional and useful for a more extended period.

**Remanufacture:** Remanufacturing involves disassembling and reassembling products to meet original specifications, making them as good as new. This process reduces the need for manufacturing new products from scratch.

**Recycle:** Recycling is the process of converting waste materials into new products or raw materials, reducing the demand for virgin resources and diverting waste from landfills.

**Table. 1 Elemental compounds and composition of agricultural biomass and its application in bioenergy generation.**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **S.No** | **Agro biomass** | **Elemental Compounds** | | | | **Composition (wt %)** | | | | **Bioenergy** | **References** |
| **C** | **H** | **N** | **O** | **Ash** | **Moisture** | **Volatile matter** | **Fixed carbon** |
| 1 | Palm Kernel Shell | 43.20 | 6.84 | 0.92 | 38.03 | 10.67 | 3.03 | 69.66 | 16.64 | Bio-oil | Sohni *et al.* (2018) |
| 2 | Peanut | 59.27 | 8.18 | 3.30 | 22.39 | 6.86 | - | 93.95 | 0.81 | Biomethane | Ugwu and Enweremadu (2020) |
| 3 | Wood pellet | 51.0 | 6.0 | 0.4 | 42.5 | 0.3 | 8.0 | 76.5 | 15.2 | Biofuel | Kim *et al.* (2021) |
| 4 | Rice husk | 44.2 | 6.2 | - | 52.4 | 14.2 | 7.0 | 59.5 | 20.8 | Bioenergy | Naqvi *et al.* (2020) |
| 5 | Groundnut shell | 51.1 | 5.9 | 1.1 | 41.9 | 4.4 | 6.7 | 61.7 | 27.2 | Bio-oil | Bhatnagar *et al*. (2020) |
| 6 | Coffee husk | 46.41 | 6.33 | 2.66 | 44.51 | 3.55 | 9.06 | 77.09 | 19.36 | Bio-oil | Setter *et al.* (2020) |
| 7 | Neem Press Seed Cake | 44.71 | 4.22 | 3.7 | 42.08 | 4.95 | 12.5 | 75.05 | 7.5 | Bio-oil | Dhanavath *et al.* (2019) |
| 8 | Lignin | 61.3 | 6.23 | 0.70 | 31.4 | 0.3 | 3.4 | 74.0 | 26.1 | Biofuel | Farrokh *et al*. (2018) |
| 9 | Corn straw | 50.80 | 6.24 | 1.21 | 41.54 | 9.40 | 8.7 | 75.1 | 15.5 | Bio-oil | Delgado *et al.* (2013) |
| 10 | Wheat straw | 46.3 | 5.7 | 2.0 | - | 8.0 | 8.9 | 16.0 | 56.0 | Agglomerates | Funke *et al.* (2018) |
| 11 | Rice husk | 38.23 | 5.46 | 0.32 | 39.44 | 16.53 | - | 70.60 | 12.87 | Bio-oil | Zhang and Xiong (2016) |
| 12 | Corn stalk | 72.28 | 3.14 | 1.09 | 22.47 | 16.73 | 4.36 | 23.79 | 55.12 | Biochar | Wang *et al*. (2014) |
| 13 | Pine sawdust | 70.68 | 3.60 | 2.40 | 23.11 | 12.33 | - | 23.95 | 63.72 | Biosorption | Peng *et al.* (2012) |
| 14 | Sugarcane Bagasse | 32.5 | 5.0 | 0.36 | 61.5 | - | - | 49.61 | 42.79 | Bioelectricity | Kanwal *et al.* (2019) |
| 15 | Spent coffee grounds | 52.99 | 7.29 | 2.50 | 37.22 | 0.74 | 3.16 | 86.0 | 10.1 | Biofue | Zhang *et al.* (2018) |

# Innovations in Green Technology for energy generation

Innovations in green technology encompass a wide array of advancements and developments aimed at creating more sustainable and eco-friendly solutions. These innovations seek to address environmental challenges, reduce resource consumption, and minimize the ecological footprint of various industries and human activities. Some notable innovations in green technology from agricultural sector include renewable energy technologies (such as more efficient solar panels and advanced wind turbines), energy storage solutions, electric and autonomous vehicles, sustainable building materials, smart grid technologies, waste- to-energy processes, water purification and desalination technologies, eco-friendly packaging materials, and advancements in green chemistry and biotechnology. These innovations continuously evolve to meet the growing demand for sustainable solutions and contribute to a more environmentally conscious and resilient future.

# Green Technology Strategies

* + 1. **Green Product Strategy:** Companies have made significant changes to their products based on consumer needs and requirements, aiming to produce environmentally friendly products. Environmentally friendly products conserve natural resources and reduce atmospheric pollution. These green products are often manufactured through recycling and reusing previously used materials. Marketers play a crucial role in understanding and communicating consumer preferences for green products, such as those made from organic and reusable materials, energy-saving technologies, and less harmful chemicals in cosmetic and personal care products (Sharma & Joshi, 2016).
    2. **Green pricing Strategy:** These strategies are regarded as a highly sensitive and critical aspect of the green marketing mix. Consumer behavior demonstrates significant responsiveness to changes in product pricing, promptly influencing their purchasing decisions (Davari & Strutton, 2014). Many consumers exhibit a willingness to pay a premium for green products due to the perceived additional value compared to conventional alternatives. Green technology must prioritize visual appeal, flavor, design, and performance while implementing premium pricing strategies for clients (Sharma & Joshi, 2016).
    3. **Availability of Green Product:** The availability of green products is a critical component of the green technology mix, focusing on the distribution channels used by marketers to make environmentally friendly products accessible to consumers. The distribution system for green products comprises two distinct aspects: the inner and outer viewpoints. The inner aspect pertains to the internal environment of the company, where positive and satisfactory behavior of the workforce influences consumers due to their perception of the company's commitment to sustainability. On the other hand, the outer aspect refers to the physical availability of green products, technologies, and services to consumers (Bisoyi & Das,

2015). This aspect involves ensuring that green products are readily accessible to consumers in the market, thereby encouraging greater adoption and consumption of environmentally friendly alternatives.

# 3 Effect of Green Technology in agriculture sector

Green technology in agriculture faces significant challenges, including identifying a viable methodology for capital production while ensuring sustainability, researching the consequences of adopting such technologies, and establishing national standards for technology approvals. These obstacles hinder the widespread adoption of green technology, which holds the promise of addressing food-related difficulties and boosting agronomic production. Key innovations in farming based on sustainable green technologies, such as precise cultivation, nano-pesticides, and low-cost decentralized water decontamination, can play a crucial role in meeting the growing demand for the production of raw material, which can be used for energy production.

Agricultural practices that are economically viable while being environmentally friendly are essential for the long-term sustainability of the sector. This requires conducting extensive research and collaborating with experts in the field to identify and implement practices that strike the right balance between productivity and resource conservation.

Research is a fundamental aspect of understanding the consequences of adopting green technologies in agriculture. Studies evaluating the environmental, economic, and social impacts of specific innovations, such as nano-pesticides and decentralized water decontamination, are essential for informed decision-making. Close cooperation between scientific researchers, government agencies, and industry players can facilitate the collection of empirical data and the evaluation of the long-term effects of green technology implementation (Khan *et al.,* 2019).

To accelerate the expansion of suitable green technologies in agriculture and food, developing and implementing national standards and regulations is crucial. Governments can play a vital role in incentivizing the adoption of green practices through policies, subsidies, and tax benefits. Collaborative efforts with international organizations can also contribute to creating globally recognized standards, promoting trade in sustainable agricultural products, and supporting technology transfer to developing countries (FAO, 2020).

# Role of Bioenergy in Agriculture

The agriculture sector provides biomass in solid, liquid, and gaseous form, which can be used of for heating, cooking, biogas production, and electricity production. The fluctuation in agricultural residue after harvesting depends upon the type of product, which can be good source of 2nd generation biofuel. Agricultural leftovers produced from each step of agricultural processing is the sustainable assets for the bioenergy production. This agro waste requires few cyclic changes, mainly pretreatment, which removes lignin from it.

# Agro waste biomass

These are leftovers from agricultural practices such as food crops, fruits and vegetables, dairy and poultry, etc. Recently, conversion of biomass has received many concerns to meet sustainable development goals-7 (SDGs-7). The biomass originated from plant waste majorly comprises of cellulose, hemicellulose, and lignin as major constituents, but these are differ from paper waste, wood waste, and grasses (Mukhopadhyay, Masto, Sarkar, & Bari, 2022). Some natural producing polymers polypropylene and polyester comes under agro waste. Due to increase in population demand of food crops also increased, thus food crops are limited to utilize for the bioenergy production. To avoid land and water use competition an alternate approach of synergic management of crop plantation is suggested and considered (Zheng, Ji, Xie, Huang, & Pan, 2022). Utilization of waste residues from agricultural field such as straw, seedpods, groundnut shell, rice husk, bagasse, and vegetable waste can be directly considered for biofuel generation (2nd generation) (Kumar et al., 2023). The pre-treatment step helps in removing lignin from LCB, through various analytical technique chemically enriched cellulose and hemicellulose can be determined. Before pre-treatment the typically LCB contain 35-45% cellulose, 15-30% hemicellulose and 20-30% lignin (Zhou & Tian, 2022). The characterization of LCB before and after pretreatment is an important and essential to understand conversion, and its recovery (Zhou & Tian, 2022). Removal lignin after pretreatment can be

valorized into value added chemicals (Chauhan & Singh). The feedstock’s like sugars, wheat, rice, beet, sorghum, barley, and cassava, etc. used for bioethanol production (Srinivasan et al., 2015). On the other hand, Other than the food crops oil producing crops such as mustard coconut, palm, sunflower, flax seeds, and hemp, etc. also used for biofuel generation (Kumar et al., 2023).

# Conclusion:

The integration of green technology into agriculture offers a pathway to a more sustainable and resilient food system as well as energy production. As the world faces environmental challenges and the need to feed a growing population, embracing green technology in agriculture becomes essential for securing food security, protecting ecosystems, and mitigating climate change effects. The researchers are now focusing on conversion of agricultural biomass as an alternate of fossil fuel for producing bioenergy. Collaborative efforts from the Governments, farmers, researchers, and industries are vital to drive the adoption and development of green technology for the generation of bioenergy from a sustainable agricultural future. Recently, collective efforts are being made to develop LCB based bioenergy production. For generation of bioenergy from LCB pre-treatment steps is the crucial step and approximately 33% percent of capital cost account for pre-treatment process. Overall, cost of raw material requirement for bioenergy production can be reduced by developing agricultural sector and its policies. Which can be reduced by suitably selecting in sustainable farming, contributing to environmental protection and improved agricultural productivity.

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