Biotechnology in Action, Enhancing Environmental Conservation Efforts in India

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Abstract:

The environment has a crucial role in supporting human life as well as that of other biotic species. An indicator of the survival and well-being of all its constituent parts is the physical environment's level of sustainability. The optimal approach to environmental sustainability involves recycling all waste materials back into the ecosystem, turning it into a valuable resource that supports the biotic and abiotic interactions that keep the aesthetically pleasing and physiologically stable balance that defines an ideal setting. The biological approach of environmental sustainability is one of the methods examined in this study. It looks into the different biotechnological tools (bio tools) that are currently in use and those that are being researched for potential future applications. Due to its potential and uses in aquaculture, agriculture, immunology, chemical manufacturing, industrial processes, pollution management, etc., biotechnology has attracted a lot of interest recently. However, without biotechnology, environmental conservation in the present day is unimaginable. Methods based on biotechnology are essential in the sectors of soil, wastewater, and exhaust air cleansing. Moreover, system biology and microbiology help purification and biowaste recycling facilities become more efficient. The biotechnology sector in India is starting to gain international recognition and has developed during the previous 20 years as a result of irregular and dispersed corporate and academic endeavours. Integrating these initiatives is essential. Despite outstanding biotechnology research and development (R&D) efforts, the biotechnology industry's growth has not been at all gratifying.

Keywords: Biosensor, Bioethanol, Bioremediation, Waste treatment, Biotransformation

Introduction:

Biotechnology has attracted a lot of public interest since the late 1980s. Through Agenda 21 of the United Nations Conference on Environment and Development (JNCED), the international community realized by 1992 that biotechnology would play a significant role in the environment, health sector, and agriculture (UNCTAD/ITE/IPC/2004/2). The natural world, which includes soil, water, air, and plants, is the initial and primary world(Arora and Fatima, 2024). He has gradually developed another comfortable environment with a variety of production methods and processes through the use of science, technology, and other social and political institutions as his requirements have grown. Currently in the 21st century, these two realms are now essential to survival. But the need for a more technologically advanced society has caused tension in the life of man. His need for unending ease has driven him to take advantage of abundance and resources of nature swiftly and indiscriminately (Ezeonu *et al.*, 2012). There is a growing need for innovative, cost-effective, and dependable biological means of treating pollution due to numerous issues with traditional methods such as landfills or incineration (Ezeonu *et al.*, 2012; Said *et al.*, 2024). Integrating these initiatives is essential. Despite outstanding biotechnology research and development (R&D) efforts, the biotechnology industry's growth has not been at all gratifying. As a result, the expertise and labour generated in this field have not been fully utilized. It's time to adopt an appropriate strategy to advance biotech activities in healthcare, agriculture, medicine and genomics, diagnostics, and environmental protection, given the high return on investment (ENVIS Centre) (Richmond, 2008). Natural ecosystems have suffered as a result of the growing human population on Earth, and shifts in the equilibrium of natural cycles have had an adverse effect on living things, including humans (Bull, 1996). Hence, there is a wealth of scientific data demonstrating that humankind is not living in a sustainable manner, and it will take a significant group effort to bring human usage of natural resources back within reasonable bounds. In light of the difficulties posed by population growth and the resulting rise in pollution, biotechnology continues to be the most dependable method of sustaining the environment. The government and citizens of many countries are concerned about the endemicity of pollutants (the majority of which are resistant) in our otherwise beautiful environment, since the globe is currently in danger (Earth Policy Institute). The contribution of plastic pollution like fishing nets, bags, microwave container, and other large plastic items are breakdown biochemically to produced tiny fibres that enter the environment and become microplastic pollutants (Varsha & Singh., 2025). Additionally, the design of products and processes that cannot be made to function using petroleum as a feedstock or conventional chemistry is made possible by biotechnology (*Biotechnology for the Environment in the Future: Science, Technology and Policy*, 2013) (Smirnova *et al.*, 2023).

A. Enzymes extraction from natural sources

In biology, enzymes that are extracted from naturally existing microorganisms, plants, and animals can be highly selectively and efficiently employed to catalyse chemical reactions (Macfarlane *et al.*, 2022). Biocatalytic methods typically utilize less energy, generate less waste, and use fewer organic solvents (which must subsequently be treated and disposed of) than conventional chemical processes (Das *et al.*, 2023).

B. Molecular evolution of enzymes

The function of naturally existing enzymes can be enhanced by mimicking natural selection and evolution (Lean, 2024). Enzymes can be quickly 'evolved' by genetic engineering or mutation, and they can be chosen through high-throughput screening to catalyse particular chemical reactions and enhance their functionality in particular environments, such hot temperatures (Matthews *et al.*, 2019).

C. Metabolic engineering of pathway

Genetic engineering can also be used to alter the metabolic processes of microorganisms (Mannion, 1992). The goal is to make each cell a highly effective "mini reactor" that can create at a high yield in a single step that would need multiple processes and a considerably lower yield for an organic chemist. Environmental biotechnology is a very broad field that includes developing various processes for the benefit of humanity with due diligence, replacing non-renewable resources with renewable ones, monitoring and protecting the environment, treating and recovering waste, and restoring environmental quality. in light of the legal, socioeconomic, and environmental safety factors(Kareiva and Marvier, 2012). It encourages the sustainable use of Resources from nature such as bacteria, plants, and algae used in industrial operations, as well as the production of beneficial organic compounds from the decrease of energy use, biomass bioconversion, etc.

Methodology:

The application of biotechnology to ecological and environmental issues is known as environmental biotechnology (Department of Environmental Engineering, Delhi Technological University, Shahbad Daulatpur, Delhi (110042) India. *et al.*, 2018). It is employed in studies of the natural world and living organisms' environments. The International Society for Environment Biotechnology (ISEB) defines environmental biotechnology as the development, application, and regulation of biological systems, such as cells, cell compartments, and enzymes, for the purpose of cleaning up contaminated environments (land, water, air, and sediments) and environmentally friendly processes (green manufacturing technologies and sustainable environments)(Hobman, Mankad and Carter, 2022).

Biosensors

Due to a lack of sufficient, reasonably priced methods for monitoring, surveying, monitoring, and guaranteeing compliance, many laws and regulations are seldom put into effect (at least when it comes to the major categories of pollutants like heavy metals and pesticides)(Valdez *et al.*, 2019). Analytical methods for evaluating the quality of food, land, water, and air are becoming more and more necessary in the fight against environmental degradation. The newest instruments in environmental monitoring for this purpose are biosensors (Naresh and Lee, 2021). Microbes that react to chemicals they come into touch with are known as microbial biosensors. When they come into contact with anything that could hurt them, they cease their regular emission of light. An analytical device known as a biosensor consists of biological material (such as enzymes, antibodies, hormones, nucleic acids, tissues, organs, or entire microbial cells) combined with a physical transducer to analyse biological signals and translate them into electrical impulses. Both artificially created and naturally existing light-emitting microorganisms are employed(Thévenot *et al.*, 2001). Biosensors are rapid, lightweight, and useful in the field right away. Rapid detection of pesticides, heavy metals, and COD or BOD in waste water would enable a prompt start of the treatment procedure(Dincer *et al.*, 2019).

Depending on the needs of the end user, biosensors come in a variety of forms, including calorimetric, immunosensor, optical, BOD, and gas biosensors. It's also believed that biosensors are essential for widespread coronavirus testing. By 2026, the global biosensor market is projected to grow to $38.60 billion. The coronavirus pandemic's expansion will only help this market grow even further. This will undoubtedly save expenses and emphasize the importance of using biosensors for environmental monitoring and assessment (Delhi Greens)(Bhatia *et al.*, 2024).

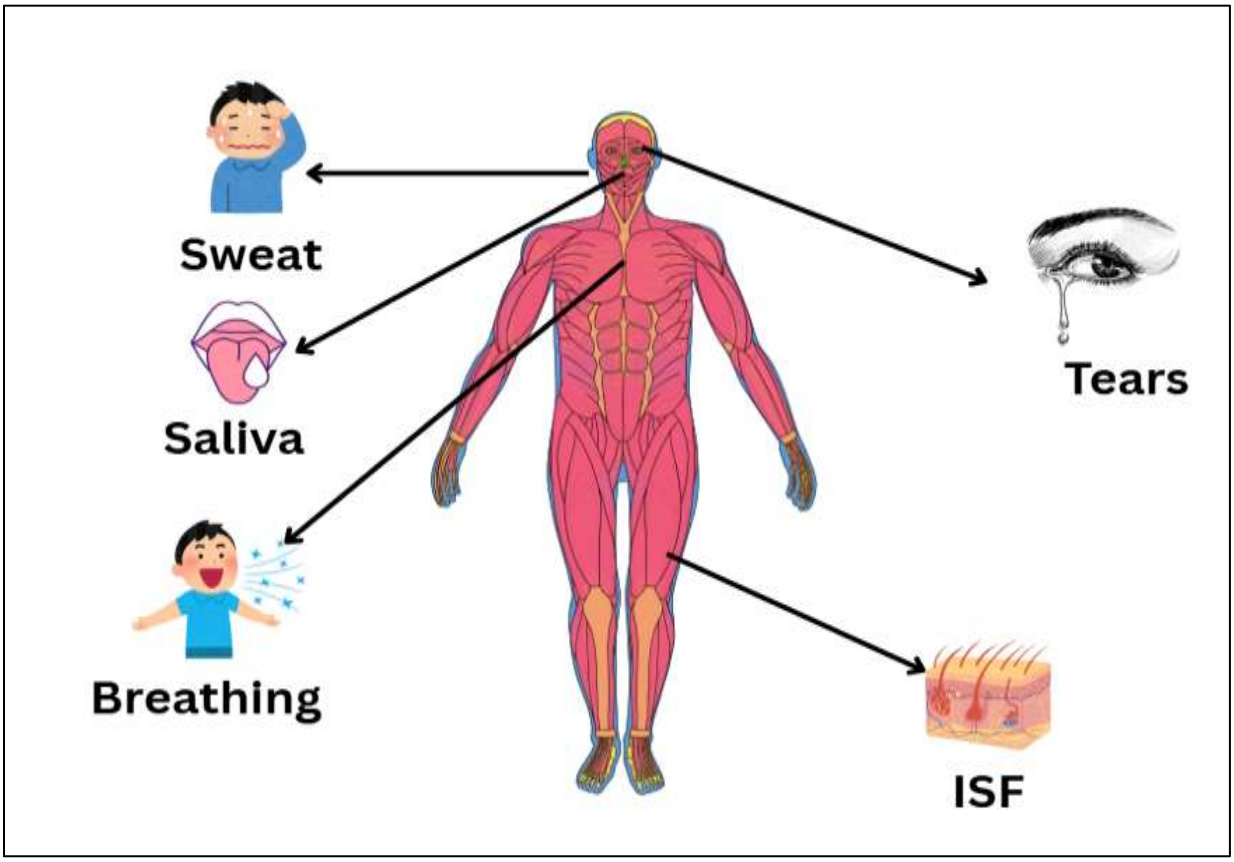


Figure-1: Schematic overview of graphene-based wearable biosensors

Bioenergy

Bioenergy is the term for energy produced by plants and other organic materials. One type of renewable energy produced by burning biomass fuel is called bioenergy. Organic material from our homes, businesses, and farms, as well as harvest leftovers and purpose-grown crops, are the source of biomass fuels (SEAI). Bioenergy must be produced and used sustainably if it is to fulfil this crucial function (Mahmoud and Abd El-Zaher, 2021). Emissions of greenhouse gases must be drastically reduced by bioenergy. Airborne carbon dioxide (CO2) is released during the bioenergy production process using organic fuel. New plants take up that CO2 during growth, offsetting this. However, inappropriate biomass sourcing and processing for energy can also be hazardous to our climate. The use of Bioenergy can also help improve our organic waste and forest management systems (Cortez, Baldassin and De Almeida, 2020).

A. Bioethanol

The two fundamental processes in the synthesis of bioethanol are fermentation and hydrolysis. Enzymes known as cellulases catalyze the chemical reaction known as hydrolysis, which breaks long, complex carbohydrate chains—like cellulose—into smaller, fermentable sugars. Sugars and other organic molecules are further broken down by fermentation to produce alcohols like bioethanol. The enzymes responsible for converting biomass to bioethanol are the subject of research (Wang *et al.*, 2013). A family of enzymes known as cellulases transforms bacteria into larger amounts of fermentable sugars and ultimately, bioethanol. Developmental contains more effective cellulases(Sassner, Galbe and Zacchi, 2008). India is now testing new engine systems that utilize fuels with high quantities of ethanol(Duff and Murray, 1996).

B. Biodiesel

Biodiesel can be made by reusing spent cooking oil, extracting oil from oilseed crops, or utilizing high temperatures to convert biomass wastes into tall oils. These oils are then refined using a method akin to that employed to refine petroleum products (Veljković, Banković-Ilić and Stamenković, 2015). The primary goal of biodiesel research is to produce plant matter that has been specially developed to have detained properties for the synthesis of biodiesel. Genetically engineered trees and oilseed crops that yield increased amounts of oil are not included in the list of plants being studied (Pruszko, 2015).

C. Biogas

Certain bacterial strains break down biomass without oxygen to produce biogas. About 60% of the biogas generated is composed of methane and 40% is carbon dioxide (Jameel *et al.*, 2024). One can use the remaining organic residue as a fertilizer that is high in nitrogen. Anaerobe digestion systems, which efficiently convert biomass into carbon dioxide and methane, are being studied by researchers (Tsapekos, Kougias and Angelidaki, 2015).

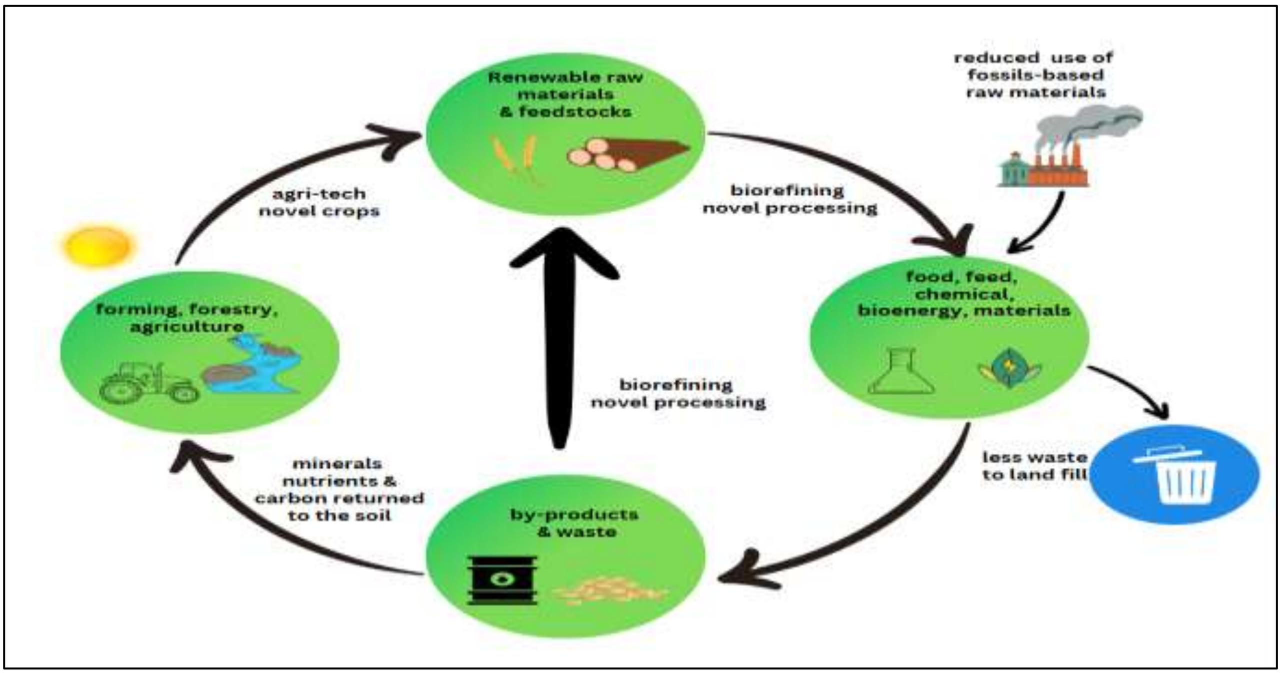


Fig 2. A carbon economy, a

bioeconomy represents the infrastructure, technologies, and processes needed to produce energy and products from organic materials (I-WEST)

Bioremediation

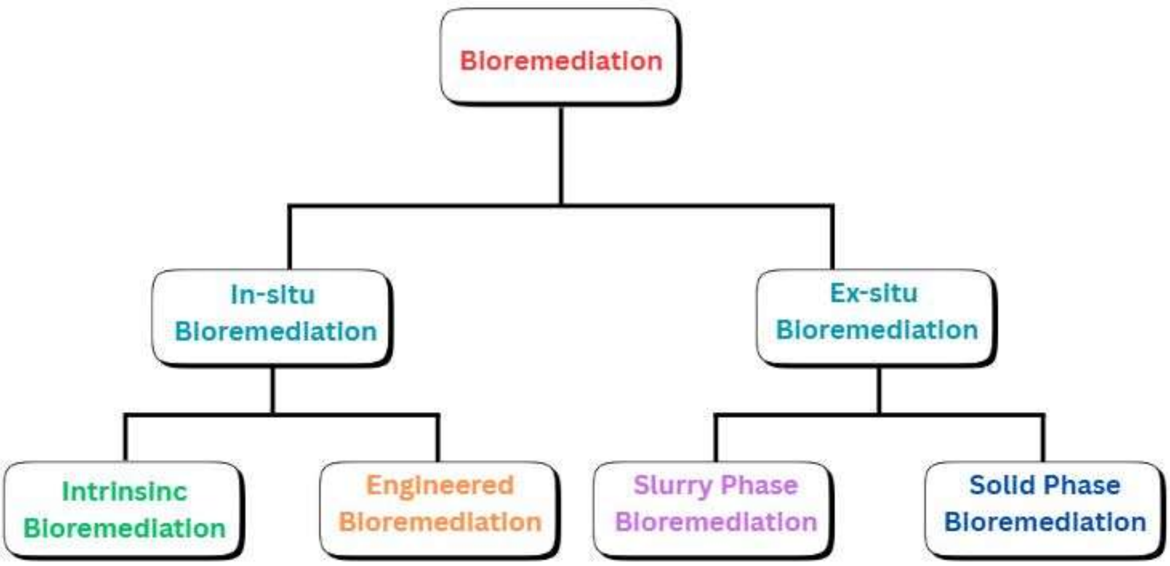
Bioremediation is a branch of biotechnology that uses living organisms to remove pollutants, toxins, and contaminants from water, soil, and other ecosystems. They could include microbes such as bacteria. Heavy metal ions are now an inherent part of the current environment due to increasing industrialization and changes in agricultural practices(Ayilara and Babalola, 2023). They build up in biological systems and are inherently persistent and non-biodegradable. Several unfavourable ecological circumstances result from this. Pollutants from sophisticated and harmful industrial processes also end up building up in natural systems. Bacteria and other essential microorganisms convert complex dead organisms into nutrients and organic stuff. However, the researchers claim that not all pollutants can be removed from the environment through the bioremediation method. For example, microbes cannot break down lead (Pb) or cadmium (Cd) (Biochemical Cell. Arch) (Abo-Alkasem, Hassan and Abo Elsoud, 2023).

Types of Bioremediation

1. In situ Bioremediation: It is used to treat groundwater and saturated soils for the breakdown of pollutants. Because it is less expensive and uses safe microorganisms to break down the pollutants, it is an excellent way to clean contaminated surroundings. It entails either introducing certain designed microorganisms to the contamination location or stimulating native or naturally occurring microbial populations (by feeding them foods and oxygen to improve their metabolic activity) (Sutar and Kumar, 2012).

2. Ex Situ Bioremediation: Using ex-situ bioremediation techniques, contaminants are removed from contaminated areas and subsequently moved to another location for treatment. Ex-situ bioremediation methods are frequently taken into account depending on the extent, kind, and expense of the contamination, as well as the location of the contaminated site. The selection of ex-situ bioremediation procedures is also governed by performance standards (Bala *et al.*, 2022).

Figure-3: Bioremediation approaches for environment clean-up



Slurry-phase bioremediation

When compared to other treatment methods, slurry-phase bioremediation is a somewhat faster process. In order to provide the best conditions for the microorganisms to break down the toxins in the soil, contaminated soil is mixed with water, nutrients, and oxygen in a bioreactor. The stones and debris must be removed from the polluted soil during this processing step. Pollutant concentration, rate of biodegradation, and soil physicochemical characteristics all affect the amount of water provided. Following this procedure, centrifuges, vacuum filters, and pressure filters are used to extract and dry the dirt. The next step is to dispose of the soil and treat the resulting fluids in advance(Tripathi and Gaur, 2021).

Solid-phase Bioremediation

An ex-situ technique called solid-phase bioremediation involves digging up the contaminated soil and piling it. Together with home, industrial, and municipal trash, it also includes organic wastes like leaves, animal dung, and agricultural wastes. Pipes are positioned all over the heaps to transport bacterial growth. For microbial respiration and ventilation, air must pull through the pipes. Compared to slurry-phase procedures, solid-phase systems demand a large amount of area and take longer to clean up. Composting, land farming, windrows, biopiles, and other methods are examples of solid-phase treatment methods (IOSR-JESTFT, 2014).

Biotransformation

The changes in the biology of the environment, which are changes of the complex compound from simple non-toxic to toxic, is called the biotransformation process. One environmentally friendly method of cleaning contaminated areas is biotransformation of different contaminants(Beiras, 2018). Using the naturally occurring microbial catabolic diversity, these bioremediation and biotransformation techniques can break down, alter, or accumulate a wide range of substances, such as pharmaceuticals, metals, radionuclides, hydrocarbons (like oil), polychlorinated biphenyls (PCBs), and polyaromatic hydrocarbons (PAHs)(Beketov *et al.*, 2013). Recent significant advances in methodology have made it possible to perform extensive genomic, metagenomic, proteomic, bioinformatic, and other high-throughput analyses of microorganisms that are relevant to the environment. These analyses have provided previously unattainable insights into the processes involved in biotransformation and biodegradation as well as the capacity of organisms to adapt to changing environmental conditions (bionity)(Shanu-Wilson *et al.*, 2020).

The idea of biotransformation makes use of three different naturally occurring mitigation mechanisms: bioaugmentation, biostimulation, and natural attenuation. Natural attenuation is a term used to describe biotransformation that happens naturally, except from human intervention other than observation. The activities of native soil microorganisms and environmental factors are what cause this natural attenuation. In order to restore polluted soils, biostimulation also makes use of native microbial communities. It involves enriching soil with nutrients and other materials in order to speed up the natural attenuation processes. In bioaugmentation, exogenous microorganisms (found outside the soil environment) that are capable of detoxifying a particular pollutant are introduced. There may be times when using genetically modified microbes is required(Salter *et al.*, 2019).

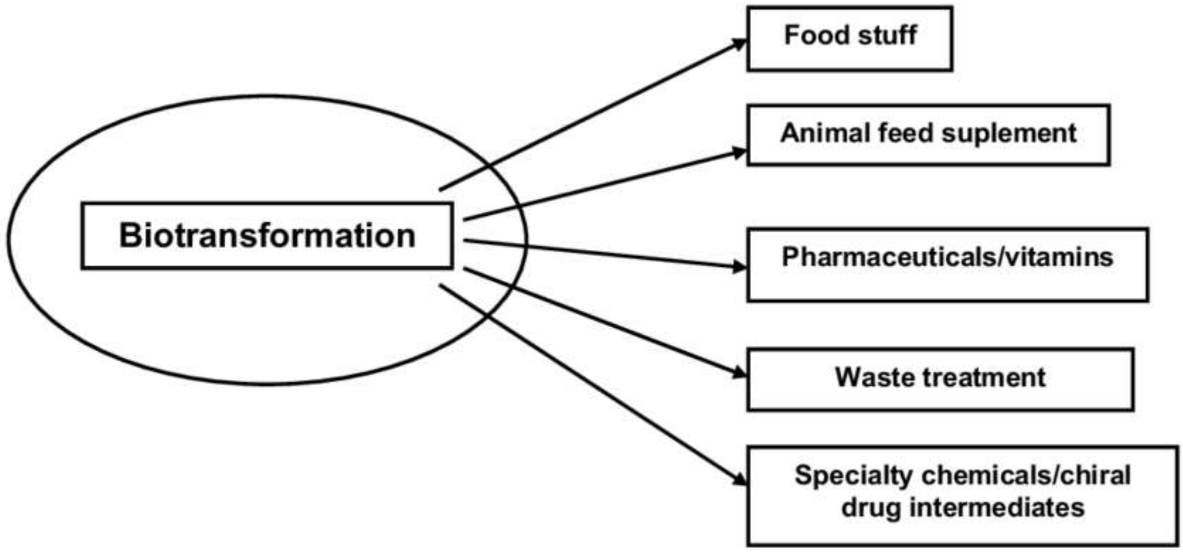


Figure-4: Applications of biotransformation

Environmental Biotransformation

According to Speight (2005) and Speight and Arjoon (2012), environmental biotransformation is a technique used to address contamination caused by petroleum, petroleum products, and petroleum waste streams. Usually, the process is carried out by microorganisms breaking down petroleum or a petroleum product (biotransformation) (Sattar *et al.*, 2022). This type of remediation usually uses natural bacteria, or microorganisms, as opposed to conventional (chemical and physical) techniques. The involved microorganisms are also capable of carrying out a range of biotransformation (detoxification) reactions. Additionally, biotransformation studies offer insights into the environmental fate of a chemical or combination of petroleum-derived chemicals (e.g., oil spills and process wastes)(Fenner *et al.*, 2021). This opens the scientific door to the development of additional clean-up techniques by analyzing contaminated sites, selecting the most environmentally friendly method, and refining cleanup techniques that result in the emergence of new processes(Guo *et al.*, 2023).

Discussion:

Significant progress has been made in biodiversity and environmental conservation. Numerous initiatives pertaining to the preservation of rare and endangered medicinal plants in vitro, micropropagation, ethnobotanical plants, and the microbiological variety of the Northeast have received funding. Significant initiatives on the genetic variety of ferns, lichen, and liverworts, as well as their usage as markers of pollution, have also received support. Biotechnology tools are being used to regulate pollution in the environment, restore environmental quality, produce cleaner technology, and save economically and medicinally significant endangered plant species. For plants that are threatened and can be found in southern coastal environments, tissue culture techniques have been created. Rare desert plant germplasm has been gathered in order to preserve it.

The Indian government has placed a strong focus on using biotechnology to advance society. Support is provided for specific programs aimed at women, individuals living in rural areas, and members of the socially disadvantaged population. Through the execution of numerous projects, biotechnology-based programs for SC/ST communities have benefited almost 50,000 people. The programs cover aquaculture, floriculture, poultry farming, seaweeds, mushrooms, spirulina, and other aromatic and medicinal plant cultivations; biological management of plant pests and diseases; vermiculture and vermicomposting; biofertilizers; aquaculture, floriculture, and human health care interventions, among other things.

In 1987, India became the world's first nation to create a distributed biotechnology information system (BTIS) network. There are 50 distributed information sub centres (DISCs) and 10 distributed information centres (DICs) in this network.

Conclusion:

It is clear from the explanation above that biotechnology has a wide range of applications in the environmental realm. By using biotechnology, environmental issues can be lessened or resolved, which helps to maintain a healthy ecosystem for living things. Renowned institutions such as the Indian Institute of Science and Biotechnology (ISEB) conduct studies on a variety of microorganisms to find ways to clean the ecosystem while also identifying the source of renewable energy. The preservation of the natural ecosystem, which includes the land, water, air, soil, and sediments, is the primary objective of the International Society for Environmental Biotechnology. The environment is facing many challenges due to urbanization, industrialization, and human activity, such as contamination of natural areas and the depletion of natural resources. These difficulties can be successfully and efficiently resolved by utilizing biotechnology applications. Biotechnology has been useful in mitigating environmental contamination through the utilization of eco-friendly methods and materials. According to the study mentioned above, environmental biotechnology is used to create and control biological systems for the purpose of cleaning up contaminated land, water, and air, as well as for environmentally friendly activities. The ultimate goal of biotechnology is to create a sustainable and safe environment.

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