Chapter 14
Environmental Biotechnology: For Sustainable Future

Malik Muzafar Manzoor

14.1 Introduction

Environmental sustainability is one of the biggest issues faced by humankind. Rapid and rampant industrialization and urbanization have put global land resources under severe threat. To make our planet a sustainable ecosystem and suitable habitable for future generations, we not only need to make corrections in existing methods but also need to remediate the polluted natural resources using natural ways. Recycling of biomass, development of production processes that makes optimal use of natural resources, recovering energy, and minimizing waste generation can have favourable effects on the environment. Despite escalating efforts to prevent waste accumulation and to promote recycling, the amount of environmental damage caused by the high standard of living, over-consumption, the quantities of waste generated, and the degree of unsustainable land use appear likely to continue growing. Environmental biotechnology is one of the options to prevent, arrest, and reverse environmental degradation through the appropriate use of biotechnology in combination with other technologies while supporting safety procedures as a primary component of the program. Biotechnological processes and their products can be applied with a view of long-term ecological security to protect environmental integrity (Dervash et al. 2020). While bioremediation is acknowledged as a promising technology for restoring polluted and degraded lands, its field potential is limited for various reasons. However, recent biotechnological advancements, including producing efficient microbial consortia, applying enzymes with higher degrees of specificity, and designing plants with specific microbial partners, are opening new prospects in remediation technology.

M. M. Manzoor
Plant Biotechnology Division, CSIR-Indian Institute of Integrative Medicine, Jammu, India

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14.2 Recent Biotechnological Advancements for On-Site Cleaning

To speed up the remediation process of the contaminated environment, the combined use of microorganisms and plants has resulted in a faster and more proficient cleanup process (Weyens et al. 2009). With the advent of the transgenic technology, plants and microorganisms can be engineered to degrade pollutants. Most of the sites are contaminated with different pollutants; thus, onsite bioremediation needs different strains of bacteria with the diverse catabolic potential to degrade pollutants. Advanced biotechnological approaches offer opportunities to isolate and culture these useful bacterial strains for their in-depth study. Next generation sequencing technology offers clues to engineer strains so that their remediation potential can be enhanced (Su et al. 2015).

High-throughput RNA sequencing can identify viable but nonculturable (VBNC) states under unfavourable conditions of biphenyl/polychlorinated biphenyl (PCB)-degrading bacteria *Rhodococcus biphenylivorans* (Su et al. 2015, Khan et al. 2017). VBNC state identification of microorganisms which are used for remediation of the polluted environment is vital for knowing their functional state during field application, and it also assists in providing favourable conditions for enhancing their remediation potential. Microbe capturing using immunomagnetic beads and colorimetric detection of their outer membrane peroxidase by oxidizing 3,3′,5,5′-tetramethylbenzene in the presence of H_2O_2 is another cost-effective method for the rapid enumeration and sensitive detection of uranium-reducing *Shewanella oneidensis* from sediment samples (Wen et al. 2014).

Genetic engineering is the recent and designer technology that can be adapted to modify microbes to make microbe assisted remediation more effective. Genetically modified *Ralstonia eutropha* was used to sequester Cd-contaminated soils using this approach, the *R. eutropha* was genetically engineered and designed to produce a cysteine-rich metal-binding protein (metallothionein) on its cell surface. These receptors could quench Cd available in the soil. The presence of sequestered metals in soil is less harmful because of their less bioavailability. Two major loopholes for this remediation approach are the controversies for the use of genetically modified organisms and the remains of sequestered metals in soil.

14.3 Bioremediation of Heavy Metal Contaminated Soils

Expanding industries, land application of fertilizers, spillage of petrochemicals, coal combustion, animal manures, wastewater irrigation, and sewage slime are the potential sources of heavy metals which contaminate soil. Different techniques of physical, chemical to biological methods for remediating metal contaminated soils exist. Most physical and chemical methods (vapour extraction, solidification, electrokinetics, soil flushing, soil washing, and stabilization) left the soil unsuitable for plant growth. On the other hand, biological approach (Bioremediation) which is achieved through natural processes encourages the use of remediated soil for the growth of plants. Phytoremediation ("Phyto" means plant) is a broad term used for a group of technologies that uses plants and associated microorganisms for in situ partial or complete removal of selected contaminants from soil, sediments, sludge, groundwater, and wastewater. Phytoremediation can be employed to remove heavy metal contaminants, organic pollutants as well as radionuclides (Ali et al. 2013). Plants because of their unique absorption, metabolic capabilities, and remarkably efficient transportation systems selectively absorb nutrients or contaminants from the growth matrix and environment.

To speed up the remediation process of contaminated soil, the combined use of microorganisms and plants has resulted in a faster and more proficient cleanup process (Weyens et al. 2009). The microbial remediation involves a cocktail of several microorganisms like bacteria (*B. subtilis*), Enterobacter (E cloacae), and Pseudomonas (P putida) that have been effectively used for the reduction of Cr (VI) to the less toxic Cr (III) (Garbisu and Alkorta 1997, Garbisu et al. 1998, Ishibashi et al. 1990). It is also reported in the literature that B. subtilis can reduce non-metallic elements. For example, Garbisu et al. (1998) studied that selenite has been decreased to the less toxic elemental selenium using *B. Subtilis*. In a study, it was observed that *Azotobacter vinelandii* showed increased siderophore production in the presence of Zn(II) (Huyer and Page 1988). The change in bioavailability could have led to the natural extraction of these metals from the soil. Besides the change in bioavailability, precipitation by sulphate-reducing bacteria (*Desulfovibrio desulfuricans*) could also lead to bioremediation. This process is indirect and mostly ex situ where the sulphate-reducing bacteria convert sulphate forms of heavy metal into their hydrogen sulphate, as in heavy metals Zn and Cd, to form insoluble forms of these metal sulphides (White et al. 1998).

One of the strategies used during bioremediation of contaminated soils to make it favourable for soil microbes is biostimulation which involves the use of organic amendments and accumulation of nutrients to the soil. Organic matter in the form of manure serves as a carbon source for soil microbes and the growth and activities of microorganisms involved in the process of remediation increase due to added nutrients, the only limitation here is to identify the right strain for biostimulation, which can be identified by using next generation sequencing and other biotechnological approaches. Typically biostimulation is used to biodegrade organic pollutants (Abioye 2011) and can also be employed for the bioremediation of soils contaminated with heavy metals. Since heavy metals are less amenable to biodegradation, biostimulation indirectly enhances their bioremediation by altering soil pH. It is the introduction of organic matter that actually reduces the soil pH (McCauley et al. 2009). Solubility and bioavailability of heavy metals get increased by the low pH of the soil, which subsequently increase its extractability from the soil (Karaca 2004). Biochar is an organic material which is known for its potential in the management of soils contaminated with heavy metals. Currently, it is being used for remediation purposes in various parts of the world. Experiments conducted by Namgay et al. (2010) stated that the presence of heavy metal in the contaminated soil amended with biochar was decreased. Unlike most other organic amendments biochar because of its ability to increase soil PH (Novak et al. 2009) reduces the bioavailability of metals for plant uptake due to increased sorption. Biochar properties differ broadly depending on the feedstock used in its production, and it also depends on the method employed during its production. Thus it is essential to note the effect of different amendments of biochar will have on its effectiveness when using for soil remediation. Further, in-depth research is required to comprehend how soil microorganisms are influenced by biochar and how remediation process of contaminated soils is amended because such reports are rear in literature. The insoluble metals are generally stored in extracellular (apoplastic) and intracellular (symplastic) compartments as precipitates of sulphate, carbonate, or phosphate (Raskin and Ensley 2000). Metal hyperaccumulator plants though are efficient in absorbing metals in large quantities from the soil, but they produce little biomass and are slow growing. To clean up contaminated sites using these plants, it may take years to decades. To overcome these shortfalls chemically improved phytoextraction has been employed. In this approach, chelating organic acids are used to enhance high biomass-producing crops to take up large amounts of metals (Nowack et al. 2006).

14.4 Wastewater Treatment

Conventional wastewater treatment systems are energy inefficient processes and inadequate to achieve discharge standards in effluent prescribed by various agencies (Caputo and Pelagagge 2001). It involves primary and secondary processes followed by disinfection for disposal of wastewater. With the advancement of technologies nutrients and harmful chemicals are removed, which ultimately decrease the oxygen demand of the wastewater and improve the quality of the treated water so that it can be reused. To stop eutrophication and elevated oxygen demand of wastewater an additional operation unit (Tertiary treatment) is added to the conventional treatment process which is generally employed to remove nutrient load (Phosphate and nitrates) which are the major drivers of eutrophication and high oxygen demand (Schaar et al. 2010). Biological wastewater treatments gained popularity in recent years. Conventional aerobic treatments used to reduce nutrients and organic load from wastewater are not efficient enough to remove most of the contaminants and it cannot be achieved without the combined use of both that is aerobic and anaerobic treatments (Okoh et al. 2010). Algae are known to breakdown the organic material to obtain energy and nourishment for their growth and development present in wastewater. They are wonderful biological mediators that own potential to convert solar energy and carbon dioxide into valuable products such as biodiesel, bioethanol, and biobutanol. Due to non-pathogenic nature and capability of algae biomass to grown in different effluents like municipal, industrial, and agricultural effluents, they are used for bioprocessing of wastewater (Chinnasamy et al. 2010). Two stage Sludge digestion system in which organic mass is digested by bacteria in absence of oxygen. The first stage of this system involves the break down of large molecules like proteins and lipids into smaller water soluble molecule by acid forming bacteria which finally ferment these molecules into fatty acids. The second stage involves the movement of soluble molecules into the second tank where bacteria convert soluble molecules into biogas (Carbon dioxide and Methane). Methane is used to generate heat for the operation of the treatment plant and is also used for the generation of electricity (Andreoli et al. 2007). Ballasted floc reactor, integrated fixed-film activated sludge (IFAS), and membrane bioreactor process are some examples of improved treatment methods of wastewater.

14.4.1 Molecular Techniques in Wastewater Treatment

Application of molecular techniques to treat wastewater is quite new and are economical than the already established techniques. Majority of these are used to make wastewater xenobiotic free. Specific nucleic acid probes are used to detect harmful microorganism from wastewater (Khan et al. 2004; Sanz and Köchling 2007). Other techniques which proved to be most effective and interesting for detection process are fluorescent in situ hybridization (FISH), genomics library, and denaturant gradient cell electrophoresis (DGGE) (Sanz and Köchling 2007). Use of recombinant technology has also its own disadvantages and limitations (Timmis et al. 1994) such as instability of recombinant strain, complex xenobiotic degradation pathways, and accidental or deliberate release of genetically modified strains into the environment.

14.5 Microbial Enzymes in Bioremediation

14.5.1 Microbial Oxidoreductase

Various bacteria, fungi, and higher plants detoxify toxic organic compounds through oxidative coupling which is mediated by oxidoreductases (Gianfreda et al. 1999: Bollag et al. 1998). These enzymes are also involved in microbial energy extraction via energy-yielding biochemical reactions. Oxidoreductases also assist in the transfer of electrons from the reduced substrate to acceptor compound, which results in oxidization of contaminant to the harmless compound. Oxidoreductases participate in the humification of the phenolic compound resulting from the decomposition of lignin, and they also can detoxify xenobiotics by binding them to humic substances or through polymerization and copolymerization with other substrates (Park et al. 2006). Enzymes of microbial origin have been exploited in the degradation and decolourization of dyes (Vidali 2001; Williams 1977; Husain 2006). Some bacterial strains have tendency to reduce the radioactive metals from their oxidized soluble form to reduced insoluble form. Some bacteria during their energy production process takes up electrons from organic compounds and make radioactive metals as the final electron acceptor. To reduce radioactive metals some strains of bacteria use intermediate electron donor. It is the redox reactions system of metal-reducing bacteria, which finally precipitate the contaminant (Leung 2004). Effluents generated from paper and pulp industry contain chlorinated phenolic compounds which are produced from the partial degradation of lignin during the process of pulp bleaching. Many fungal species due to their extracellular oxidoreductase enzymes like manganese peroxidise, laccase, and peroxidise are considered suitable for the treatment of environment contaminated with phenolic compounds. Fungi release these enzymes from their mycelium into the environment (Rubilar et al. 2008). Phytoremediation of phenolic compounds using plants from Fabaceae, Gramineae, and Solanaceae families. They degrade contaminants using their oxidoreductases is a promising natural approach to decontaminate the environment. Organic contaminants like explosives, petroleum hydrocarbons, and chlorinated solvents are generally focused (Duran and Esposito 2000, Newman et al. 1998).

14.5.2 Microbial Dioxygenases

Dioxygenases are multicomponent enzyme systems that introduce molecular oxygen into their substrate Rieske nonheme iron oxygenases is one of the large family of dioxygenases which include aromatic hydrogen dioxygenase. These dioxygenases have wide application in environmental remediation because of their involvement in the oxygenation of wide range substrates (Fig. 14.1). All members of this family have one or two electron transport proteins preceding their oxygenase components. The presence of Rieske (2Fe–2S) cluster and mononuclear iron in each alpha subunit of the enzyme has been confirmed from the crystal structure of

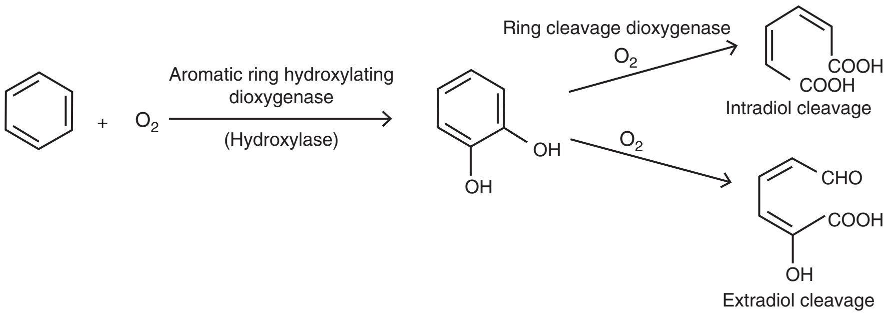


Fig. 14.1 Degradation of aromatic compound by dioxygenase

naphthalene dioxygenase (Dua et al. 2002). Catechol dioxygenases found in soil bacteria are involved in the transformation of aromatic precursors into aliphatic products.

14.5.3 Microbial Hydrolytic Enzymes

The industrialization has led to the pollution of soil and water through the discharge of effluents by the industrial units. Industrial discharge onto land contains many harmful chemicals, petroleum hydrocarbons, mineral acids, bases, and many more chemicals of unknown nature. Bioremediation provides an economical and safe alternative to commonly used chemical treatments. Organic pollutants are mostly hydrolyzed by bacterial activity. It is the extracellular enzyme activity that has the key role in degradation since bacterial cell pores can only allow molecules lower than 600 daltons to enter the cell (Vasileva-Tonkova and Galabova 2003). Disruption of major chemical bonds of toxic compounds by bacterial hydrolytic enzymes results in the reduction of their toxicity. Hydrolytic enzymes of microbial origin are effective in the biodegradation of insecticides (DDT) and oil spill (Vasileva-Tonkova and Galabova 2003; Lal 1982; Williams 1977; Shafi et al. 2018). Hydrolases are considered to be effective players in bioremediation because of their ready availability, tolerance to the addition of solvents which are water miscible and lack cofactor stereo selectivity.

14.6 Solid Waste Biotreatment

Stringent standards for the discharge of waste into the environment, as well as the cost of routine treatment options, have motivated the scientific community to look for the different treatment options (Nicell 2003; Hamer et al. 2007; Mazzanti and Zoboli 2008). Keeping the following objectives in view, these treatment processes are developed by (1) reducing costs and resource conservation, (2) minimal effluent disposal and efficient waste recycling within the facility, (3) reduction in effluent quantity, and (4) transformation of waste into valuable products. There are two ways in which waste and pollutants can be treated one is biological, and the second one is chemical. We produce biowaste in our day to day life, which includes agricultural waste, horticulture waste, wastewater treatment plants, etc. Biowaste can be categorized as: process waste, manures, and plant material. In European countries, biowaste consists of 40–60% of municipal solid waste, and it is being collected separately and used for many purposes like composting or degradation (aerobic) which improves soil texture by supplying nutrients to the soil. Biowaste is also used for the generation of biogas in many countries of the world. Biological treatment of waste involves the careful selection of organisms (Biocatalysts) to degrade the waste. It is considered as most

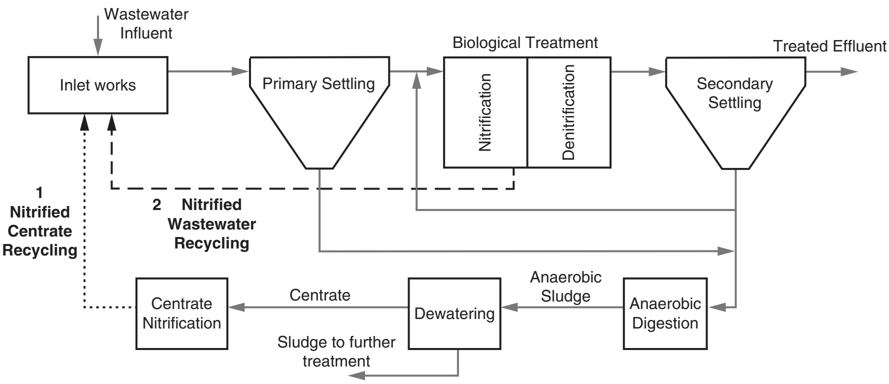


Fig. 14.2 Schematic diagram of biological wastewater treatment

favourable, stable, and bulk, reducing option which reduces the potential adverse effects on health and environment. Generating useful products and reclaiming valuable minerals for reuse are the added advantages of biotreatment. Biological treatment of solid waste can be done in situ or ex situ (Doble et al. 2004). Treatment of biological waste can be done under aerobic conditions or anaerobic conditions (Fig. 14.2). Digestion of organic waste is accelerated in anaerobic conditions under optimum conditions of temperature, pH, and moisture (Mata-Alvarez et al. 2000; Salminen and Rintala 2002), anaerobic processes are energy efficient, maintain enclosure of order, produce low sludge compared to aerobic ones.

14.7 Pollution Detection and Monitoring: Role of Environmental Biotechnology

Measuring a set of selected essential parameters on a regular basis which determine the environmental quality is environmental monitoring. There are two methods available (Biological and physiochemical) to judge the environmental health (Kaiser 2001; Lam and Gray 2003; Hagger et al. 2006). Environmental monitoring a couple of decades before was solely dependent on the measurement of physiochemical parameters and the monitoring of biological parameters were occasionally done. Physiochemical methods have limitations because of their heavy dependence on sophisticated equipment and complex analytical methodology (Gu et al. 2004).

For the protection of environment pollution detection at low concentrations is very important so that protective measures can be placed at the beginning (Durrieu et al. 2006). Monitoring of contaminants typically involves the frequent and regular measurements of various chemicals in soil, water, air, and sediments over a fixed time period. Integration of informational technology with biotechnology has made data collection, and monitoring work quit easy and accurate. It has also revolutionized the real-time analysis and data interpretation.

14.7.1 Bioindicators/Biomarkers

Environmental monitoring, apart from physiochemical measurements of contaminants, also needs to assess various biological/ecological parameters and responses. The temporal and spatial changes of selected biological responses which are used by ecologist and environmental biologists for the assessment of environmental quality (Durrieu et al. 2006; Conti 2008; Lam 2009). Organisms or communities react to changing environmental conditions by showing a measurable change in their chemical compositions/biological processes. These changes/responses are called as biomarkers/bioindicators (Kaiser 2001; Conti 2008). Thus biomarkers are used to give biological information (effect of environmental pollution). Bioindicators can be categorized into three types: those obtained on exposure, on susceptibility, and on effect.

Bioindicators that have potential to be used for biological monitoring are

- Molecular markers (Change in expression, DNA damage)
- Biochemical markers (Enzymatic, specific proteins)
- Histo-cytopathological (Cytological, histopathological)
- Physiological and behavioural

14.7.2 Biosensors

Biosensors are analytical devices consists of biomarker in the form of enzyme, antibody which is in close contact with transducer, which together relate the concentration of an analyte to a measurable electrical signal (Reiss and Hartmeier 2001; Rodriguez-Mozaz et al. 2004). Biosensing research has gained considerable attention in recent years because of the growing environmental pollution. Biosensing devices produce signals exploiting specificity of biological molecules to measure pollution levels. In broader terms biosensors are referred to any system that produces quantifiable signal on the detection of substrate using biological component. The main part of the biosensor is its biological component which can be whole cell, enzyme, antibody, genetically engineered organism. Biosensors represent the wonderful synergistic combination of microelectronics and biotechnology (Verma and Singh 2005). Biosensors can be used to detect both chemical pollutants as well as biological contaminants. Microchip biosensor with very high selective sensitivity was developed by combining biological activity with nanoelectronics (Cui et al. 2001).

Microalgal whole cell biosensors based on (Chlorophyll fluorescence or phosphatase and esterase inhibition) are used for the detection of environmental pollutions. Biosensor based on genetically modified yeast as used to detect endocrine disruptors such as oestrogen or 17-oestradiol. It was initially designed for therapeutic uses in humans. But later it was found to have potential to be used for detection of environmental pollutants (Tucker and Fields 2001). Use of biosensors has addressed many vital environmental issues which arose with other conventional methods.

14.8 Biotechnology for Cleaner Production

Use of biotechnological approach to combat environmental pollution is considered as the motor for the sustainable future. Contrary to other pollution control strategies which struggle for the tail end of the process and manage pollution once it has been generated, biotechnology works to stop pollution at its source by using different practices like (1) use of efficient raw material, (2) substituting less harmful substances for hazardous materials, and (3) eliminating hazardous toxic substances in effluents. Although the primary focus of environmental biotechnology is to develop technologies to treat waste but the basic information has been gained by people that how biotechnology can handle these wastes and the main focus is how to implement these processes as Available Technology Not Entailing Excessive Costs (BATNEEC) (Grommen and Verstraete 2002). Biotechnological processes after their successful set up are considered cost effective than conventional methods. Use of biotechnology for production processes not only contribute for the protection of environment, but also make companies economically sound and continuously improve their market image (Olguín 2000; Willke et al. 2005).

14.8.1 Pulp and Paper Industry

Biotechnological techniques like enzyme engineering, proteomics, metabolomics genetic engineering have helped in developing methods for paper production which are economically feasible, cost effective, and environmental friendly. Paper and pulp industry plays a vital role in world economy. Cellulosic pulp which is the target product is produced from pulping of wood (lignocellulosic material) by chemical or mechanical treatment for the release of fibres from the material. Most of the cellulosic pulp (90%) is produced from woody plants. Sugar cane, straw, and bamboo are the major raw material source for the pulp production (Sixta 2006).

The overall paper and pulp production process can be divided into six steps.

1. Wood preparation
2. Pulping

3. Pulp washing
4. Pulp screening
5. Bleaching
6. Paper manufacturing

From the last few decades, pulp and paper industry mostly in developed countries has been using biotechnological approaches for technological needs, which has resulted in a cleaner environment.

14.8.2 Biopulping

Use of ligninolytic enzymes or fungi cultures for the pre-treatment of raw material or wood is one of the interesting biological approaches used in the pulp and paper industry. Although there are other microorganisms which can be used for the bioprocessing of wood but fungi being the primary colonizers of wood utilizes its sugars without affecting its strength. Soft rot fungi and white fungi have high capability to degrade the wood because of their different extracellular enzymes. It is the white rot fungi in particular which are efficient ligninolytic organism producing all the necessary extracellular oxidative enzymes for the complete degradation of wood (Tekere et al. 2001). There are some fungi which are non-selective (*Trametes versicolor*) that is they simultaneously degrade hemicelluloses lignin and cellulose. While some others like *Phlebia tremellosa*, *Ceriporiopsis subvermispora,* and *Phellinus pini* degrade lignin preferentially (Otjen et al. 1987). The aim of biopulping is to utilize the special ability of selectively delignifying wood with cellulose decomposition of these specific fungi.

Fungal pre-treatment of wood chips before kraft pulping showed a significant increase in pulping yield (Mendonça et al. 2002) and decreased energy consumption (Young and Akhtar 1997). Fungal pre-treatment of woodchips before mechanical pulping process makes the wood soft for grinding. Thus to facilitate pulping this methodology does not require chemical agents, sophisticated equipment, and additional energy. Biotreatments enhance pulp quality, in addition to this biotreatment reduces energy consumption and environmental impact of the refining process, which make it more environmentally friendly than conventional methods used (Tian et al. 2012).

14.8.3 Bio-bleaching

Bleaching process of pulp needs chlorine, which is disastrous for the environment (Bajpai et al. 2006). Presence of lignin content is responsible for the brown colour of pulp. To improve the paper quality and printability, the removal of lignin content is required. Bio-bleaching is an alternative to conventional bleaching treatments by microorganisms such as fungi or their enzymes. Enzyme bio-bleaching is considered as an excellent environmentally friendly alternative due to its cost effectiveness, specificity, and decreased dependence on chemicals. Following are the main advantages for the use of bio-bleaching:

- Mill trials very simple and inexpensive with minimal risk
- Reducing the pollution from bleaching
- Enhance pulp physical properties
- Process can be easily combined with traditional bleaching
- It enhances fibrillation to give stronger paper
- Simplify the process and reduce the severity of treatment of wastewater.

Xylanase enzyme treatment in bio-bleaching reduces the operation cost and consumption of chlorine. Microbial thermostable xylanases are stable under alkaline conditions of pulping and are generally preferred enzymes for bio-bleaching (Raghukumar et al. 2004). It has been reported that xylanase pre-treatment of kraft pulps has reduced AOX discharge by 5–20%. Deposits of pitch are controlled by the use of lipases. Dewatering rate of pulp is improved by using cellulase enzymes (Foster 1986) that are also used for deinking and fibre modification. Catalase also has an important role it converts hydrogen peroxide to water and oxygen. Thus saves water and makes effluent ecologically harmless. Other enzymes like manganese peroxidise and laccase have also been used. Laccase delignify pulp directly thus replaces chemical stages of bleaching such as oxygen or ozone stage. For the control of pitch buildup and for deinking purposes, particularly when inks contain formulations of vegetable oil lipase has been used (Sharyo et al. 1993). It has been reported that in chip pre-treatment ascomycetes albino fungi reduce pitch and saves bleach cost up to 36% (Trivedy and Pathak 2015).

14.9 Bioplastics

The main threat to the environment and ecology because of plastic is due to its non-biodegradable nature and due to its production from synthetic polymers, which consumes the vast wealth of non-renewable resources (Stevens 2002; Reddy et al. 2003). Bioplastic production is based on natural substances (Proteins, fibres, sugar, and oils) thus avoids the use of non-renewable resources which in turn reduces the release of harmful gases into the environment. Microbes have an important role in converting vegetable and plant material into the building blocks of bioplastic (Luengo et al. 2003; Moldes et al. 2004). Bioplastic production from organic waste and enzyme assisted plastic reduction has addressed many environmental issues like the reduction of plastic waste and a decrease in consumption of non-renewable resources. OECD report (2001) assessed the wide spreading of industrial biotechnology, which was based on 21 companies from different sectors like chemical, paper, pharma, textile, etc. In this study, they found that industrial biotechnology has environmentally sound profound character because of its cleaner production.

14.10 Biotechnology and Agriculture

There is no doubt that the use of chemical herbicides, fungicides, and fertilizers has increased the yield and productivity of crops, but they have caused environmental hazards due to their low biodegradability. The use of biopesticides and genetically modified plants may considerably diminish the use of these harmful chemicals. Biopesticides are classified (Table 14.1) as

- Microbial pesticides (Containing microorganism as active ingredient)
- Plant-incorporated protectants (Genetic material incorporated into the plant produces active pesticide)

Table 14.1 Biopesticides and their control targets (MCD 2008)

S. no.	Organism	Target	Example
1	Bacteria	Insects	*Bacillus thuringiensis*
			Bacillus sphaericus
			Serratia entomophila
			Paenibacillus popilliae
2	Fungi	Insects	*Beauveria* spp.
			Metarhizium
			Lecanicillium lecanii
			Nomuraea
			Paecilomyces fumosoroseus
			Zoophthora
			Entomophaga
3	Protozoa	Insects	*Nosema*
			Vairimorpha
			Thelohania
4	Fungi	Weed control	*Colletotrichum gloeosporioides*
			Chondrostereum purpureum
			Cylindrobasidium leave
			Xanthomonas campestris
5	Fungi	Plant disease control	*Ampelomyces quisqualis*
			Candida spp.
			Clonostachys rosea
6	Competitive inoculants	Plant disease control	*Coniothyrium minitans*
			Pseudozyma flocculosa
			Trichoderma spp.
7	Composts, soil inoculants	Plant disease control	*Bacillus pumilus*
			Bacillus subtilis
			Pseudomonas spp.
			Streptomyces griseoviridis
			Burkholderia cepacia
8	Mollusc parasitic nematode	Nematicides	*Phasmarhabditis hermaphrodita*

- Biochemical pesticides (Include substances which control pests by non-toxic mechanisms)

Biopesticides decompose quickly and are often effective in small quantities (Boyetchko et al. 1999). According to Fraser et al. biopesticides have the following characteristics (Fraser 2005):

- Low risk to human health.
- Low potential to contaminate environmental components and resources.

Biopesticides and genetically engineered insect resistant plants have considerably diminished the use of harmful pesticides and chemicals. Thus, ultimately lead to less exposure to chemicals.

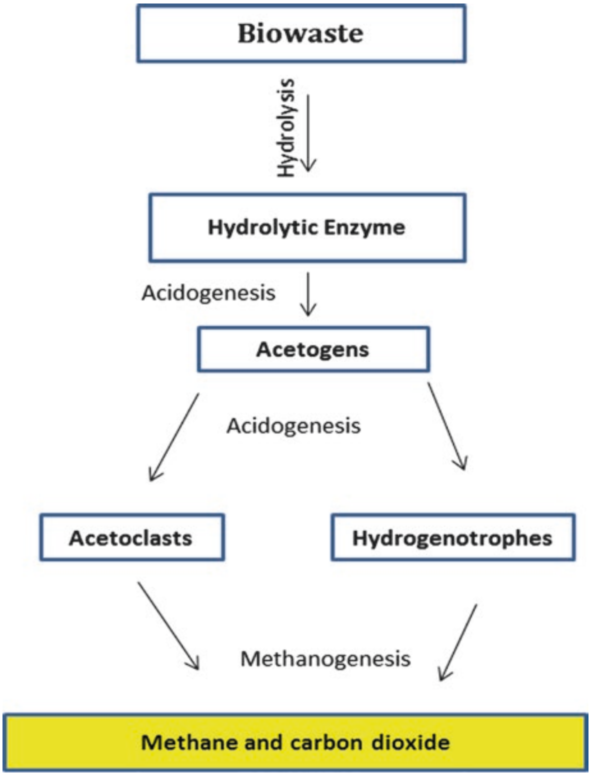
14.11 Chemicals and Biofuels

Excellent research and development is already in force across the globe for production of biofuels by the enzymatic conversion of different substrates (Agricultural waste, municipal waste, and vegetable oils) into bioethanol and biogas, etc. (Dale 2006; Willke et al. 2005). Different applications have conceived the idea of anaerobic digestion of wastes from agriculture and food industries for methane production (Fig. 14.3). Complex organic molecules present in the waste are broken-down by anaerobic bacteria for the production of methane rich combustible biogas having energy value between 21 and 28 MJ/m^3 (Doble et al. 2004).

The idea of chemical synthesis from natural renewable resources is still in its infancy, but the conversion of biomass feedstock into biofuels can have a major economic as well as environmental benefit (Gavrilescu and Chisti 2005; Willke et al. 2005; Chisti 2007). Several companies have started to produce their products from renewable resources (e.g., DuPont) (Willke et al. 2005). Production of fine chemicals using traditional methods has created severe environmental problems. Analysis performed by environmental organizations in order to evaluates two production processes, viz., chemical and biotechnological. It was found that it is the biotechnological process which is more economical and coefficient (e.g., Vitamin B_2 production process). It was found that riboflavin can be produced at cost reduced by 50% using biotechnological approaches (BIO–PRO 2008). Hydroxylation of steroids using microbes leads to the development of steroid drug used for arthritis (Dutta and Samanta 1997).

The key intermediate for the production of penicillins used for chemotherapy is 6-aminopenicillanic acid (6-APA). Synthesis of aminopenicillanic acid (6-APA) using biological approach was found to be 20% cheaper than its chemical synthesis.

Fig. 14.3 Biowaste methanisation



14.12 Conclusion

Globally there are thousands of environmental challenges, and new challenges are evolving at a faster rate. New technologies are currently under development, and some already established ones are gaining more and more ground in practice. There is a need of a technology which can harness the potential of plants and microbes as robust and eco-efficient agents in a variety of practical situations. Along with a vast group of technologies to achieve the objectives of sustainability, biotechnology is fighting from the front and will continue to play a vital role in the field of environmental protection, food, renewable materials, and bioremediation. Environmental biotechnology is a sustainable approach to develop efficient protocols, clean processes, and products with reduced environmental impact. Environmental and economic benefits that biotechnology can offer in manufacturing, monitoring, and waste management are in balance with technical and economic problems which still need to be solved. All this is being achieved with reduced environmental impact and enhanced sustainability. An evaluation of the consequences, opportunities, and challenges of modern biotechnology is important for both policymakers and the industry.

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