Environmental Biotechnology – A Review

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Abstract: Environmental biotechnology is a broad field encompassing diverse disciplines of natural sciences and engineering. The progresses in research are occurring at a rapid pace, and applications that have broad implications socially, economically and ecologically are emerging. Along with remarkable settlement, environmental consequences that affect core quality-of-life issues for present and future generations are materializing. With the aim of achieve the use of organisms, cells, parts thereof and molecular analogues for products and services to clean our surroundings. The environmental impacts of aquaculture, crop growing, genetically modified organisms (GMOs) and even pharmaceuticals are elevating public concerns and demonstrate the need for guidance from a variety of social, economic and scientific disciplines to insure the benefits. The pollution of the environment has become a major global concern due to rapid growth of industrialization, urbanization, modern agricultural development and energy generation which have exploited natural resources for fulfilling the human desires and needs, resulted in disturbing the ecological balance on which the quality of environment depends. Technological innovations and advancements in products and processes in industries have given rise to new products and new pollutants in abundant level which have self cleaning capacity of the environment. At present there are different horizons of this technology including nanotechnology, these are discussed in this review with brief history of environmental biotechnology.

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1. Introduction

Environmental Biotechnology is the multidisciplinary assimilation of sciences and engineering in order to exploit the enormous biochemical potential of biological organisms including microorganisms, plants and parts thereof for the re-establishment and protection of the environment and for the sustainable use of resources (Zylstraa and Kukor, 2005). Environmental biotechnology is defined as the development, use and regulation of biological system e.g. cells, cell compartments, enzymes, for remediation of contaminated environments and for environment-friendly processes (green manufacturing technologies and sustainable development).

Other way to describe Environmental biotechnology is when biotechnology is applied to and used to study the natural environment (Fig.1). Environmental biotechnology could also imply that one try to harness biological process for commercial uses and exploitation. The International Society for Environmental Biotechnology defines environmental biotechnology as "*the development, use and regulation of biological systems for remediation of contaminated environments (land, air, water), and for environment-friendly processes (green manufacturing technologies and sustainable development)*".

Environmental biotechnology can simply be described as "the optimal use of nature, in the form of plants, animals, bacteria, fungi and algae, to produce renewable energy, food and nutrients in a synergistic integrated cycle of profit making processes where the waste of each process becomes the feedstock for another process.

The most important role of environmental biotechnology is to develop better approaches for sustainable development and for understanding processes in the natural environment (Rittmann and McCarty, 2001). The driving force of biotechnology is abilities of microorganism utilizations of various carbon sources natural occurring as pollutants. The microbial ecology and biotechnology science area emphasizes investigations of microbial processes at population, organism, and gene function levels to address environmental threats from contamination and pathogens, and to use the capabilities and properties of microbial systems for wastewater purification, biodegradation of chemicals, biological solid waste treatment, induced corrosion, biofuel production and other applications (Soetan, 2011**)**.

Researchers expound and tie together the capabilities of microbial processes through the following disciplines and methods: molecular-to-field scale studies, technology development, bioinformatics, microbial genomics, community dynamics, extremophiles, genetically engineered microorganisms and bioremediation. Biosafety is another issue related with environmental biotechnology. It includes all measures that should avoid or decrease risk associated with any biological agents. In a classical form it comprises technical (e.g., flow box) and/or organization (e.g., education of personnel) means to protect human health when handling dangerous organisms. With the beginning of recombinant DNA techniques (genetic engineering, genetic modification) in the middle of seventies of the last century similar safety measures were applied in this field (Okpokwasili, 2007). First they were of a voluntary or recommended character (Asilomar conference in USA, Ashby group in UK); later in the EU they became obligatory by legislation (Directives, Regulation). With the introduction of biotechnology in agriculture, biosafety was extended to the risk to the environment and to the biodiversity. Within the frame of UNEP (UN Environmental Programme) biosafety was implemented by a protocol to CBD (Convention on Biological Diversity) known as the Cartagena Protocol (Su, 1998).

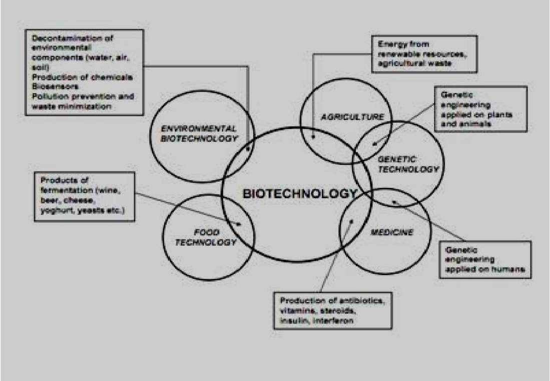


Figure 1: Different aspects of biotechnology in today's world

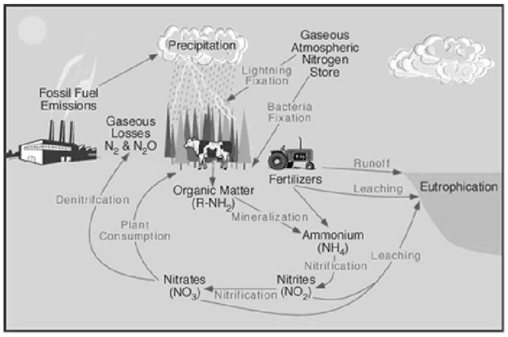


Figure 2: Geochemical cycles running in Environment

Since the development of new techniques, environmental pollution has become a major global concern due to rapid growth of industrialization, urbanization, modern agricultural development, energy generation etc., which have exploited natural resources for fulfilling the human desires and needs, resulted in upsetting the ecological balance on which the quality of environment depends. Technological innovations and advancements in products and processes in industries have given rise to new products and new pollutants in abundant level which are above the self cleaning capacity of the environment. It is the Industrial revolution that gave birth to environmental pollution. Pollution is introduction of contaminants in the environment that causes instability, disorder, harm and discomfort to the ecosystem. Waste generated during extraction of raw materials, processing of raw materials in to intermediates and final products, consumption of final products and other human activities. The disposal of waste is and will continue to be an environmental problem unless a proper treatment is adapted. The treatment technique involved physio-chemical and biological methods are not efficient and/or effective to treat the contaminants to acceptable level. Therefore, Bioremediation/Phytoremediation technology using the microorganisms or plants to reduce, eliminate or transfer contaminants present in soil, sediment or water would be effective/efficient and cost-effective green technology (Gilbert and Colwell, 1988).

Over the past few decades enormous quantities of industrial pollutants have been released into the environment. A large number of them, particularly those structurally related to natural compounds, are readily degraded or removed by microorganisms found in soil and water. However, superimposed on the wide variety of pollutants present in the environment are an increasing number of novel industrial compounds rarely found in nature. These xenobiotic compounds are usually removed slowly and tend to accumulate in the environment. Due to the high degree of toxicity, their accumulation can cause severe environmental problems. Because of the problems associated with pollutant treatment by conventional methods, such as incineration or landfills, increasing consideration has been placed on the development of alternative, economical and reliable biological treatments. Although natural microorganisms collectively exhibit remarkable evolutionary capabilities to adapt to a wide range of chemicals, natural evolution occurs at a relatively slow rate, particularly when the acquisition of multiple catalytic activities is necessary. In these cases, the acceleration of these events via genetic engineering/processing engineering is helpful since the desirable traits can be carefully designed and controlled. The drive toward this goal represents the essence of environmental biotechnology (Cupples *et* *al*., 2004).

Environmental biotechnology is concerned with the application of biotechnology as an emerging technology in the context of environmental protection, since rapid industrialization, urbanization and other related developments have resulted in a threatened clean environment and depleted natural resources (Fig. 3).

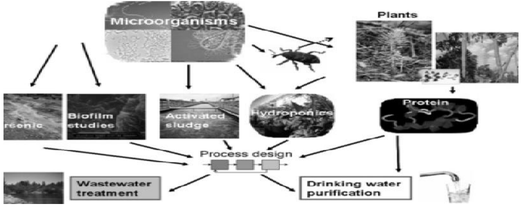


Figure 3: Various aspects of Environmental biotechnology

1.1. Historical Background

Biotechnological processes to protect the environment have been used for almost a century now, even longer than the term 'biotechnology' exists. Municipal sewage treatment plants and filters to purify town gas were developed around the turn of the century. Earlier, technologies such as composting, waste water treatment were the initial stones towards this aspect. In its early stage, environmental biotechnology has evolved from chemical engineering. They proved very effective although at the time, little was known about the biological principles underlying their function. Since that time our knowledge base has increased enormously. But later on, other disciplines such as biochemistry, environmental microbiology, environmental engineering, ecology and molecular biology also contribute to this technology development (Alvarez-Coque and Valdes (1997).

This review describes the state-of-the-art and possibilities of environmental biotechnology. It also deals with the societal aspects of environmental biotechnology.

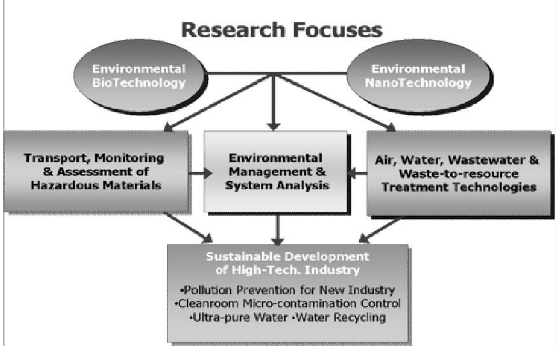


Figure 4: Research focuses of Environmental biotechnology

1.2. Role of Environmental biotechnology

The development of multiple human activities, the increase in living standard and high consumer demand have amplified pollution of air, water, soil, the use of disposable goods or non-biodegradable materials, and the lack of proper facilities for waste contributing towards pollution hazards. With increasing knowledge it is now known that these pollutants can be easily degraded or removed through biotechnological solutions by the agencies like microbes, plants, animals under specified conditions that envisage abiotic and biotic factors, leading to non-aggressive products through compounds mineralization, transformation or immobilization.

Advanced techniques are now possible to treat waste and degrade pollutants with the help of living organisms or to develop products and processes that generate less waste and preserve the natural non-renewable resources and energy (Fennell, 2004).

The major methods include: (1) Improved treatment for solid wastewater, (2) Bioremediation: cleaning up contamination and phyto-remediation, (3) Ensuring the health of environment through bio-monitoring (4) Energy production from biomass, (5) Cleaner production: manufacturing with less pollution or less raw materials, (6) Genetic engineering for environmental protection and control.

Biological treatment is environmentally friendly, performed at ambient temperatures, and it does not generate nitrogen oxides or secondary waste streams. Bioscrubing, trickling biofiltration and biofiltration are typical waste gas cleaning technologies. Biofiltration appears to be cheapest and also most studied and most extensively used technology. Bioscrubing and trickling biofiltration are used rather to special applications. Trickling biofilter and biofilter are packed columns with organic or anorganic carrier material which is covered with biocatalyst. Microorganisms convert pollutants into simply inorganic compounds such as carbon dioxide and water (Cupples et al., 2004).

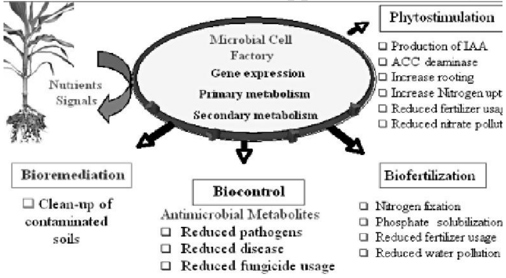


Figure 5: Utilization of microbes to promote sustainable agriculture

Biotechnology can also be used to develop products and processes that generate less waste and use less non-renewable resources and energy. In this respect biotechnology is well positioned to contribute to the development of a more sustainable society, a principle which was advocated in the Brundtland Report in 1987 and in Agenda 21 of the second Earth Summit in Rio de Janeiro in 1992 and which has been widely accepted in the mean time.

Biotechnological techniques to monitor the quality of the environment are presented in the section on detection and monitoring. Recombinant DNA technology has improved the possibilities for the prevention of pollution and holds a promise for a further development of bioremediation. These topics will be discussed in the section on genetic modification. The development of modern biotechnology has been accompanied by the establishment or adaptation of regulations to deal with genetically modified organisms.

What this means for environmental biotechnology is embodied in the section on legislation. The section on public opinion, dialogue and debate highlights how people feel about environmental biotechnology and ways in which their opinion is influenced.

1.3. Environmentally friendly Methods

(1) Improved treatment for solid wastewater

Classical biological analytics has been used for many years for water and waste water monitoring. This includes the monitoring of oxygen demand in waste water or toxicity testing with living organisms. End-of-pipe technologies are still the most important application area for biotechnology in the environment. In waste-water treatment biotechnological processes are state-of-the-art. These are applied not only for metabolizing carbon compounds, but also for the elimination of nitrogen, phosphorous and sulphur compounds as well as for organic pollutants such as solvents and pesticides. Biofilters and biowashers have been developed that use enzymes or microorganisms to degrade and eliminate pollutants and odours. Research in this area aims to identify microorganisms that are able to degrade several pollutants in parallel and under adverse conditions.

Researchers have taken advantage of this phenomenon and use it for bioremediation purposes. A complete biodegradation results in detoxification by mineralizing pollutants to carbon dioxide, water and harmless inorganic salts. Incomplete biodegradation will yield breakdown products which may or may not be less toxic than the original pollutant.

However, despite the apparent simplicity of microorganisms, the different strategies for dealing with pollutants are as diverse as the organisms themselves. The process of biodegradation must therefore be investigated on several levels; biochemical, genetic and physiological. The amount of data to be acquired in order to develop a feasible remediation technology is vast. In addition, environmental engineering has the unfortunate characteristics that no universal technology, applicable to any sort of pollution, can be engineered on principle. As there exist certain synthesis procedures for a chemical, so do only certain methods successfully deplete the chemical from a contaminated site?

1.4. Bioremediation

The use of microorganisms is likely to save billions of dollars in the cost of cleaning up subsurface contamination. Subsurface microorganisms play a key role in the breakdown of toxic compounds to form non-toxic products. The ability of treating subsurface contamination in-situ using subsurface microorganisms, instead of bringing them to the surface for treatment and disposal can provide a huge cost savings, as well being a more sustainable way of dealing with these problems.

Therefore, the nutritional versatility of microorganisms can also be exploited for biodegradation of environmental pollutants. This process is called bioremediation (Vadali, 2001) and is based on the capability of certain microorganisms to metabolize toxic pollutants, obtaining energy and biomass in the process. Ideally, the chemicals are transformed into harmless compounds such as carbon dioxide and water. Using microorganisms to degrade harmful compounds is an attractive option for cleanup of polluted environments. Bioremediation is the use of biological systems for the reduction of pollution from air or from aquatic or terrestrial systems. Microorganisms and plants are the biological systems which are generally used. Biodegradation with micro-organisms is the most frequently occurring bioremediation option. Micro-organisms can break down most compounds for their growth and/or energy needs. These biodegradation processes may or may not need air. In some cases, metabolic pathways which organisms normally use for growth and energy supply may also be used to break down pollutant molecules. In these cases, known as co-metabolism, the microorganism does not benefit directly.

However, once developed, remediation technologies based on biological agents, bacteria and fungi being the most commonly applied, represent a viable substitute to chemical and physical methods, mainly due to lower set costs. Therefore, it is truly of primary interest to acquire sufficient information about microbial processes to allow a more general approach to process design that would consequently lower the price of environmental biotechnology. Additionally, based on the knowledge of metabolic pathways of intractable pollutants, genetically modified microorganisms can be engineered.

A promising example was the transfer of the PCB degradation pathway into indigenous microorganisms as a method to avoid time-consuming adaptation of the degrader to specific conditions of the polluted site (Dietmar, 2004). Enhanced bioremediation is a process in which native or inoculated micro-organisms (e.g. fungi, bacteria, and other microbes) degrade organic contaminants found in soil and/or ground water, converting them to innocuous end products. Nutrients, oxygen, or other amendments may be used to enhance bioremediation and contaminant desorption from subsurface materials. In the presence of sufficient oxygen (aerobic conditions), and other nutrient elements, microorganisms will ultimately convert many organic contaminants to carbon dioxide, water, and microbial cell mass. In the absence of oxygen (anaerobic conditions), the organic contaminants will be ultimately metabolized to methane, limited amounts of carbon dioxide, and trace amounts of hydrogen gas. Under sulfate-reduction conditions, sulfate is converted to sulfide or elemental sulfur, and under nitrate-reduction conditions, dinitrogen gas is ultimately produced. Sometimes contaminants may be degraded to intermediate or final products that may be less, equally, or more hazardous than the original contaminant. For example, TCE is anaerobically biodegrades to the persistent and more toxic vinyl chloride. To avoid such problems, most bioremediation projects are conducted in situ. Vinyl chloride can easily be broken down further if aerobic conditions are created. Enhanced bioremediation of soil typically involves the percolation or injection of ground water or uncontaminated water mixed with nutrients and saturated with dissolved oxygen. Sometimes acclimated microorganisms (bioaugmentation) and/or another oxygen source such as hydrogen peroxide are also added. An infiltration gallery or spray irrigation is typically used for shallow contaminated soils, and injection wells are used for deeper contaminated soils. Although successful in situ bioremediation has been demonstrated in cold weather climate, low temperature slows the remediation process. For contaminated sites with low soil temperature, heat blankets may be used to cover the soil surface to increase the soil temperature and the degradation rate. Enhanced bioremediation may be classified as a long-term technology which may take several years for cleanup of a plume (Marta, 2011).

Biological waste gas technologies are applied to a lot of decontamination cases such as *in-situ* soil and underwater cleaning (venting, air-sparing) and off-gases cleaning (food, oil and chemical industry, agriculture, waste water plant, gas station etc.). They can be used for removing of wide range of organic (hydrocarbons, chlorinated hydrocarbons, ketones, esters, aldehydes, odours) and inorganic compounds (hydrogen sulphide, carbon disulphide, ammonia, nitrogen oxides). They are relatively cheap in comparison to conventional techniques such as incineration, condensation, absorption or adsorption.

1.5. Environment friendly Biodegradation of organic pollutants

Dietmar *et al.*, 2004, discussed that several new methodologies have enabled recent studies on the microbial biodegradation mechanisms of organic pollutants. Culture-independent techniques for analysis of the genetic and metabolic potential of natural and model microbial communities that degrade organic pollutants have identified new metabolic pathways and enzymes for aerobic and anaerobic degradation. In addition, structural studies of the enzymes involved have revealed the specificities and activities of key catabolic enzymes, such as di-oxygenases. Genome sequencing of several biodegradation-relevant microorganisms have provided the first whole-genome insights into the genetic background of the metabolic capability and biodegradation versatility of these organisms. Systems biology approaches are still in their infancy, but are becoming increasingly helpful to unravel, predict and quantify metabolic abilities within particular organisms or microbial consortia.

Recent years have seen marvelous efforts to understand the natural diversity of biodegradation, with the aim of exploiting these findings for bioremediation purposes.

New genes, enzymes and metabolic routes have been discovered for the aerobic and anaerobic degradation of organic pollutants. Methods have been fine-tuned to gain a more detailed insight into structure–function relationships, leading to the identification of structural elements and single amino acids (and therefore nucleotides) that determine protein activities and specificities. The broad knowledge acquired has allowed us to use culture-independent studies based on functional characteristics to assess the diversity and quantity of catabolic genes in response to pollution, rather than just changes in community structure. The integration of new methodologies, like stable isotope probing, has allowed changes in the community to be linked with functional characteristics and has enabled active community members to be identified. The availability of the complete genomes of environmentally important microorganisms paves the way for obtaining global insights into the metabolic potential and activity of microorganisms. It will also learn how the genomes are utilized by microorganisms under various environmental conditions. Modeling approaches to predict and quantify the metabolic capabilities of particular organisms or microbial consortia have only recently appeared, but a combination of such approaches with mechanistic knowledge of biodegradation processes, the elucidation of structure–function relationships and knowledge on the ecology of microorganisms will provide the basis for successful interventions into environmental processes, leading into improved intervention strategies for bioremediation.

1.6. Engineered Environmental Processes

Engineered environmental processes play a major role in maintaining clean water, air, soil, and sediments in our state, as well as cleaning up from the legacy of poor environmental practices. Organic chemicals poured or spread on the ground and now in the subsurface have left a legacy of contaminated sites that pose risk to human health and the environment. Examples include pesticides, herbicides, insecticides, cleaning agents and degreasers, and additives to gasoline (Fig. 6). Some of these compounds move rapidly through the subsurface, resulting in the contamination of our groundwater resources. Examples of affected areas relevant to Oregon are the US Department of Energy (DOE) Hanford site, the Umatilla Weapons Depot, and the Portland Harbor Superfund Site. Subsurface microorganisms play a dominant role in the transformation and the breakdown of these organic compounds, both under natural "intrinsic" conditions as well as under engineered conditions of bioremediation. The potential for microbial transformations to help clean-up contaminated sites has been the subjected of several National Research Council studies: Alternatives for Groundwater Cleanup (1994), Innovations in Groundwater and Soil Cleanup: From Concept to Commercialization, and Groundwater and Soil Cleanup (1997), and Groundwater and Soil Cleanup Improving Management of Persistent Contaminant (1999).

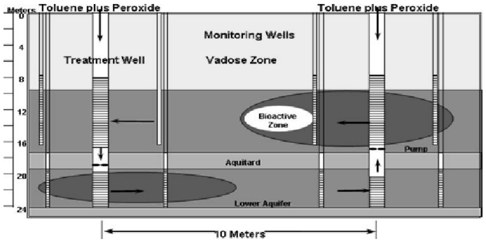


Figure 6: A diagram representing Engineered Environmental processes

Chemical engineers are uniquely poised to contribute in this emerging area since many of the potential solutions require a combined perspective from modern biology and process engineering, two areas where chemical engineers excel. For example, the realization of environmental biotechnology into practical solutions requires the implementation of process design, which is the foundation of the chemical engineering discipline. The same is also true at the cellular level, where the functions of cells are determined primarily by networks of specific catalytic reactions. The nature and activities of these networks are dictated by the genetic information, thereby de-fining the ways in which engineers can influence cellular functions and metabolic capabilities toward the designed of improved biocatalysts for environmental remediation1. Although, superficially these strategies seem distant from traditional chemical engineering, a deeper inspection reveals that the design of biological catalysts, based on defined techniques from biochemistry and biology is indeed parallel to our understanding of chemical kinetics, transport, separation, and control. In addition, advances in genomics and proteomics are providing opportunities to predict, in a quantitative manner, the potential manipulations necessary. Even though chemical engineers are well prepared to contribute new research directions in environmental biotechnology, only a few are working in this area today. Fortunately, the number of chemical engineers showing interest is growing every year and with the recent research emphasis on biotechnology, it is easy to envision that many others will join this exciting research area in the near future (Wu *et al*., 2006).

1.7. Engineering Bio-sorbents for Heavy Metal Removal

Immobilization of heavy metals into biomass or precipitation through reduction to lesser bioactive metal species, such as metal sulfide are the major mechanisms employed by nature(microorganism, animals and plants) to counteract heavy metal toxicity. These natural mechanisms can be easily exploited to optimize biosorbents that are more efficient for heavy metal removal. In one example, a sulfide-dependent metal removal strategy was developed by engineering the sulfate reduction pathway into a robust bacterium *E. coli*. The resulting strains produced significantly more sulfide and removed more than 98% of the available cadmium under anaerobiosis. Further improvement in metal precipitation was achieved by engineering effective sulfate reduction under aerobic conditions. *E. coli* expressing both serine acetyltransferase and cysteine desulfhydrase overproduced cysteine and converted it to sulfide.

The resulting strain was effective in aerobically precipitating cadmium. This aerobic approach of metal precipitation is particularly attractive as large-scale processes could be implemented under aerobic conditions. The challenges are to incorporate these genetic modifications into a robust environmental microbe that could survive and thrive under the required operation conditions. Similar success in engineering enhanced biosorbents has been achieved by displaying metal-binding peptides onto the cell surface. One example was recently reported by creating are petitive metal-binding motif consisting of (Glu-Cys)nGly. These peptides emulate the structure of phytochelatins, metalchelatingmolecules that play a major role in metal detoxification in plants and fungi. The use of *Alcaligenes eutrophus* strains in bioreactors for the bioaccumulation of Cd, Zn and other heavy metals and radionuclides (Wo *et al.*, 2006).

The use of *Citrobacter* species in the bioaccumulation of heavy metals (Whiteley and Lee, 2006). The use of *Methylobacillus* species for uranium biosorption and of other bacterial species for silver biosorption. Uranium, thorium and radium biosorption from mine waters (Bunge *et al.*, 2003).

Biosorption of metals is generally characterized by high selectivity as compared to ion-exchange resins or other adsorbents. This selectivity is considered to be a desirable feature in designing processes for pollution control and/or metal value recovery (Gadd, 2000a). In addition to selectivity, biosorptive processes have the following advantages: solution toxicity does not inhibit microbial biosorptive uptake, microbial biomass growth requirements need not be met; culture purity maintenance is not a concern. Biosorptive processes are excellent candidates for use for the recovery of metal values from dilute industrial complex aqueous solutions, the extraction of radionuclides, e.g. uranium, thorium or radium from mine leachates, and similar metal value recovery or water pollution control applications (Gadd, 2000b).

1.8. Technological considerations

The engineering applications of biosorption or bioaccumulation commonly involve a dilute complex ionic matrix and large volumes of aqueous process or waste solutions from which the selective extraction and, occasionally, recovery of targeted elements via the use of the microbial biomass is intended. Regardless of the detailed engineering configuration of such a process, a stage which significantly affects the overall efficiency and the economics of the technology is the separation of the microbial biomass from the waste or process waters following contact (SENES Consultants, 1985). As a result of this constraint, contact systems making use of microbial biomass immobilized on a support medium have been developed and proposed for use. Two generically different types of immobilized biomass contact systems have been proposed. The first type is based on the use of immobilized biomass particles which are produced via the use of a wide range of biomass binding agents, such as synthetic polymers (e.g. polysulphones), natural polymers (e.g. alginates) or chemical biomass treatment . The second type is based on the use of microbial biomass films, immobilized on support media such as membrane sheets, disks or inorganic particles (Gadd, 2000a; b). Each one of the two types of immobilized biomass necessitates the implementation of different contact reactor design, such as up flow or down flow packed-bed reactors, rotating biological contactors, membrane sheet or tubular reactors, etc.

1.9. Use of Biotechnology for the sustainability of Environment

For the sustainability of Environment, in the post-industrial civilization, waste management is integrated in the concepts of liability, trustworthiness and stability. Therefore industry and public office are thankful to implement the concepts of structured environmental management systems more and more firmly. The endpoints are dependent on the type of wastes and on the priorities set by society. They will with time evolve towards more restriction of all kinds of emissions. This will require increasing inputs of labour, information technology and energy into waste treatment and overall waste management. Particularly for aqueous and gaseous wastes that are not contained, continuously improving treatment with maximum re-use and minimum dissipation in the ecosphere will be the trend of the future. Moreover, the public in general and the individual citizen in particular will request to have (bio) assays to monitor regularly and autonomously the quality of his environment. Such advanced waste management requires considerable energy input. It thus may come in conflict with current concerns about CO_2-emissions and the Kyoto agreements. Innovative approaches to combine waste management and the International Climate Change Partnership (ICCP) directives, for instance by implementing biological carbon sequestration, are therefore warranted. Biotechnology has a major role to play particularly in terms of advanced treatment down to ng/l-levels and in terms of validating the quality of the environment by means of powerful and intelligent bio-monitoring devices (Verstraete, 2002).

1.10. Monitoring Environment Pollution by Microbes

Rising environmental legislation which controls the release and the levels of certain chemicals in the environment has created a need for dependable monitoring of these substances in air, soil and especially water. Old analytical techniques, though highly precise, suffer from the disadvantages of high cost, the need for skilled workers and the fact that they are mostly laboratory bound. Biosensors because of their specificity, fast response times, low cost, portability, ease of use and a continuous real time signal, can present distinct advantages in certain cases. Their biological base makes them ideal for toxicological measurements which are suited for health and safety applications. Over the last 3-4 years there has been an increase in the number of publications concerning biosensors for environmental monitoring, especially in the field of pesticide measurements.

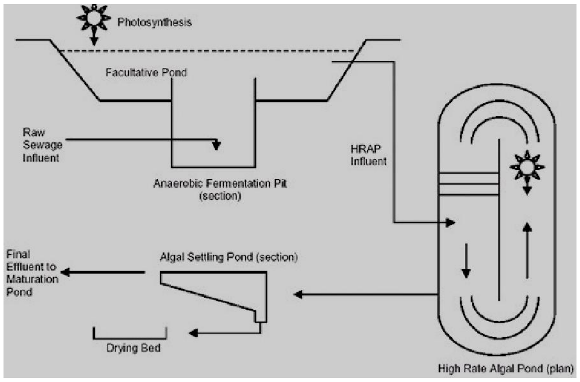


Figure 7: The IAPS system at the Environmental Biotechnology Research Unit stationed at the Grahamstown Municipal Sewerage works. Diagram courtesy of Prof. Peter Rose, EBRU.

1.11. Role of Bacteria in upbringing of Environmental biotechnology

Bacteria signify the great success story of life's pathway. They dwell in a wider domain of environments and span a broader range of biochemistries than any other group. They are flexible, imperishable and superbly varied (Daini, 2000). This is the 'age of bacteria' as it was in the beginning, is now and ever shall be. Bacteria are found all over the place on the earth, from hot deserts in Antarctica to deep-sea thermal vents, from high up in the atmosphere to several kilometers into the Earth’s crust. Their metabolism is remarkably elastic and they can grow in a wide range of environmental conditions. Humans depends on bacteria for survival; as they colonize our skin and digestive tract as part of our immune system, certain bacteria in our gut provide us with vitamin K, and bacteria were initially responsible for the oxygenation of the Earth’s atmosphere. The adaptability of bacteria can be harnessed in a number of biotechnological applications. For example, microorganisms can be used for production of substances such as insulin in the pharmaceutical industry, for manufacture of biodegradable plastics and as sources of novel enzymes with activities at temperature extremes (Fig. 5).

In a review by Girotti *et al*. (2008) which deals with the applications of bioluminescent bacteria to the environmental analyses. The ecotoxicological assessment, by bioassays, of the environmental risks and the luminescent approaches are reported. It also includes a brief introduction to the characteristics and applications of bioassays, a description of the characteristics and applications of natural bioluminescent bacteria (BLB), and a collection of the main applications to organic and inorganic pollutants. The light-emitting GM bacteria applications, as well as the bioluminescent immobilized systems and biosensors were outlined. Considerations about commercially available BLB and BLB catalogues were also reported. Most of the environmental applications of luminescent organisms are on wastewater, seawater, surface and ground water, tap water, soil and sediments, air (Ogawa and Shimizu, 1999).

1.12. Harnessing microbial activities for environmental cleanup

Nature provides a blueprint for innovative solutions, and recent efforts demonstrate that harnessing the metabolisms of naturally occurring bacteria provides effective, economically feasible solutions for environmental cleanup and restoration. Laboratory-based, fundamental scientific discovery will remain a crucial prerequisite for developing new technologies and well instrumented field-scale demonstrations will guide their successful implementation. In concert with traditional microbiology, biochemistry, molecular biology and engineering approaches, the rapid progress in high-throughput screening technologies, computational and systems biology, biogeochemical modeling and database development will enhance current progress. Clear examples of how the integration of genomics (Lovley, 2003), proteomics (Mahadevan *et al*., 2006) and systems biology (Maymo´ -Gatell , 1999) can significantly enhance our understanding of complex subsurface microbial processes are emerging. As an illustration, genome sequences are now being used to build sophisticated metabolic flux models for a variety of organisms, including the groundwater microbe *G. sulfur reducens* (Maymo´ -Gatell , 1999) . The application of combined experimental and computational approaches will be invaluable for elucidating the roles of individual organisms in complex subsurface systems. These integrated approaches will significantly contribute to moving bioremediation from a relatively empirical practice to a predictable science with widespread application.

Recently, a successful field demonstration of U (VI) bioremediation has been recently completed at the Field Research Center (FRC) in Oak Ridge, Tennessee. The low pH and the presence of co-contaminants required conditioning of the treatment zone, which was accomplished by flushing, above ground removal of inhibitors and clogging agents, and pH adjustment. Subsequent bio-stimulation with ethanol demonstrated that the native microflora efficiently reduced soluble U (VI) to immobile U(IV) (Lo¨ffler and Edward, 2006).

This excellent field study demonstrates that engineering design based on scientific principles and accomplished by interdisciplinary teams leads to innovative and successful solutions for environmental restoration and stewardship.

Biotechnology as the eventual cleaner production for agriculture

Concerning the potential environmental benefits and hazards associated with agricultural biotechnology there has been much debate. Some disagree that it can eliminate the need for a wide range of material inputs such as pesticides and herbicides. Others argue that it will increase the demand for non-sustainable and potentially hazardous 'agri-business' practices. Recently, Hall and Crowther (1998) tested these claims against the cleaner production approach. They found that pressures to accept this technology are strong enough to overcome initial resistance, and biotechnology, as it applies to agriculture, is not consistent with a cleaner production approach due to the high level of risk. They suggest that this type of technology adds an additional dimension to the cleaner production argument.

1.12. Biotechnology and increased crop productivity in environmentally friendly way

Genetically modified (GM) cotton is widely adopted and the list of GM technologies in trials is impressive in China (Huanga *et al.*, 2004). Although there was an active discussion on when China should commercialize its GM food crops. After the assessment of some of the issues surrounding the environment, adoption and commercialization of biotechnology. Based on unique data from empirical micro-level study and field trials in China and a modified GTAP model, indicate that the development of biotechnology has an important impact on China's production, trade and welfare. Therefore the beginning of biotechnology presents basic challenges to the global agri-food industry. While the scientific base for agri-food production is being revolutionized, it is not clear if or how the technology will be used. Proponents of biotechnology and a large portion of agri-food policy makers around the world project a positive prospect in which technology overcomes food shortages, improves the environment, heals or eliminates disease and leads to a prosperous and healthy society. A smaller but significant group of policy makers, citizens and consumers fear that the technology will worsen food timidity, threaten the environment, endanger human health and ultimately deprive society itself. Although scientists and industry are certain that the fears are unfounded, it is not clear that our social institutions will be able to become accustomed, accept and use the technology in a way that will satisfy society and improve social welfare along with the environment.

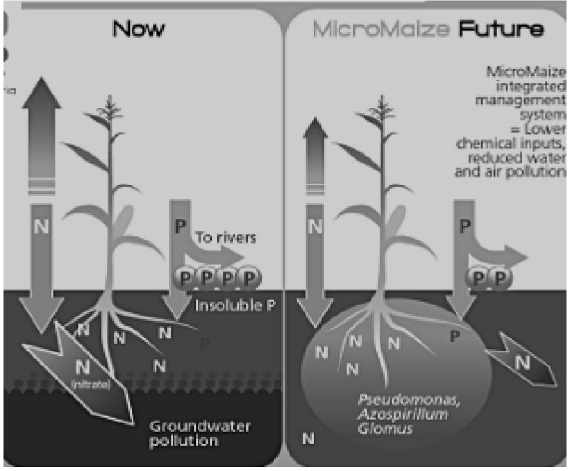


Figure 8: Management of plant beneficial microbes to balance fertilizers input in Maize monoculture (source Micromaize)

1.13. Prospects to integrate technology and sustainability

The compatibility of current biotechnology and sustainability was recently discussed by Ervin *et al.* (2010). On the basis of complete analysis on a sustainability framework that includes the full spectrum of environmental, economic and social impacts. A review on each impact revealed that 'crop biotechnology cannot fully be assessed with respect to fostering a more sustainable agriculture due to key gaps in evidence, especially for socio-economic distributive effects'. First generation GM crops generally showed progress in reducing agriculture's environmental footprint and improving farmers profits; however, these crops fall short of the technology's capacity to develop a more sustainable agriculture (Fig. 8). The latter was based on the assumption that all stakeholders should be engaged and salient justice issues should be addressed. For realization of the potential of biotechnology, fundamental changes are required in the way public and private research and technology development and commercialization are structured. More public/private partnerships in advanced research using enabling technologies are needed during the pre-competitive phase. In addition, transparency in objectives and methodologies should be realized through an open dialogue with all stakeholders. A good example is the concerted action taken by CGIAR research institutes (CIMMYT and ICARDA), advanced research institutes and national institutes in Ethiopia and Kenya to deal with the outbreak of the race Ug99 of the stem rust *Puccinia graminis tritici* causing severe epidemics in wheat. A major threat to wheat production not only regionally but also globally, because of the susceptibility of the existing plant material and the rapid spread by air of spores over large distances in North Africa, Middle East and West-South Asia. Within 10 years new seed material could be released as a result of rigorous screening in labs and the field on resistance for the race. Combining genetics, molecular assisted selection and modern breeding made it possible to control a disease that potentially could destroy half of the global wheat production.

An appeal for radically rethinking agriculture for the 21st century was presented by advocating systems that close the loop of nutrient flows from microorganisms and plants to animals and back (Spiertz, 2010). By making better use of sunlight and seawater it would become possible to decrease the land, fossil energy, and fresh water demands of agriculture, while at the same time ameliorating the pollution currently associated with agricultural chemicals and animal waste. A combination of scenario development and back-casting will be required to identify ways where science and technology can contribute effectively.

The study of solar-powered drip irrigation of vegetables in the rural food-insecure Sudano-Sahel region of West Africa (Burney *et al*., 2010) nicely shows the potential of modern technologies to augment both household income and nutritional intake in a cost-effective manner compared to conventional technologies. The prospects to integrate enabling technologies and sustainability while securing the needs for food, feed, fibre and fuel should be explored at various scales: molecular, cell, plant, field, agroecosystem and landscape.

Integration of crop modeling into genetic and genomic research facilitates ‘breeding by design’, because the impact of changing traits on crop performance can be explored for various scenarios of environmental conditions and climate change. The use of robust crop models to understand Genotype - Environment - Management (G – E-_ M) quantitatively did get more attention recently (Yin *et al*., 2004).

Assessments of the relationship between crop productivity and climate change rely upon a combination of modeling and measurement (Challinor *et al*., 2009). It was argued that the generation of knowledge for adaptation should be based on reliable quantification of uncertainty, combining diverse modeling approaches and observations and judicious calibration of models. This approach is not just an improvement of the methodology, but it also contributes to more transparency.

On the level of the crop and field a science-based understanding of the dynamics of phenology, plant physiological processes and soil conditions is required to implement precision agriculture. Adapting inputs (water, fertilizers, pesticides, etc.) site-specifically allows a better use of resources in crop production, while preventing emissions to the environment (Ramaekers *et al*., 2010). A dedicated approach with modern technologies (sensors, IT, machinery, etc.) and knowledge-intensive decision support systems (DSS) can enhance resource-use efficiencies, and enhance the quantity and quality of agricultural produce (Gebbers and Adamchuk, 2010). There are no easy generic solutions that fit to all agro-ecosystems as was nicely shown for conservation agriculture in Africa (Giller *et al*., 2009). Technologies that integrate biophysical and ecological processes into the framework of sustainable food production by an efficient use of natural resources (land, climate, and water) and minimizing the use of non-renewable inputs (especially fossil energy and phosphorus) should get strong support by making use of knowledge transfer and modern communication means engaging all actors in the food chain (Flora, 2010; Douthwaite and Gummert, 2010; Vergragt and Brown, 2008).

Therefore it is evident that the concerns for the impact of agriculture on the environment are convincing. However, it is not pragmatic to target the environmental load of agro-ecosystems with those of nature areas. Specific entry values are needed that meet the standards of food safety and environmental health. Technology, especially plant breeding and crop management, and government policies have contributed to counter-balance the explosive growth in food demand during the last four decades. On average, food availability per capita improved despite the doubling of the global population in the recent past. To meet the huge future demands during the next four decades, it will be necessary to make use of the best science and technology to raise crop productivity per unit of land on average with 2% per year and resource-use efficiencies of water and nutrients. New insights in genetics, systems functioning, climate change and multiple stresses can guide the development of improved cultivars and highly productive farming practices to close the yield gap. So far, a combination of advanced plant breeding, systems innovations, development of best practices and legislation turned out to be effective in developing more environment-friendly agricultural systems that are profitable, ecologically safe and socially good enough.

1.14. Biotechnology tools and their applications to environmental protection

In environmental concerns associated with biotechnology, it should be known that biotechnology is providing valuable tools supporting environmental protection, particularly in the areas of environmental forensics. Research on the application of molecular biomarkers of exposure to physical and chemical stressors has confirmed that specific proteins are up-regulated (or in some cases down-regulated) by organisms exposed to toxicants and other stressors, and this research is allowing the determination of basis and consequence relationships and an understanding of the synergistic effects of multiple stressors.

Conventionally, environmental monitoring programs have focused on mortality as the metric of change, tracking the loss of individuals, populations or species. In order for environmental assessment and monitoring programs to be effective, they must be able to detect changes at the sub-lethal level, prior to mortality, when intervention can yield positive results (Downs, 2005). Molecular biomarkers of stress can be used to determine causation and the effectiveness of mitigation measures.

For example, classes of cytochromes P450 are produced in response to xenobiotic exposure. Other proteins are indicative of oxidative stress (superoxide dismutases), protein metabolic condition (ubiquitin) and genomic integrity (mutY) (Downs, 2006). When used in the context of environmental health assessments, molecular biomarkers allow quantification of responses, both positive and negative. The up-regulation of specific protein biomarkers of exposure indicates an organism is undergoing and responding to stress, whereas down regulation can indicate a reduction of stressor impacts and the effectiveness of mitigation activities.

As such, biotechnology can be used to guide and evaluate responses to a variety of environmental problems, including pollution and climate change. Research in the field of population genetics is also providing valuable tools applicable to environmental protection.

Studies of species biodiversity have already been used to evaluate the effects of anthropogenic disturbance on ecosystems, but assessing genetic variation within populations is also important. Genetic diversity is the basis of the evolution and survival of species in a changing environment. Tracking the loss or the differential survival of specific genotypes in response to anthropogenic disturbances provides an unprecedented tool for understanding the role of genes and their products in adaptation and homeostatic regulation. For example, regional coral bleaching events caused by global climate change and the subsequent mass mortality of affected colonies might set the stage for the ‘Irish Potato Famine’ of these diverse ecosystems because both species and population diversity are lost and few resistant genotypes remain. As genotypic diversity decreases, the chance of local extinction events increases. Maintaining genetic diversity within a population is a central problem in the emerging field of restoration biology, because replacing lost plants and animals with cultivated or transplanted individuals representing a single genotype sets the stage for a single pathogen or physical stressor to be able to eradicate the ‘restored’ populations (Richmond, 2005). Reductions in biodiversity are also a central concern with GMOs, which might hybridize with wild stock and eliminate novel genotypes. Advances in molecular genetics are allowing for a better understanding of gene flow among populations, data that are critical to the establishment of networks of marine protected areas (MPAs) and for identifying corridors for wildlife migration.

Bioremediation is a third area that holds promise for environmental protection. This technology uses bacteria, fungi or plants to convert some organic, inorganic and metal compounds and waste into a less environmentally harmful state (Vadali, 2001). The advantages over traditional remediation techniques include *in situ* treatment versus moving contaminants from one site to another and costs, which might be lower than with more labor-intensive measures.

According to Boening (2000) and Connor (2007), concerns remain regarding large-scale applications of bioremediation, the longer time periods needed and the potential toxicity problems, because ‘breakdown’ products might be more toxic or bioactive than the original compounds (e.g. the methylation of mercury by bacteria rendering it bio available). To date, several applications of ‘designer bacteria’ have yielded positive results, for example for cleaning up oil spills, and the potential for future uses in environmental improvement are under investigation (Harvey, 1990; de Lorenzo, 2006).

1.15. Environmental Biotechnology and Renewable Energy

Renewable technologies are considered as clean sources of energy and optimal use of these resources minimize environmental impacts, produce minimum secondary wastes and are sustainable based on current and future economic and social societal needs. Sun is the source of all energies. The primary forms of solar energy are heat and light. Sunlight and heat are transformed and absorbed by the environment in a multitude of ways. Some of these transformations result in renewable energy flows such as biomass and wind energy. Renewable energy technologies provide an excellent opportunity for mitigation of greenhouse gas emission and reducing global warming through substituting conventional energy sources.

A comprehensive literature survey of major renewable energy gadgets for domestic and industrial applications such as solar water heaters, solar cookers, dryers, wind energy, biogas technology, biomass gasifiers, improved cookstoves and biodiesel was made.

The review gives an overview of the development and scope of CO_2 mitigation for clean and sustainable development. The use of solar drying of agricultural produce has good potential for energy conservation in developing nations. Biodiesel from non-edible vegetable oil reduces carbon dioxide emissions and petroleum consumption when used in place of conventional diesel (Carraretto *et al.* ., 2004). Biodiesel is technically competitive with or offer technical advantages compared to conventional petroleum diesel fuel. The presence of oxygen in biodiesel improves combustion and, therefore, reduces hydrocarbon, carbon monoxide, and particulate emissions; oxygenated fuels also tend to increase nitrogen oxide emissions (Demirbas, 2005; 2009). Wind energy also present good potential in minimization of greenhouse gases where wind potential is available. The application of biomass gasifier at small scale industries is found suitable and it save considerable amount of conventional fuel. The improved cook stoves provide better kitchen environment to rural women and improve their health standards. At the same time it also reduces fuel collection burden for them. Recently Panwara *et al.*, (2011) clearly points out the greenhouse gas emission mitigation potential depending on the use and availability of renewable energy sources and fuel replaced by it.

1.16. Agricultural practices to alleviate greenhouse gas emissions

Agriculture is a source for three primary greenhouse gases (GHGs): CO_2, CH_4, and N_2O. It can also be a sink for CO_2 through C sequestration into biomass products and soil organic matter. As a summary based on the literature on GHG emissions and C sequestration, providing a perspective on how agriculture can reduce its GHG burden and how it can help to mitigate GHG emissions through conservation measures. Although GHG emission derived from soil has been researched for several decades, there are still geographic regions and agricultural systems that have not been well characterized.

There is a need to estimate GWP across a wide range of agricultural systems. Ideally, a standard or conventional method of calculating GWP should be established. Methodology to improve the accuracy of determining changes in SOC and GHG emissions would reduce the uncertainty of estimating GWP.

Agricultural practices that promote good land stewardship appear to minimize or reduce GWP. Such practices include (1) reducing tillage, which helps prevent soil erosion and has the potential to increase SOC, and may enhance CH_4 consumption, even though in some instances it may be partially offset by N_2O emission; (2) eliminating fallow and keeping the soil covered with residue, cover crops or perennial vegetation, which have the potential to increase SOC; (3) avoiding over application and using split N application rates to meet plant need, which would reduce N_2O emission and minimize potential water degradation; and (4) manipulating animal diet and manure management practices to reduce CH_4 and N_2O emission. Opportunities exist in all segments of agriculture to reduce environmental impacts. As a society, we (farmer/producers and consumers) need to take ownership of the anthropogenic impacts we are having on the environment to avoid disastrous climate change. Conservation programs need to be integrated and linked to C management.

Policies that support best agricultural land management practices and land stewardship rather than promoting production of specific crops are needed. Furthermore, concerted efforts are needed to curb fossil fuel demand in the agricultural sector and throughout society. Agriculture has the potential to reduce its environmental footprint and offset GHG emissions. Burning fossil fuel is by far the greatest contributor to GHG emission. We need to develop sustainable alternatives to fossil fuels to reduce our energy demand, thereby, stabilizing GHG emissions and minimizing anticipated global climate change (Jane *et al*., 2007). Page (2009) have explored the implications of technology – near-term technology and expectations regarding longer term technology – for emissions, costs, and energy system evolution over the coming 40 years under two cumulative emissions constraints. The scenarios have assessed the implications of technology availability for the costs of mitigation and the time path of emissions reductions, and illuminated the very different energy systems that might emerge over time as technology evolves and new technologies become available. All of the advanced technology scenarios require that a range of key technology barriers be overcome. For example, a future built on end-use energy efficiency and renewable technologies is possible, but the costs and the consequent likelihood of social and political feasibility depend on technological improvement in a number of areas. These include the availability and deployment of low-cost energy-saving equipment, improvements in complementary technologies such as electricity storage and grid management, the viability of alternative fuels at the end-use level such as electricity in transportation, and reductions in the costs of large-scale renewable energy production. Similarly, expansion of nuclear power and deployment of CCS would require resolution of issues such as nuclear safety, nuclear proliferation, and nuclear waste, regulatory barriers to underground injection or CO_2 transport, and questions regarding the viability of long-term carbon storage. Moreover, an electric sector comprised entirely of base load technologies would present systems management challenges just as would an electric sector with a high share of intermittent renewable energy sources. In short, the technical obstacles to any low-emissions future – one that will require dramatically larger deployments of low emissions technologies – will be substantial.

Second, a fundamental theme that emerges from the scenarios in this paper is that although near-term mitigation is absolutely critical for meeting an aggressive long-term climate target, the value of technology for U.S. emissions reductions is inherently a longer-term concern. There is little question that some degree of mitigation can be achieved over the next decade, and that this will be facilitated by the deployment of low carbon technologies, particularly end-use technologies. But these emissions reductions will take place on the investment margin, which will be small in the next decade relative to what it will be in the next 40 years (and also small relative to the investment margin in the next decade in developing regions such as India). It is the future reductions, as emissions ultimately approach zero, that will truly test social and political commitments to climate stabilization and, therefore, in which the advances that will overcome barriers to a dramatically new energy system will be most critical. In this modeling exercise, if it is expected that new and more advanced technologies will not be available in the future, it calls for higher near-term CO_2 prices and greater near-term emissions reductions. In the real world, however, a lack of technological availability in the future, when truly deep reductions are required, could call the entire enterprise of long-term climate change mitigation into question (van der Werf *et al*., 2011)..

Burning fossil fuel is by far the greatest contributor to GHG emission. We need to develop sustainable alternatives to fossil fuels to reduce our energy demand, thereby, stabilizing GHG emissions and minimizing anticipated global climate change (van der Werf *et al*., 2011).

Livestock production is recognized to contribute significantly to emission of greenhouse gases (GHGs)mainly through emission of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) and CO_2 is released from combustion of fossil fuels to power machinery, from burning of biomass, and from microbial decay related to, for example, changes in land use or in crop management. CO_2 can be sequestered also by transforming arable land into permanent grassland. CH_4 is produced when organic matter decomposes in oxygen deprived conditions, for example, during enteric fermentation (especially in ruminants) and storage of manure. CH_4 is also inadvertently released during fossil fuel extraction and refining. N_2O is released during microbial transformation of nitrogen in the soil or in manure (i.e. nitrification of NH_4 + into NO_3, and incomplete denitrification of NO_3 into N_2; as well as during nitrate fertilizer production. The animal food chain contributes significantly to emission of greenhouse gases (GHGs). We explored studies that addressed options to mitigate GHG emissions in the animal production chain and concluded that most studies focused on production systems in developed countries and on a single GHG. They did not account for the complex interrelated effects on other GHGs or their relation with other aspects of sustainability, such as eutrophication, animal welfare, land use or food security. Current decisions on GHG mitigation in animal production, therefore, are hindered by the complexity and uncertainty of the combined effect of GHG mitigation options on climate change and their relation with other aspects of sustainability. There is an urgent need to integrate simulation models at animal, crop and farm level with a consequential life cycle sustainability assessment to gain insight into the multidimensional and sometimes conflicting consequences of GHG mitigation options (van der Werf *et al*., 2011).

Some mitigation options, such as precision farming, clearly contribute to reduction in net GHG emissions along the animal chain and show synergy with other goals of sustainability. For many mitigation options described in the literature, however, the combined effect on all GHGs along the life cycle or the impact or dependency on other aspects of sustainability is complex and unknown.

There is an urgent need for integrated LCA to gain insight into the multidimensional and sometimes conflicting consequences of GHG mitigation options. Such an integrated life cycle sustainability assessment is complex, but elucidates mitigation options that overall contribute to sustainability and might address new areas of GHG mitigation.

1.17. Enzyme technology and biological remediation

(Whiteley and Lee, 2005) studied the heterogeneous complexity of sludges and wastewaters and stated that it has created gross uncertainty and deviations in predictions of suitable models for their measurement. At the same time, it is becoming increasingly obvious that the current paradigms and ideologies are wrought with problems and limitations suggesting the need to move to a more consolidated analytical objective evaluation. Rapid developments in understanding activated sludge processes and wastewater remediation warrants exploitation of different strategies for studying their degradation.

It is time to replace subjective terms like sludge volume index (SVI), zone settling velocity (ZSV), filament index (FI), fractal dimension (D), flocculating ability, surface charge (ζ), degree of hydrophobicity, chemical oxygen demand (COD) with a mathematical one that can provide an absolute quantitative relationship for the properties of wastewater and/or a sludge floc. There are no current objective values that can be introduced to represent the plethora of biological remediation terminologies such as bioleaching, biosorption, bioaugmentation, biostimulation, biopulping, biodeterioration, biobleaching, bioaccumulation, biotransformation and bioattenuation.

Enzyme technology has been receiving increased attention and this review focuses on the latest developments on the enzymology of biological remediation. Scientists discussed the present pitfalls with current strategies and suggests that sludge–floc parameters, such as internal structure and composition, sludge retention time, microbial ecology, nutrient concentration, dissolved oxygen and type of industrial wastewater, whether from an aerobic or anaerobic system, are replaced by quantitative kinetic terms (*K*m, *V*max, *K*cat) associated with the enzymology of the sludge floc and/or wastewater (Ogawa and Shimizu, 1999).

The development and preparation of novel enzymes for use in biological remediation or for the industrial solubilization of activated sludge remains a key challenge and a safe and economic alternative to commonly, and perhaps now redundant, physicochemical strategies. There are perhaps two approaches: rational and evolutionary. With the former, amino acid sequences, functional properties and structural features of different enzymes are compared, combined, then tested to see if the desired effect is accomplished. In the evolutionary design, a large library of random mutations in proteins is made followed by a selection of enzymes that work well with a particular contaminant. In principal, multiple environmental factors would ‘select’ enzymes to meet these challenges. Molecular evolution (Stemmer, 1994; Zhao *et al*.., 1998) is a useful tool for evolving enzymes with extended substrate specificities for any recalcitrant pollutant. Furthermore, this technology is more likely to ‘succeed’ then rational approaches as the latter requires multiple sets of structural and biochemical information on every enzyme involved. Sequences encoding specific enzymes can be retrieved direct from environmental samples thereby circumventing the process of isolating and screening wild-type organisms. Degenerate primers can be used to amplify central segments from these genes by PCR and inserted into the original functional gene. Such an approach allows rapid exploitation of the natural sequence diversity already present in the environment for creation of novel hybrid enzymes (Okuta *et al*., 1998).

With the advent of molecular engineering the principle of developing a new “designer” enzyme and the creation of micro assemblers or microchips with the role of the computer as a delivery vehicle cannot be too far into the future. One major feature to consider is to generate a new novel structure for use in activated floc solubilization. In view of the extreme conditions that the activated sludge digesters may operate, the new enzyme molecules often have to be stable and active under unusual and extreme conditions of temperature, acidity, solvents, chemicals and pH. Enzyme properties, can be exploited to engineer active-site topology, to enlarge binding pockets and to alter the substrate specificity and stability. Consequently, the ability to modify a protein or structure to make it more stable to such conditions, or make it more resistant to self destruction, or make it target directed and functional in the presence of other toxic elements creates enormous challenges for enzymologists. Over the next 20 years, the enzyme–floc model will be exploited at a molecular level from a rational design to specific delivery of enzymes to the active areas disguised in vectors called nano particles. These will be the tools and scientific technological platforms for the investigation and transformations of any activated wastewater or biological system.

Under these pretexts biological remediation’s can only be rationalized by specific finite measurements, for each floc enzyme in the study, of maximal enzymatic rate (*V*max), substrate specificity (*K*m), turnover number (*k*cat), enzyme efficiency (*k*cat/*K*m) (Couto and Herrera, 2006).

Enzymes have applications in many fields, including organic synthesis, clinical analysis, pharmaceuticals, detergents, food production and fermentation. The application of enzymes to organic synthesis is currently attracting more and more attention.

The discovery of new microbial enzymes through extensive and persistent screening will open new, simple routes for synthetic processes and, consequently, new ways to solve environmental problems. He concluded that the discovery of new catalysts and molecules that rival natural enzymes in their substrate specificity and catalytic turnover is one of the major aims of biotechnology. The *de novo* design and synthesis of catalysts from organic molecules, the modification of existing catalysts such as enzymes or ribozymes, and the creation of catalytic antibodies are now under examination.

However, there are still a large number of organisms, particularly microorganisms, that have not been screened or examined for their ability to catalyze specific reactions, and the breadth of reactions catalyzed by enzymes will certainly continue to expand.

There have been attempts to screen microorganisms that, as yet, remain uncultivated. Here, microorganisms from natural habitats are concentrated by filtration, their DNA extracted without further cultivation and a variety of enzyme activities screened from their DNA cosmid libraries. This approach enables the screening of enzyme activities in as-yet-uncultivated prokaryotes and could represent a superior method to discover new, powerful enzymes. However, the enzyme is totally separated from its original function in the microorganism.

To find a novel enzyme means to find a novel microbial function; in this respect, gene-library screening misses original microbial function, although classical screening techniques, which include enrichment and isolation strategies, remain powerful tools, because they involve living cells that maintain the original functions. The potential of classical screening, alone and in combination with new concepts such as gene libraries, will offer exciting possibilities. The classical, but still important, philosophy for the screening of novel enzymes is to examine as many microorganisms as possible with a well-considered screening system based on microbial diversity and versatility.

Together with new developments based on the same philosophy, this will widen the field of application of microbial enzymes. One hundred million microorganisms are present in each gram of soil; how many enzymes are still waiting to be found? (Ogawa and Shimizu, 1999).

Laccases have been reviewed several times in recent years, generally with emphasis on narrow aspects. The reviews by Messerschmidt (1993, 1997) and by Solomon *et al.* (1996) provide excellent summaries of the enzymology and electron transfer mechanism of the laccases and a book edited by Messerschmidt (1997) contains a series of articles dealing with different aspects of laccase kinetics and mechanism of action and the possible roles of this enzyme. The intend of this appraisal is to highlight the potential industrial and biotechnological applications of laccase enzyme.

Laccases have received much attention from researchers in last decades due to their ability to oxidise both phenolic and nonphenolic lignin related compounds as well as highly recalcitrant environmental pollutants, which makes them very useful for their application to several biotechnological processes. Such applications include the detoxification of industrial effluents, mostly from the paper and pulp, textile and petrochemical industries, use as a tool for medical diagnostics and as a bioremediation agent to clean up herbicides, pesticides and certain explosives in soil. Laccases are also used as cleaning agents for certain water purification systems, as catalysts for the manufacture of anti-cancer drugs and even as ingredients in cosmetics. In addition, their capacity to remove xenobiotic substances and produce polymeric products makes them a useful tool for bioremediation purposes. The applications of laccases within different industrial fields as well as their potential extension to the nanobiotechnology area is significant, but the most important obstacles to commercial application of laccases are the lack of sufficient enzyme stocks and the cost of redox mediators. Marked progress has been made over the last years to solve these problems and it is expected that laccases will be able to compete with other processes such as elemental chlorine-free (ECF) and totally chlorine-free (TCF) bleaching. Thus, efforts have to be made in order to achieve cheap overproduction of this biocatalyst in heterologous hosts and also their modification by chemical means or protein engineering to obtain more robust and active enzymes.

On the other hand, the development of an effective system for laccase immobilization also deserves great attention. Immobilization could be achieved by chemical modification of the substrates. Hence, micro-patterning, SAMs and LbL techniques can be used to functionalize flat and curved surfaces in order to have specific adsorption.

Laccase encapsulation with polyelectrolytes will be used as a microreactor for catalytic reactions by changing the permeability properties of the capsule wall. Since the general goal is to obtain stable catalysts with long life times and low cost, we think that the combination of these techniques will enhance: i) the adsorption of laccase on a suitable substrate, ii) the lifetime of the laccase activity and iii) reutilization of the substrate/laccase product. Our research group is currently working in this direction.

Hazardous waste, impact on health and environment for development of better waste management strategies in future in India. Industry has become an essential part of modern society, and waste production is an inevitable outcome of the developmental activities. A material becomes waste when it is discarded without expecting to be compensated for its inherent value. These wastes may pose a potential hazard to the human health or the environment (soil, air, water) when improperly treated, stored, transported or disposed off or managed. Currently in India even though hazardous wastes, emanations and effluents are regulated, solid wastes often are disposed off indiscriminately posing health and environmental risk. In view of this, management of hazardous wastes including their disposal in environment friendly and economically viable way is very important and therefore suggestions are made for developing better strategies. Out of the various categories of the wastes, solid waste contributes a major share towards environmental degradation. The nature of the wastes, waste generating industries, waste characterization, health and environmental implications of wastes management practices, steps towards planning, design and development of models for effective hazardous waste management, treatment, approaches and regulations for disposal of hazardous waste were outlined. Appraisal of the whole situation with reference to Indian scenario is attempted so that better cost-effective strategies for waste management are evolved in future.

With the issuance of the hazardous waste regulations, awareness has been created for the management of hazardous wastes; however, effective practice for safe management is yet to be enforced in India. The technical issues pertaining to the waste treatment and disposal needs to be strengthened and the technology input requirements have to be worked out to achieve sustainable development. Although, most expensive and advanced methods can be adopted to treat hazardous waste, they still result in potentially hazardous residues that are no longer amenable to cost-effective treatment. Therefore, approach of waste minimization is to be envisaged in order to avoid the problems of treatment and disposal. The technologies for hazardous waste treatment are expensive and it may be economically viable to reduce the other alternative adopted in the industrialized countries is to go in for the so-called dclean technologies that involve a change in the process and raw materials. Also, there is need for adequately qualified human resources to operate and monitor such facilities.

In India, the commercialized hazardous waste treatment and disposal facilities are not existing and only some major industrial units have self-contained hazardous waste treatment and disposal facilities. The introduction of dclean technologies would require extensive input of such technologies from the developed countries through transfer of technology. The waste minimization concept could thus be introduced through simple waste reduction systems without involving a major change in the process or raw materials. It is felt that the introduction of waste minimization concept in the administrative, technological and legal systems, will lead to better strategies (Mishra and Pandey, 2004).

The horticultural sector has seen much structural change both nationally and internationally over the last Decades (Katharina *et al*., 2010), but the implications for plant health have been neglected. In the context of the risk of emerging plant diseases recent developments including the movement towards a global horticultural market, the rise of the horticultural industry of many developing countries, and the economic integration of the European Union. North America is typically well ahead of other regions in economic developments, and in horticulture this is shown for example by the growing importance of Mexican growers. Asia is rapidly catching up also in horticulture, with China and India becoming key producers. Australia and New Zealand show the impact of change in horticulture extension services. The Eastern enlargement of the EU is having profound influences on fruit and vegetable growers both in the new and in the old member countries. Similar developments are taking place in South America and Africa. In all continents, there is a general trend towards fewer and larger horticultural growers, an increasing role of supermarkets and a concentration of the retail pathways. These developments have consequences for the control of plant pathogens and invasive species. Technical issues seem to be of lesser consequence in terms of structural change compared with labour and trade aspects. However, examples can be found where technical innovations have opened up new opportunities or provided solutions to pressing problems, as can be seen in the hardy nursery stock and ornamental industry in the UK. Future technical, economic and social impacts on the sector are likely to play a key role for securing a diverse and reliable food supply for the still expanding world ’ s population. Recent advances in modeling disease spread in complex networks representing trade pathways should be used to target control of introductions of new plant pathogens. There is a need for more long-term research on how structural change in the horticultural sector will affect and be affected by climate change.

The increasingly globalized horticultural industry is an important factor in securing a diverse and reliable food supply for the whole of humanity. Change in the structure of this industry has been widespread and profound, with a general tendency towards fewer and larger growers, but also newer developments such as the direct sale of plants to customers through the internet and an increased role of cooperatives of producers (Alvarez-Coque *et al.*, 2009; Riedel *et al.*, 2009). These are probably developments which would have been inevitable even without the adoption of free trade policies and the increasingly easier transport of crops from continent to continent. However, comprehensive, long-term and multi-scale analyses of structural features of the world’s horticultural sector and of their implications for the long-range transport of plant pathogens are still needed. There is an urgent requirement to include plant health considerations in guidelines for best practice in the horticulture and ornamental production, as well as certification schemes in international trade and local planting (Petit-Jean, 2008; Jullien, 2009).

A series of environmental indicators have been developed in the last years that were found suitable to be applied at corporate level for the evaluation of production processes and products. The indicators reviewed and classified into four main groups: (1) Indicators of Energy and Material Flows; (2) Indicators with a Territorial Dimension; (3) Indicators of Life-Cycle Assessment; (4) Indicators of Environmental Risk Assessment. Integrative and single index indicators such as the ecological footprint or carbon footprint were found as the most appealing for enterprises, although there is a need to advance in the field to combine the simplicity required at corporate level for tracking and reporting environmental data, and the scientific rigor and transparency necessary to make the scores reliable. Hence, for each of the indicators revised it was stated what they do and do not measure so that misleading information was not used for decision making at corporate level.

In their review, indicators of different nature have been reviewed under a corporate approach, from those with a territorial dimension to the more generic material and energy flows, life-cycle or risk assessment indicators. The importance and usefulness of each of them have been highlighted, as well as the similarities among them and complementary characteristics.

Environmental performance indicators measure the current or past environmental performance of an organization, depicting the vast quantity of environmental data in a comprehensive and concise manner, and compare it to the targets set. Frequently, only data readily available are employed, since they do not aim to offer a comprehensive analysis but rather to represent the key characteristics of a business. Hence, the single index indicators reviewed in this paper, such as energy flows or the ecological footprint were considered to be more useful for the corporate level. In spite of the difficulty of a land-based indicator to measure all kinds of anthropogenic impacts, the EF is one of the most promising indicators since it does not only account for the environmental impacts derived from energy consumption but also from other material resources. Nevertheless, to make its application to products and production processes completely fair and reliable, there is a need to jointly standardize the different proposals to improve the methodology published in the last years and to develop reliable databases that provide all factors necessary for calculations. Once this is done, the EF could allow for consistent measurement, labeling and comparative evaluation across products and industries.

In spite of the appealing idea of using one single score to express all the environmental information, there are certain aspects that can hardly be ever part of such an indicator. When applied to assess the environmental performance of a production process, a more comprehensive analysis of all environmental burdens is required; otherwise, the results reported could be misleading and useless when comparing two production processes or products from an environmental point of view. Hence, the evaluation of production processes or products that imply the presence of toxic pollutants should always be accompanied by risk assessments. Also, when a more detailed analysis is required LCA may be necessary, although this can be substituted by any of the energy or material single indicators when the problem being studied is particularly concerned with any of these issues (Herva *et al.*, 2011).

1.18. Management of household food waste

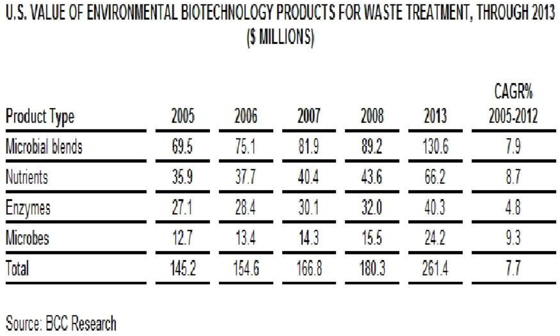
In a Swedish full-scale case study by Bernstad and Jansen (2011), environmental impacts from incineration, decentralized composting and centralized anaerobic digestion of solid organic household waste are compared using the EASEWASTE LCA-tool. The comparison is based on a full scale case study in southern Sweden and used input-data related to aspects such as source-separation behavior, transport distances, etc. are site-specific. Results show that biological treatment methods – both anaerobic and aerobic, result in net avoidance of GHG-emissions, but give a larger contribution both to nutrient enrichment and acidification when compared to incineration. Results are to a high degree dependent on energy substitution and emissions during biological processes. It was seen that if it is assumed that produced biogas substitute electricity based on Danish coal power, this is preferable before use of biogas as car fuel. Use of biogas for Danish electricity substitution was also determined to be more beneficial compared to incineration of organic household waste. This is a result mainly of the use of plastic bags in the incineration alternative (compared to paper bags in the anaerobic) and the use of biofertilizer (digestate) from anaerobic treatment as substitution of chemical fertilizers used in an incineration alternative.

Net impact related to GWP from the management chain varies from a contribution of 2.6 kg CO_2-eq/household and year if incineration is utilised, to an avoidance of 5.6 kg CO_2-eq/household and year if choosing anaerobic digestion and using produced biogas as car fuel. Impacts are often dependent on processes allocated far from the control of local decision-makers, indicating the importance of a holistic approach and extended collaboration between agents in the waste management chain.

Anaerobic digestion with use of biogas and digistate as substitution for vehicle fuel and chemical fertilizers, respectively, results in greater avoidance of global warming and formation of photochemical ozone compared to composting or incineration of food waste.

Both anaerobic and aerobic biological treatments increase net contribution to nutrient enrichment and acidification compared to incineration. Use of biogas as substitution of fossil car fuel result in larger avoidance of GHG-emissions compared to when using biogas for electricity generation, while the latter results in a better energy balance. In the case of composting, emissions of NH_3, N_2O and CH_4 during the aerobic degradation is responsible for the largest negative environmental impacts during the treatment chain, while emissions connected to the on-land application of digestate and CH_4-emissions from digestion plant is of high importance in relation to an anaerobic treatment alternative, with the assumptions used in the earlier studies.

The assumed environmental profile of energy and materials substituted by goods produced in waste treatment chain has a large impact on the results and can potentially change the hierarchy between compared treatment alternatives. Factors that are visual for households – such as use of bags for collection of food waste and transports to treatment facilities – were seen to be of little importance to the overall results. Thus, many of the factors with large effect on the overall environmental impact from the food waste treatment chain are located far from the decision-makers of municipal waste management strategies. This indicates the importance of a holistic approach and need for an extended collaboration between the different agents involved in the management chain if a sustainable management of organic household waste and potential environmental benefits connected to the same are to be achieved (Spiertz and Ewert, 2009).



U.S. VALUE OF ENVIRONMENTAL BIOTECHNOLOGY PRODUCTS FOR WASTE TREATMENT, THROUGH 2013
($ MILLIONS)

Product Type	2005	2006	2007	2008	2013	CAGR% 2005-2012
Microbial blends	69.5	75.1	81.9	89.2	130.6	7.9
Nutrients	35.9	37.7	40.4	43.6	66.2	8.7
Enzymes	27.1	28.4	30.1	32.0	40.3	4.8
Microbes	12.7	13.4	14.3	15.5	24.2	9.3
Total	145.2	154.6	166.8	180.3	261.4	7.7

Source: BCC Research

Table 1: Value of Environmental Biotechnology products for waste treatment in U.S.

1.19. Environmental fate and toxicity of ionic liquids:

In a review by Pham *et al*. (2010), ionic liquids (ILs) are organic salts with low melting point that are being considered as green replacements for industrial volatile organic compounds. The reputation of these solvents as ‘‘environmental friendly’’ chemicals is based primarily on their negligible vapor pressure. Nonetheless, the solubility of ILs in water and a number of literatures documenting toxicity of ILs to aquatic organisms highlight a real cause for concern. The knowledge of ILs behavior in the terrestrial environment, which includes microbial degradation, sorption and desorption, is equally important since both soil and aquatic milieu are possible recipients of IL contamination. This article reviews the achievements and current status of environmental risk assessment of ILs, and hopefully provides insights into this research frontier.

Ionic liquids, of which the most often cited attribute is their negligible vapor pressure, have been suggested as a green alternative to traditional organic solvents with the desire to minimize diffusion to the atmosphere. Low volatility, however, does not completely eliminate potential environmental hazards and might pose serious threats to aquatic and terrestrial ecosystems. The studies of environmental fate and toxicity of ILs have shown that the ILs commonly used to date is toxic in nature and their toxicities vary considerably across organisms and trophic levels. In general, the effect of anionic moieties is not drastic as the alkyl length effect except for the case of [$(CF_3SO_2)2N$], which shows a clear (eco) toxicological hazard potential. The other per fluorinated anions has been also proved to be hazardous due to hydrolytically unstable properties. In addition, the introduction of functional polar groups to the alkyl chain has been shown to reduce the toxicity of ILs and increase the biodegradation efficiency to some extent. This indicates the possibility of tailoring ILs by coupling suitable functional groups to their structure, which in turn leads to a more environmental friendly compound. The side chain length effect has been found to be consistent in all levels of biological complexity as well as different environmental compartments. Also, an increase in alkyl-chain length, or lipophilicity, was observed to be related to an increase in the rate of degradation as well as an increase in toxicity. This indicates a conflict of aims between minimizing the toxicity and maximizing the biodegradability of these neoteric solvents (Conner *et al*., 2001). Regarding the cationic compartment, pyridinium has been found to be more environmental friendly than imidazolium from both viewpoints of toxicology and microbial degradation. It can therefore be suggested that the structural manipulation of the pyridinium skeleton should be considered in design of a sustainable IL. From the currently available data, it is clear that some commonly used ILs are very far away from the image of green chemicals that are often cited in the literature. The uncertainties in their sustainable development hinder the applications of ILs under real conditions. Although some attempts have been made to give important hints in the prospective design and synthesis of inherently safer ILs, comprehensive studies dealing with the behaviors of ILs in aqueous media still await to be conducted. The important features required for the thorough insight into environmental fate of ILs include, but are not limited to: (1) Providing more fundamental understanding into the mechanism for IL-induced toxicity to different levels of biological complexity. The underlying mechanisms of IL toxicity have rarely been studied; (2) - Assessing the biodegradability of cationic and anionic compartments and toxicity of their degradation intermediates. This may provide useful information in consciously designing safer chemicals; (3) - Investigating the aerobic and anaerobic biodegradation of ILs, which would suggest initial guidelines for the treatment of ILs waste by using the existing aerobic and anaerobic wastewater treatment facilities. Especially, anaerobic degradation awaits to be investigated; (4) Defining which organisms or enzymes may promote degradation pathways and determining specific microbial consortium or cultivatable communities capable of biotransformation of ILs; (5) Performing the ecotoxicity and biodegradation tests in real environmental conditions instead of controlled conditions of laboratory experiments, which would be advantageous in understanding the fate and behavior of ILs under real conditions. For this, the potential toxicological effects at population level and community level should be addressed. It must be encouraged to use tools such as experimental mesocosms to study the effects of ILs at higher levels of organization; (6) Creating database of environmentally benign structure moieties of ILs based upon their toxicological and biodegradation information, which would be practically useful as a reference for manufacturers and regulators to properly develop and regulate the use of ILs.

1.20. Water management and crop production for food security

Khan *et al*. (2009) assessed the present scenario of China regarding water management for food security and stated that, food security is a high priority issue on the Chinese political agenda. China's food security is challenged by several anthropogenic, sociopolitical and policy factors, including: population growth; urbanization and industrialization; land use changes and water scarcity; income growth and nutritional transition; and turbulence in global energy and food markets.

Sustained growth in agricultural productivity and stable relations with global food suppliers are the twin anchors of food security. Shortfalls in domestic food production can take their toll on international food markets. Turbulence in global energy markets can affect food prices and supply costs, affecting food security and poverty. Policy safeguards are needed to shield food supply against such forces. China must make unremitting policy responses to address the loss of its fertile land for true progress towards the goal of national food security, by investing in infrastructure such as irrigation, drainage, storage, transport, and agricultural research and institutional reforms such as tenure security and land market liberalization.

The links between water and other development-related sectors such as population, energy, food, and environment, and the interactions among them require reckoning, as they together will determine future food security and poverty reduction in China. Climate change is creating a new level of uncertainty in water governance, requiring accelerated research to avoid water-related stresses.

The national development policy in China puts food security at its heart. China's food security is challenged by several anthropogenic and sociopolitical policy factors, including: Population growth; Urbanization and industrialization; Land use changes and water scarcity; Income growth and nutritional transition; Turbulence in global energy and food markets.

Population growth and urbanization will continue to put pressure on food demand. Feeding a larger and affluent population with higher preference for meat-based diets will pose significant challenges. Further challenges will arise from the increasing demand for biofuels, growing realization to preserve ecological function and the increasing competition for land and water resources currently devoted to food production.

Implications for food policy are clear. Sustained growth in agricultural productivity and stable relations with global food suppliers are important anchors of food security. Shortfalls in domestic food production can impact international food markets. Turbulence in global energy markets can affect food prices and supply costs. Policy safeguards are needed to shield food supply against such forces.

Water resources are essential to agricultural and human development. China must implement policies to address the loss of fertile land, and it must invest in infrastructure such as irrigation, drainage, storage, and transportation. Further investments in agricultural research and institutional reforms such as tenure security and land market liberalization are needed. Policies and technical support are needed also to improve water use efficiency and protect water quality on the North China Plain, where groundwater levels are declining. Policies that support the production of genetically modified crops can improve the welfare of China's poor.

Increasing water scarcity and emerging signs of groundwater stress are driven by complex socioeconomic and geophysical factors, requiring further research. Any water crisis in the future may not be caused by physical scarcity of water, but more likely by inadequate or inappropriate water governance. Cross sectored policy responses are needed to address the linkages between water and other development related sectors such as population, energy, food, environment, and the interactions among them.

1.21. Nanotechnology

Discoveries related to nanotechnology in the 21st Century are going to play an important role in economic growth in Oregon. Nanotechnology means the building of devices by manipulation or placement of atoms and molecules. Subsurface microorganisms can be considered biochemical factories with the ability to create mineral particles at the nano scale. Nanoparticles may have distinct advantages over particles produced by physical and chemical methods because biologically produced nanoparticles are more uniform in size and shape, and can have specific physical and chemical properties based on environmental and nutrient growth conditions. Three examples of related research areas are:

1. The development of nanoparticles as catalysts for the transformation of environmental pollutants
2. The fabrication of nanoporous materials for capturing environmental pollutants or the enrichments of valuable chemical products, such as drugs.
3. The development of biosensors, using DNA chips and other devices that use gene expression to monitor exposure to environmental contaminants or toxins introduced to the environment.

Environmental biotechnology has a history extending back into the last century. As the need is better valued to move towards less disparaging patterns of economic activity, while maintaining upgrading of social conditions in spite of increasing population, the responsibility of biotechnology grows as a tool for remediation and environmentally sensitive industry. Already, the technology has been demonstrated in a number of areas and future developments assure to widen its scope. Some of the new techniques now under consideration make use of genetically modified organisms designed to deal efficiently with precise tasks. As with all situations where there is to be a release of new technology into the environment, concerns exist. There is a potential for biotechnology to make a further major contribution to protection and remediation of the environment. Hence biotechnology is well placed to contribute to the development of a more sustainable society. In this millennium it will become even more crucially important as populations, urbanization and industrialization will continue to go up.

2. Conclusion

Environmental biotechnology has a history extending back into the last century. As the need is better valued to move towards less disparaging patterns of economic activity, while maintaining upgrading of social conditions in spite of increasing population, the responsibility of biotechnology grows as a tool for remediation and environmentally sensitive industry. Already, the technology has been demonstrated in a number of areas and future developments assure to widen its scope. Some of the new techniques now under consideration make use of genetically modified organisms designed to deal efficiently with precise tasks. As with all situations where there is to be a release of new technology into the environment, concerns exist. There is a potential for biotechnology to make a further major contribution to protection and remediation of the environment. Hence biotechnology is well placed to contribute to the development of a more sustainable society. In this millennium it will become even more crucially important as populations, urbanization and industrialization will continue to go up.

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