Biotechnology and Sustainable Industrialisation for National Development

Abstract

This study aims to educate people about biotechnology and its role in the socio-economic advancement and development of a nation so that they can make informed choices. there is a growing appreciation that nationally, regionally and globally the management and utilisation of natural resources need to be improved and that the amounts of waste and pollution generated by human activity need to be reduced on a large scale. Economic growth provides jobs and income, goods and services and opportunities to improve the standard of living for an increasing world population. It is evident from various reports that, over the years, the requirement of biomass for food, fodder and fuel has been responsible for different types of environmental problems like deforestation, eutrophication, contaminated agricultural fields, etc. The ecoefficiency of industrial bioproducts and bioprocesses can provide a basis for moving a broad range of industries toward more sustainable production. However, these applications are occurring as a "thousand points of light", that is, without a guiding principle or strategic orientation. It is concluded that biotechnology occupies a very strategic position in the socio-economic advancement and development of the nation in particular and the world at large. Investments, therefore, should be made on more sustainable and renewable raw materials – a bio-based economy rather than the conventional or the traditional methods to provide a cleaner and healthier environment.

Keywords: Biotechnology, industrialization, bioproducts, renewable energy

Introduction

Human activities – industrialisation, urbanisation, agriculture, fishing and aquaculture, forestry and silviculture as well as petroleum and mineral extraction – have profound impacts on the world's environment as well as on the quality of life. As a result, there is a growing appreciation that nationally, regionally and globally the management and utilisation of natural resources need to be improved and that the amounts of waste and pollution generated by human activity need to be reduced on a large scale. This will require a reduction and, if possible, elimination of unsustainable patterns of production and consumption. As a result, the emphasis is growing on industrial sustainability because this is increasingly recognised as a key means of bringing about such a reduction of environmental impacts and improving quality of life.

Biotechnology is any technique which involves the application of biological organisms or their components, systems or processes to manufacturing and service industries make or modify products, to improve plants or animals or to develop micro-organisms for special uses (Tietyen *et al*., 2000; Edema, 2004). Some people use the term biotechnology to refer to the tools of genetic engineering that have been developed since 1973 (Tietyen *et al*., 2000). But biology, technology, and human-directed genetic change have been a part of agriculture since the beginning of cultivated crops some 10,000 years ago. Biotechnology has, in a general sense, been used as a tool for food production since the first breeders decided to selectively plant or breed only the best kinds of corn or cows. Technology is a tool we use to achieve a goal, such as improved food quality (Tietyen *et al*., 2000; FAO, 2000, 2004; Edema, 2004). Scientific advances through the years have relied on the development of new tools to improve socio-economy such as health care, agricultural production, and environmental protection. Individuals, consumers, policymakers, and scientists must ultimately decide if the benefits of biotechnology are greater than the risks associated with this new approach (Tietyen *et al*., 2000). The technology tools used in biology have changed rapidly since scientists moved the first specific gene from one organism to another in 1973. This new era began in 1953 when scientists James Watson and Francis Crick determined the structure of DNA (Tietyen *et al*., 2000; Edema, 2004). DNA is the chemical language that determines the features and characteristics of all living organisms: plants, animals, and microorganisms. Once scientists understood how DNA was put together, they could determine which parts of the DNA (genes) are responsible for certain traits (Tietyen *et al*., 2000; FAO, 2000, 2004). Genes determine traits by controlling the production of proteins, including enzymes. Proteins and enzymes are used by all living organisms to grow, metabolize energy, and become what their genetic code dictates. Each cell of an organism contains the entire genetic code needed to create the organism. The interaction of genetic makeup and environmental factors shapes the nature of all living things. When people eat a "healthy" diet, they are controlling environmental factors that will, within the limits of their genetic makeup, decrease their risk of developing a disease (Tietyen *et al*., 2000). In Europe, a vast diversity of high-quality foods provide the carbohydrates, fats, proteins, minerals and vitamins needed in the everyday diet of consumers. At the heart of food production is biotechnology. One aspect of biotechnology which has been used for centuries is the selective breeding of crop plants and farm animals to produce improved food. Another is fermentation, in use for millennia to produce fermented foods like cheese, bread, beer, sauerkraut and sausages (Tietyen *et al*., 2000; FAO, 2000, 2004). Gene technology includes any biotechnological technique for the controlled modification or transfer of genes from one organism to another to give a desired characteristic. The first use of gene technology two decades ago opened up the potential for many additional advances in both selective breeding and fermentation. Each specific step forward might be relatively small, but together they could add up to further improvements in the nutritional quality, appearance, flavour, convenience, cost and safety of foods which are an integral part of socio-economic advancement and national development.. This overview seeks to provide science-based information about discoveries in biotechnology as it affects mankind and is designed to help us understand and assess the risks and benefits of biotechnology. It also provides information about biotechnology with examples of how these new tools of biology and agriculture are used in food production as part of socioeconomic advancement and national development. It includes a perspective showing how biotechnology fits into the history and future of science and food for mankind. Its purpose is to educate people about biotechnology and its role in the socio-economic advancement and development of a nation so that they can make informed choices.

What is Industrial Sustainability?

The World Commission on Environment and Development (Brundtland 1987) has provided insight on sustainable patterns of production and consumption through its description of sustainable development:

"Sustainable Development: *Strategies and actions that have the objective of meeting the needs and aspirations of the present without compromising the ability to meet those of the future*".

This definition of sustainable development can be adapted to provide a conceptual definition of industrial sustainability:

"Industry is sustainable when it produces goods and services in such a manner as to meet the needs and aspirations of the present without compromising the ability of future generations to meet their own needs".

A closer look shows that industry is sustainable when it is:

• Economically viable (uses natural, financial and human capital to create value, wealth and profits).

• Environmentally compatible (uses cleaner, more eco-efficient products and processes to prevent pollution, depletion of natural resources as well as loss of biodiversity and wildlife habitat).

• Socially responsible (behaves ethically and manages the various impacts of its production through initiatives such as Responsible Care).

This "triple bottom line" for the industry is captured in a quote from the Shell Report 2000:

"*Excellent environmental performance is meaningless if no wealth is created. Wealth in a destroyed environment is equally senseless. No matter how wealthy, a society fundamentally lacking in social equity cannot be sustained."*

Moving Toward More Sustainable Industries

Developing sustainable industries implies constantly assessing and improving industrial performance. The aim is to uncouple economic growth from environmental degradation so that industry will be more profitable and, simultaneously, environmental quality will also improve.

Economic growth provides jobs and income, goods and services and opportunities to improve the standard of living for an increasing world population. Environmental protection recognises the intrinsic value of nature and living things. It also recognises the potential of organisms living in ecosystems to provide insights and the means for developing sustainable industrial products, processes and production systems. Sustainable industrial development can be achieved if the three requirements (economic, environmental and social) outlined above are applied to guide the pathway and shape the process by which industry and the economy grow (OECD, 2001).

At a very basic level, sustainable industrial development means doing more with less – increasing eco-efficiency, that is, decreasing the level of pollution and at the same time the amount of energy, material and other inputs required to produce a given product or service. A major way of accomplishing this is through cleaner production. Cleaner production involves a paradigm shift where innovation is used to develop:

• Processes and production systems which:

− save costs and are more profitable because they are less wasteful of materials and energy (resulting in less emission of greenhouse gases, persistent organic chemicals and other pollutants).

− enable greater and more efficient utilisation of renewable resources (energy, chemicals and materials), lessening our dependence on non-renewable resources such as petroleum and reducing associated greenhouse gas emissions.

• Products which are:

− better performing, more durable and don't persist after their useful life.

− Less toxic, more easily recyclable and more biodegradable than their conventional counterparts.

− derived as much as possible from renewable resources and contribute minimally to net greenhouse gas emissions (OECD, 2001).

Advances in Specific Areas of Food Processing

Improved Food Ingredients

Necessary changes to the key food ingredients, starches and oils, are usually made by processing. Biotechnology opens up the possibility of altering crop plants to produce exactly the type of ingredients needed

Starches

Plant breeders have introduced a bacterial gene into potato plants which increases the proportion of starch in the tubers whilst reducing their water content. This means that the potatoes absorb less fat during frying, giving low-fat chips. Sweeter potatoes have also been produced which have higher sucrose content than traditional varieties.

Oils

Both rapeseed and sunflower are being altered to produce more stable and nutritious oils, which contain linoleic acid instead of linolenic acid and have lower saturated fat content. Rapeseed has also been modified to produce a high-temperature frying oil slow in saturated fat (Henkel,1995; Betsch, 1998; Tietyen *et al*., 2000; Peterson, 2000; Lemaux, 2000; IFIC, 2000; Biotech, 2000; Bessin, 2000; ADA, 2000).

Product Quality

Biotechnology has been employed to change the characteristics of the raw material inputs so that they are more attractive to consumers and more amendable to processing (Biotech, 2000). Biotechnology researchers are increasing the shelf life of fresh fruits and vegetables; improving the crispness of carrots, peppers and celery; creating seedless varieties of grapes and melons; extending the seasonal geographic availability of tomatoes, strawberries and raspberries; improving the flavor of tomatoes, lettuce, peppers, peas and potatoes; and creating caffeine-free coffee and tea. Japanese scientists have now identified the enzyme that produces the chemical that makes us cry when we slice an onion. Knowing the identity of the enzyme is the first step in finding a way to block the gene to create “tearless” onions (Tietyen *et al.*, 2000). Much of the work on improving how well crops endure food processing involves changing the ratio of water to starch. Potatoes with higher starch content are healthier because they absorb less oil when they are fried, for example. Another important benefit is that starchier potatoes require less energy to process and therefore cost less to handle. Many tomato processors now use tomatoes derived from a biotechnology technique, somaclonal variant selection. The new tomatoes, used in soup, ketchup and tomato paste, contain 30 percent less water and are processed with greater efficiency. Another food processing sector that will benefit economically from better quality raw materials is the dairy products industry. Scientists in New Zealand have now used biotechnology to increase the amount of the protein casein, which is essential to cheese making, in milk by 13 percent (Betsch, 1998; ADA, 2000).

Better Raw Materials

In improving raw food materials, many plant breeding programmes have been directed towards boosting yield or allowing more environmentally compatible agriculture by increasing the resistance of crops to viruses, pests or herbicides. Increasing yield has clear benefits in helping to feed the world's ever-increasing population and could provide cheaper food. Plants which are resistant to attack by insect pests and diseases would need fewer pesticide applications; resistant crops such as maize, tomatoes and potatoes are already being developed (Peterson, 2000). Crops have also been produced with tolerance to modern, more environmentally compatible herbicides, with the aim of achieving optimal weed control with reduced levels of herbicide (Tietyen *et al*., 2000). Today, there is increasing interest in improving the nutritional value, flavour and texture of raw materials. This could help encourage greater fruit and vegetable consumption in line with government guidelines on healthy nutrition (IFIC, 2000; Biotech, 2000; ADA, 2000).

Safety of the Raw Materials

The most significant food-safety issue food producers' face is microbial contamination, which can occur at any point from farm to table. Any biotechnology product that decreases microbes found on animal products and crop plants will significantly improve the safety of raw materials entering the food supply. Improved food safety through decreased microbial contamination begins on the farm. Transgenic disease-resistant and insect-resistant crops have less microbial contamination (Peterson, 2000; Biotech, 2000; Bessin *et al*., 2000; ADA, 2000). New biotechnology diagnostics detect microbial diseases earlier and more accurately, so farmers can identify and remove diseased plants and animals before others become contaminated (Tietyen *et al*., 2000). Biotechnology is improving the safety of raw materials by helping food scientists discover the exact identity of the allergenic protein in foods such as peanuts, soybeans and milk, so they can then remove them. Although 95 percent of food allergies can be traced to a group of eight foods, in most cases we do not know which of the thousands of proteins in a food triggered the reaction. With biotechnology techniques, great progress are been made in identifying these allergens. More importantly, scientists have succeeded in using biotechnology to block or remove allergenicity genes in peanuts, soybeans and shrimp (Tietyen *et al*., 2000; Lemaux, 2000; IFIC, 2000). Finally, biotechnology is helping us improve the safety of raw agricultural products by decreasing the amount of natural plant toxins found in foods such as potato and cassava (Tietyen et al., 2000) Enhanced food safety In addition to the many ways biotechnology is helping us enhance the safety of the food supply; biotechnology is providing us with many tools to detect microorganisms and the toxins they produce. Monoclonal antibody tests, biosensors, polymerase chain reaction (PCR) methods and DNA probes are being developed and will be used to determine the presence of harmful bacteria that cause food poisoning and food spoilage, such as *Listeria* and *Clostridium botulinum* (BREI, 2006). In addition, *E. coli* 0157:H7, the strain of *E. coli* responsible for several deaths in recent years, can now be distinguished from the many other harmless *E. coli* strains. These tests are portable, quicker and more sensitive to low levels of microbial contamination than previous tests because of the increased specificity of molecular technique. For example, the new diagnostic tests for Salmonella yield results in 36 h compared with the three or four days the older detection methods required. Biotechnology-based diagnostics have also been developed that they allow us to detect toxins, such as aflatoxin, produced by fungi and molds that grow on crops, and to determine whether food products have inadvertently been contaminated with peanuts, a potent allergen (BREI, 2006).

Biotechnology Applications in Production of Food Ingredients

Flavouring agents, organic acids, food additives and amino acids are all metabolites of microorganisms during fermentation processes. Microbial fermentation processes are therefore commercially exploited for production of these food ingredients. Metabolic engineering, a new approach involving the targeted and purposeful manipulation of the metabolic pathways of an organism, is being widely researched to improve the quality and yields of these food ingredients. It typically involves alteration of cellular activities by the manipulation of the enzymatic, transport and regulatory functions of the cell using recombinant DNA and other genetic techniques. Understanding the metabolic pathways associated with these fermentation processes, and the ability to redirect metabolic pathways, can increase production of these metabolites and lead to production of novel metabolites and a diversified product base (FAO, 2000).

Biotechnology Applications in Diagnostics/Food Testing

Many of the classical food microbiological methods used in the past were culture-based, with microorganisms grown on agar plates and detected through biochemical identification. These methods are often tedious, labour intensive and slow. Genetic based diagnostic and identification systems can greatly enhance the specificity, sensitivity and speed of microbial testing. Molecular typing methodologies, commonly involving the polymerase chain reaction (PCR), ribotyping (a method to determine homologies and differences between bacteria at the species or sub-species (strain) level, using restriction fragment length polymorphism (RFLP) analysis of ribosomal ribonucleic acids (rRNA) genes) and pulsedfield gel electrophoresis (PFGE, a method of separating large DNA molecules that can be used for typing microbial strains), can be used to characterise and monitor the presence of spoilage flora (microbes causing food to become unfit for eating), normal flora and microflora in foods. Random amplified polymorphic DNA (RAPD) or amplified fragment length polymorphism (AFLP) molecular marker systems can also be used for the comparison of genetic differences between species, subspecies and strains, depending on the reaction conditions used. The use of combinations of these technologies and other genetic tests allows the characterization and identification of organisms at the genus, species, sub-species and even strain levels, thereby making it possible to pinpoint sources of food contamination, to trace microorganisms throughout the food chain or to identify the causal agents of food borne illnesses. Monoclonal and polyclonal antibodies can also be used for diagnostics, e.g. in enzyme-linked immunosorbent assay (ELISA) kits (FAO, 2000, 2004). Microarrays are biosensors which consist of large numbers of parallel hybrid receptors (DNA, proteins, oligonucleotides). Microarrays are also referred to as biochip, DNA chip, DNA microarray or gene arrays and offer unprecedented opportunities and approaches to diagnostic and detection methods. They can be used for the detection of pathogens, pesticides and toxins and offer considerable potential for facilitating process control, the control of fermentation processes and monitoring the quality and safety of raw materials (FAO, 2000, 2004; BREI, 2006). Biotechnology applications in the enzymes production Enzymes are biological catalysts used to facilitate and speed up metabolic reactions in living organisms. They are proteins and require a specific substrate on which to work. Their catalyzing conditions are set within narrow limits, e.g. optimum temperature, pH conditions and oxygen concentration. Most enzymes are denatured at temperatures above 42°C. However, certain bacterial enzymes are tolerant to a broader temperature range. Enzymes are essential in the metabolism of all living organisms and are widely applied as processing aids in the food and beverage industry (FAO, 2000, 2004; BREI, 2006). In the past, enzymes were isolated primarily from plant and animal sources, and thus a relatively limited number of enzymes were available to the food processor at a high cost. Today, bacteria and fungi are exploited and used for the commercial production of a diversity of enzymes. Several strains of microorganisms have been selected or genetically modified to increase the efficiency with which they produce enzymes. In most cases, the modified genes are of microbial origin, although they may also come from different kingdoms. For example, the DNA coding for chymosin, an enzyme found in the stomach of calves, that causes milk to curdle during the production of cheese, has been successfully cloned into yeasts (*Kluyveromyces lactis*), bacteria (*E. coli*) and moulds (*Aspergillus niger var. awamori*). Chymosin produced by these recombinant microorganisms is currently commercially produced and is widely used in cheese manufacture (FAO, 2000, 2004). The industrial production of enzymes from microorganisms involves culturing the microorganisms in huge tanks where enzymes are secreted into the fermentation medium as metabolites of microbial activity. Enzymes thus produced are extracted, purified and used as processing aids in the food industry and for other applications. Purified enzymes are cell free entities and do not contain any other macromolecules such as DNA. Genetic technologies have not only improved the efficiency with which enzymes can be produced, but they have increased their availability, reduced their cost and improved their quality. This has had the beneficial impact of increasing efficiency and streamlining processes which employ the use of enzymes as processing aids in the food industry. In addition, through protein engineering, it is possible to generate novel enzymes with modified structures that confer novel desired properties, such as improved activity or thermostability or the ability to work on a new substrate or at a higher pH. Directed evolution is one of the main methods currently used for protein engineering. This technique involves creating large numbers of new enzyme variants by random genetic mutation and subsequently screening them to identify the improved variants. This process is carried out repeatedly, thus mimicking natural evolution processes (Tietyen *et al*., 2000; IFIC, 2000; Biotech, 2000; ADA, 2000).

Promising Crop Plants

Improved Nutritional Value

Crops in development include soybeans with higher protein content; potatoes with more nutritionally available starch and with improved amino acid content; pulses such as beans which have been altered to produce essential amino acids; crops which produce betacarotene, a precursor of vitamin A; and crop plants with a modified fatty acid profile. An example is a strain of oilseed rape which produces a special type of polyunsaturated fatty acid (the so-called w3-fatty acids). These have been linked to brain development and have potential in a range of speciality, clinical and infant foods (Tietyen *et al*., 2000).

Better Flavour

Different types of peppers and melons with improved flavour are currently in field trials. Flavour can also be improved by enhancing the activity of plant enzymes which transform aroma precursors into flavouring compounds (Tietyen *et al*., 2000).

Improved Keeping Properties

There is improved keeping properties with the aim of making transport of fresh produce easier, giving consumers access to nutritionally valuable whole foods and preventing decay, damage and loss of nutrients. Examples include the improved tomatoes now being sold in the US, and recently approved in the UK, which have been genetically altered to delay softening. Research is underway on making similar modifications to broccoli, celery, carrots, melon and raspberries. The shelf-life of some processed foods such as peanuts has also been improved by using raw materials with a modified fatty acid profile (Tietyen *et al*., 2000; BREI, 2006).

Reduced Levels Of Toxicants

There is reduced level of toxicants thereby allowing a wider range of plants to be used as food crops, such as the edible strain of sweet lupin which has been developed through conventional breeding techniques (BREI, 2006).

Biotechnology Application in Environment

Biotechnology application to microorganisms for environmental purposes includes bioremediation, biofuels, etc. Bioremediation is often successful and the most inexpensive method, it is only one of many techniques for dealing with hazardous wastes.

Waste Management

Waste disposal and waste management has become a cause of concern worldwide. US industry generates more than 300 million tons of hazardous waste and approximately 600 million tons of nonhazardous waste annually. To meet existing regulations, US industry spends more than US$40 billion every year on pollution control, and waste-treatment and-disposal costs are rising faster than the growth of industrial products (Alper, 1992). Experts in USA are of unanimous opinion that instead of spending ever-increasing amounts to manage their waste mountains, it would be wiser to prevent waste (Zechendorf, 1999). In order to move towards this goal, it is required to improve the efficiency of production processes and reuse as much of the raw materials as possible, thus reducing the input of both energy and materials. This could be achieved by recycling reusable materials, replacing non-degradable substances with biodegradable compounds, applying biological extraction methods in mining, redesigning production processes to avoid waste generation and developing efficient and specific monitoring devices (Zechendorf, 1999). Biotechnology, till date, has made little contribution to recycling despite its great potential, except in the area of paper recycling. The treatment of aqueous and solid wastes of industrial, agricultural and domestic origin offers a number of opportunities to apply a wide range of biotechnological methods. The effectiveness of these methods is based on the ability of the organisms to degrade organic material or absorb hazardous substances (Zechendorf, 1999). Bacteria (Beard, 1993), microalgae (Mallick and Rai, 1994), fungi (Maheshwari *et al*.,1994), yeasts (Schaub and Leonard, 1996), and plants (Markert, 1993) have been found to degrade organic wastes to some extent, and the fixed costs per cubic metre of bioremediation can be 10-20 times lower than incineration. Composting trials showed that certain pharmaceutical solid wastes can be broken down by 90% in 10 days of biological treatment (Luton, 1997). It has also been shown that the biotransformation of waste paper to ethanol by recombinant bacteria is cost effective compared with the conventional process using yeast and added enzymes (Zechendorf, 1999). Biotechnology finds application in the fields of treatment of wastewaters by biological methods and disposal of solid wastes by composting technique through environmental engineering. Treatment of municipal wastewater by activated sludge method was perhaps the first major use of biotechnology in bioremediation applications. Activated sludge treatment remains a workhorse technology for controlling pollution of aquatic environment. Similarly, aerobic stabilization of solid organic waste through composting has a long history of use. Both these technologies have undergone considerable improvement (Gavrilescu and Chisti, 2005). More recently, microorganisms and enzymes have been successfully used in diverse bioremediation applications (Pletsch *et al*., 1999; Macek *et al*., 2000; Gavrilescu, 2004b; Jordening and Winter, 2004). Effective and controlled bioremoval of nitrate and phosphate contamination from wastewater has become possible today (Khin and Annachhatre, 2004; Liu and Tay, 2004). Overall, the biotechnological methods employed in wastewater treatment are activated sludge, trickling filters, oxidation ponds, biofilters and anaerobic treatment. Besides, solid waste composting techniques, biotrickling filters and biosorption are the examples of biotechnology applications in environmental engineering. In all these methods, it is essential to use suitable microorganisms that will bring about the degradation of organic substances and complete the treatment process in favourable conditions (Buyukgungor and Gurel, 2009). The wastewater produced from domestic and industries vary greatly in their qualities. The organic wastes present in wastewater are carbohydrates (starch, polysaccharides, lignin, cellulose, and hemicelluloses), proteins-simple and conjugated, lipids (fats, oils, wax, lipopolysaccharides, and lipoproteins), hydrocarbons and organic acids (Mohapatra, 2006). Different types of microbes use these organic materials as substrates for their growth. The first step of degradation involves the hydrolysis of complex polymers catalysed by numerous enzymes like cellulases, xylanases, amylases, proteases, lipases etc. Considerable progress has been made in the development of treatment systems for efficient and fast removal of organic matters and nutrients from wastewater. Various microbial processes are also involved in the degradation of the organic wastes. Biological degradation of organic matters and other organic chemicals proceeds via aerobic and anaerobic processes. Several species of microbes like *Zooglea*, *Nitrobacter*, *Beggiota*, *Thiothrix*, *Achromobacter*, *Flavobacterium*, *Nocardia*, *Mycobacterium*, *Nitrosomonas*, *Nitrosococcus*, *Nitrosovibrio*, *Nitrosospira*, *Arthrobacter*, *Thiosphaera*, *Paracoccus*, *Acinetobacter*, *Pseudomonas*, *Alcaligenes*, *Xanthomonas*, *Nocardia*, *Corynebacterium*, *Bacillus*, *Geotrichum*, *Clostridium*, *Ruminococcus*, *Fibrobactor*, algae, yeasts and lower fungi are the main pathways of total or partial decomposition of organic matters. Processes have been developed to use these wastes as substrates for industrial production of alcohol, organic acids, aldehydes, ketones and biogas. In spite of progress in the development of efficient methods for treatment of wastewater, in most of the cases, it is released into the surface water with partial or no treatments thus deteriorating the surface water quality. One main aspect of waste processing should to take into account all direct and indirect expenses and the profitability ratio for its feasibility. Today, numerous microbial waste processing schemes can be carried out, if not, in a cost-effective manner, but in a sustainable mode by harnessing the bye products generated from the treatment of wastes. For instance, solid and liquid wastes containing high organic substances are used for obtaining methane, thus giving rise to a new source of energy that can be utilized for running the treatment plant. Again, anaerobic microbial degradation of organic wastes generates biogas as the major end product, a vital renewable and alternative source of energy (Mohapatra, 2006). Wastes belonging to municipality and industries (liquid, solid and gaseous) need suitable treatment to prevent environmental pollution and threat to health. In the removal of these types of contaminants, cost of the project may be considered less important (Buyukgungor and Gurel, 2009). The existence of environmental laws and regulations are prerequisites to the formation of a waste treatment market. Though several nations have enacted environmental regulatory programmes, enforcement of regulations and funding of hazardous waste infrastructures are often insufficient. A hurdle to the international use of bioremediation is the notion, held by many that pollution control costs industry money and makes industry, in its own view, less competitive in world markets (McCarty, 1987). To some, investment in and operation of effluent treatment facilities is money down the drain (Harrier, 1985). Several Organization of Economic Co-operation and Development (OECD) countries have been carrying out biotechnology research and development (R&D) in order to improve waste treatment, notably the Netherlands, France, Japan, and Germany (McCarty, 1987). Still, research efforts are generally negligible in many countries, and the dissemination of research results into commercial applications is insignificant as compared to other sectors influenced by biotechnology. This is due to sloppy regulations that support the payment of fines by industry for waste emission rather than the use of systems to reduce or cleanup pollution (OECD, 1988). Improved and alternative solid waste disposal systems are being suggested to reduce environmental degradation. Sanitary landfilling has emerged as an environmentally acceptable solid waste disposal method and in many countries such disposal practices form an integral part of urban solid waste management (Mohapatra, 2006). The quality of landfill designs, based on technical, social, and economic developments have improved significantly in recent years. Design concepts are intended to ensure minimal environmental impacts. The primary environmental concerns connected with landfills are the release of leachates during degradation process and the present landfill technology concentrate on preventing and controlling leachate problems. To minimise the emission of greenhouse gases, the control of landfill gases draws utmost attention. For significant reduction of such landfill emissions in future, the capacity assessment of the landfill to house the biodegradable organic matters is essential. Moreover, mechanical, biological and thermal pre-treatments may be required to achieve better solid waste management. Advanced methods of solid waste management opened up the scope to use these processed wastes as resources to be utilised for various other purposes. Aerobic composting processes are available to process organic wastes from households, industries, agriculture, horticulture, sludge from the wastewater treatment systems etc. The present composting technology provides efficient composting systems allowing maximum microbial activity in the compost and minimise the loss of valuable resources. Further research is needed to optimise various factors of composting so as to enhance the decomposition and degradation processes. Contrary to commonly established composting systems, the technique of anaerobic fermentation of wastes is relatively young and dynamic. Through research and expenditure, new progress has been made in process development and optimisation of anaerobic degradation of wastes. Further scope of research on technological and biological aspects of anaerobic solid waste management is still wide open. Anaerobic microbial degradation of organic wastes generates biogas as the principal and most important end product which is an alternative source of energy. For industrial scale production of biogas various factors like water content, temperature, pH etc., in the fermentation reactors need optimisation as the conditions vary with the ratio of different groups of microbes and the substrates. In order to achieve optimised and uninterrupted biogas production, these factors require special attention in addition to synchronised consecutive degradation steps (Mohapatra, 2006). Ashden Award recognised its achievement in developing technologies to manage domestic and municipal organic waste at source, and produce biogas for cooking and electricity generation. In households and institutions, plants handle waste food and sometimes have toilets connected. Biogas thus produced is used for cooking, displacing about 50% of LPG use. Larger systems used at markets and municipal sites, where biogas is cleaned and then used to generate electricity for lighting. Between 2004 and 2007, 12,000 domestic plants (serving about 48,000 people), 200 institutional plants and 19 energy-from-waste projects were installed by BIOTECH in southern part of India. Installation and operation of these plants save about 3,700 tonnes/year of $CO2$ in avoided LPG and diesel use. Besides, biogas plant effluent makes a useful fertiliser, resulting in higher food production. For markets and councils, removal of food waste reduces health risks associated with disposal onto streets.

Biological Transformation and Bioremediation

Increasing human activities have led to a significant reduction capacity of land. Unsuitable use of agricultural land, poor soil and water management practices, improper crop rotation, poor irrigation practices, use of chemical pesticides, mining activities and entry of acid mine drainage, a wide variety of industrial activities like release of industrial effluents etc. have resulted in changes in global elemental distribution and pollution of aquatic and terrestrial habitats including cropland ecosystems and contributed to wasteland formations. Chemical and biological transformation of metal ions is a dominant process in the environment, which keep the bioavailable metal species under control (Singh, 1999; Gupta, 2004; Mohapatra, 2006). Biological transformation involves both microbes and higher plants. The potential of microorganisms and higher plants to transform toxic metal species into non-toxic or less toxic forms has not yet been fully utilised. However, progress in biotechnology has provided methods to generate microbial systems or crop types suitable for biotransformation and removal of elements and reclamation of wastelands. Sustainable advancement has been made in identifying metal tolerant herbs and tree species, and in some instances they have been successfully introduced for the same purpose. Many plants have been shown to have the capacity to absorb heavy metals, for instance *Thlaspi caerulescen*s (cadmium and zinc), *Zea mays* and *T. rotundifolium* (lead), and Alyssum (nickel) (Chaney *et al*. 1997). The normal accumulation range of plants varies from 0.1 to 100 mg (kg plant mass)-1 while, in exceptional cases it can reach 1-3%, with a record of 25% by dry mass for a nickel-accumulating plant (Cunningham *et al*., 1995). Such hyperaccumulators are, however, slow grower, have a small biomass and survive best under extreme environmental conditions (e.g. contaminated soils), thus making cultivation difficult (Cunningham *et al*., 1995). Microbial inoculation (e.g. *Nostoc spp., Cylindrospermum spp., Plectonema spp., Tolypothrix spp., Calothrix spp., Scytonema spp., Plectonema spp., Oscillatoria spp., Anabaena spp., Microchaete spp.* etc.) has also been exercised in localised way in different saline and alkaline soils; and mine wastelands to reduce metal bioavailability and to reclaim the concerned site for plantation. Lignocellulolytic and phosphate solubilising microbes in conjunction with lignocellulosic organic base (e.g. saw dust, leaf dust etc.) and rock phosphate are applied in mine-spoils to facilitate metal leaching to deeper soil layers and to mobilise metals. There is a wide scope for research and application of biotechnological principles for reclamation of more and more wastelands in view of ever increasing demand for arable land (Singh, 1999; Gupta, 2004; Mohapatra, 2006). Development In the specialized field of oil recovery from major oil spills, the potential, as well as the limits, of bioremediation has already been shown. The complex nature of crude oil demands the application of various microbial strains (Zechendorf ,1999). Even though over 30 genera of oil-degrading bacteria and fungi have been identified (Sigoillet *et al*. 1997), it is nearly impossible to produce the right microorganism balance for each type of oil (Swannell and Head, 1994). The use of biofertilizers and adequate aeration has been shown to increase the natural rates of oil biodegradation (Atlas, 1993). Moreover, the marine environment makes the effective application of microorganisms difficult. Genetically modified microorganisms are presently considered unsuitable for the purpose and even the only patented oil degrading pseudomonad has not yet been used in case of an emergency (Atlas, 1993). Bioremediation is considered to be far more cost effective than traditional cleaning technologies, with probable savings of 65-85%. Despite justified optimism for future growth, some problems are impeding further progress (Zechendorf, 1999): each waste site has unique characteristics, demanding costly tailor-made applications; various industrial pollutants cannot be degraded satisfactorily under natural conditions as yet; in situ applications of engineered microbial strains could lead to considerable ecological risks; and, the technique is often time consuming.

Biotechnology in Agriculture

Applications of biotechnology to plants or animals have improved their food processing properties (e.g. development of the Flavr Savr tomato variety, genetically modified to reduce its ripening rate) and the production of proteins from genetically modified (GM) microorganisms to improve plant or animal production (e.g. production of bovine somatotropin (BST), a hormone increasing milk production in dairy cows, by GM bacteria) (Lemaux, 2000; Tietyen *et al*., 2000).

Development and Use sof Biopesticides

Majority of chemical pesticides and herbicides that are used by farmers causes environmental pollutions as the toxic chemicals present in them enter food chains and ecosystems. Numerous instances of bioaccumulation of different organosynthetic insecticides and pesticides exist due to their large scale use in the past few decades (Singh, 1999; Gupta, 2004; Mohapatra, 2006). The potential environmental and health hazards of these chemicals have been fully realised. Microorganisms of various kinds are known to break and modify these complex pesticide molecules and their activities have been shown to diminish the toxicity of xenobiotics (Munnecke *et al*. 1982). The pesticides with low half-life are less toxic as compared to those with long half-life as degradation processes are increased with long half-life. After release into the environment, the pesticides and herbicides are degraded chemically and biologically thereby minimising the bioaccumulation and environmental effects. The microbial activities convert the xenobiotics into water-soluble intermediates which are then acted upon by primary or secondary group(s) of microbes to form inorganic end-products, resulting in complete biodegradation. A variety of microbes viz. bacteria, cyanobacteria, fungi, planktonic algae and protozoa are involved in the degradation of pesticides. Some examples of the microbes involved in degradation of pesticides are - *Aerobacter aerogenes, Escherichia coli, Proteus vulgaris, Clostridium ssp., Klebsiella pneumoniae, Pseudomonas flurescens, Nocardia spp., Streptomyces spp., Pseudomonas spp., Acetomonas spp., Acinetobacter spp., Hydrogenomonas spp., Arthrobacter spp., Bacillus spp., Corynebacterium spp., Actinomyces, Rhizobium spp., Streptococcus spp., Xanthomonas spp., Sphingomonas spp., Flavobacterium spp., Erwinia spp., Kurthia spp., Micrococcus spp., Enterobacter spp., Klebsiella spp.,* etc.

Use of chemical pesticides though increases the crop production but it is associated with various environmental problems. To minimise the environmental pollution, it is now encouraged to use biopesticides in conjunction with chemical pesticides. Practically, in the present scenario, an integrated approach to pest control has become necessary. Biopesticides are generally based on bacterial spores, crystal proteins and inert fillers. Thus, the biologically active compounds, dead or living parts of the plants or animals, or the whole plant, animal or microbes applied to control agricultural and domestic pests are called biopesticides (Singh, 1999; Gupta, 2004; Mohapatra, 2006). Biopesticides generally tend to be highly target specific, do not leave toxic residues, reduce the risk of resistance development in the target species and produce a lesser overall impact on the environment than conventional chemical pesticides (Pimentel, 2002). Some of these biopesticides are based on *B. thuringiensis*. Some bioinsecticides used commercially in various parts of world are: *Verticillum lecanii* (Commercial in Europe), *Metarhizium anisopliae* (Commercial in South Africa), *Hirsutella thompsonii* (Commercial in USA), Heliothis nuclear polyhedrosis virus (Commercial in USA) and many more are under field trials (in USA, UK and other countries) for commercial release. Similarly some microbial herbicides are used commercially in USA to control the weeds (e.g. *Phytophthora palmivora, Colletotricum gloeospriodes*) and some are in experimental state in USA (e.g. *Agrobacterium radiobacter*). Hindustan Lever Research Centre (HLRC) at Mumbai and IARI at New Delhi (Agarwal, 2005, 2007, 2009) isolated mutant strains of *B. thuringiensis* (Bt) which produce crystal proteins and form no spores. Bioinsecticides based on these mutants are expected to be ecologically safe and have been successfully tested on insects affecting cotton, maize, cabbage, sunflower etc. The progress towards the development and commercialisation of biopesticides is sluggish as compared to the acts on banning chemical pesticides (Agarwal 2005, 2007, 2009). Biopesticides exhibited some impressive successes, but there have been concerns related to their effectiveness (Auld and Morin 1995). Biopesticides formulation and application in agricultural fields is gaining momentum in different parts of the world. The variety of biopesticides is already large and increasing (Hall and Menn 1999; Koul and Dhaliwal 2002). Species of Bacillus and Pseudomonas have been successfully used for seed dressings to control certain soil borne plant pathogens (Johnsson *et al*. 1998). Besides biologically produced chemicals, pest pathogenic bacteria, fungi, viruses and parasitic nematodes are being developed or used to manage a range of pests. Both spore-forming and non-sporulating bacterial entomopathogens are being used or assessed for biopesticidal application. Non-sporulating species in the Pseudomonaceae and Enterobacteriaceae families are potential biocontrol agents. The spore-formers *B. popilliae* and *B. thuringiensis* (Bt) are already well established insecticides (Gavrilescu and Chisti 2005). Thus, optimization of production, multiplication (of living biopesticides) and extraction (for bioactive products), and logistical development for commercial production of biopesticides require extensive funding and, research and extension. The real sustainable pest management can be achieved through the adoption of the concept of 'integrated pest management' (IPM), which encompasses different biocontrol means and traditional methods, such as alternating crops, growing different plant species together, creating refuges and using agrochemicals in moderate amounts. The aim of IPM is not to annihilate plant pests but to establish a system of coexistence.

It has already shown promising results in Europe and in developing countries (Zechendorf, 1995; Persley, 1996; Stone, 1992).

Development and Use Of Biofertilizers

Biofertilizers are the fertilizers derived from biologically active products or microbial inoculants of bacteria, algae and fungi (singly or in combination), which help in biological nitrogen fixation for the benefit of the plants or otherwise improve the fertility of the soil (Singh, 1999; Gupta, 2004; Mohapatra, 2006). These also include organic fertilizers (manure etc.) as they are produced via microbial degradation of biological organic products. Biofertilizers thus include:

(i) symbiotic nitrogen fixers-*Rhizobium spp*., *Frankia spp.,*
(ii) asymbiotic nitrogen fixers-*Azotobacter spp*., *Azospirillum spp*., etc.,
(iii) algal biofertilizers (blue green algae or BGA in association with Azolla),
(iv) phosphate solubilising bacteria (*Thiobacillus spp., Bacillus spp.*, etc.)
(v) mycorrhizae (mycorrhizal fungi like *Azotobacter*, *Aspergillus*, *Azospirillum*, *Beijerineleia*, *Glomus* etc.) and
(vi) organic fertilizers.

Ever increasing use of chemical fertilizers has resulted in considerable damage to environment. Use of biofertilizers is both economical and environment friendly. Increased use of biofertilizers is expected to contribute significantly to reducing pollution, energy and resource consumption associated with the use of conventional fertilizers (Gavrilescu and Chisti 2005). The prospects for such biological fertilizers are very promising. For instance, Kenya is producing BIOFIX, a *Rhizobium inoculant*, 100 g of which (costs about US$1.25) fertilizes 1 hectare of beans thus replaces 90 kg of chemical nitrogen that costs approximately ten times more (Odame 1997). The inoculation of rice with mycorrhizal fungi and *Alcaligenes faecalis* showed that nitrogen fixation rate could be increased by 15-20% and rice yields by 5-12%11,12 (Secilia and Bagyaraj 1994). The US sales of biofertilizers accounted for US$690 million in 2001 and are expected to grow to US$1.6 billion by 2006 (Tengerdy and Szakács 1998). In India, to meet the ever increasing demand of food supply with reduced environmental impact, the practical approach would be to develop an integrated nutrient supply system combining both chemical fertilizers and biofertilizers. Vermicomposting has emerged as a new technology for the production of commercial compost from biological wastes such as vegetable or food waste, bedding materials and such other resources, and are utilised as eco-friendly manure in the agricultural field. The normal vermiculture technology depends on the natural degradation efficiencies of earthworm, fungi, thermophilic and mesophilic bacteria which coexist in a composting bin forming a degradation system enabling the organisms to act together on the substrate (Mohapatra, 2006). With water-soluble nutrients, vermicompost is an excellent, nutrient-rich organic fertilizer and soil conditioner (Kelly and Knutzen, 2008). Large-scale vermicomposting is practiced in Canada, Italy, Japan, Malaysia, the Philippines, and the United States (Aalok *et al*., 2008). In India, most of the production of biofertilizers is being done in the public sector by research institutions, universities and the National Biofertilizer Development Centre. A few state and co-operative fertilizer units also have ventured into this field. Surprisingly, the involvement of the private sector is extremely limited in spite of it being a low investment and high benefit technology.

Development and Use of Bio-Based Substrates In Industry

Bio-Based Substrates in Paper Industry

Manufacture of paper from wood involves-wood processing, pulping, bleaching and sheet formation. Pulping of wood requires separation of the wood fibres from each other, which are then reformed into a sheet. The wood fibres are glued together by lignin and separation of these fibres is called chemical pulping. The chemical pulp is also subjected to bleaching to remove traces of lignin to increase the brightness of the paper. The bleaching results in production of numerous toxic derivatives of lignin which are hazardous to the environment. To minimise the action of bleaching, biotechnological approach can be adopted in paper industry. Through biotechnology and improved silviculture, trees and other bioresources used in paper making can be specifically tailored to match the properties required in cellulose fibres for different product applications (BuschleDiller and Ren, 2002). This can significantly enhance useful paper yield from trees, boost product quality and reduce need for energy and chemicals used in papermaking. Production of optimal fibres for paper making through genetic engineering is an important long-term goal that calls for a better understanding of fibre biosynthesis in plants. Moreover, application of genetically modified microorganisms and enzymes can displace many of the environmentally adverse practices used in pulp processing (Buschle-Diller and Ren, 2002). Biopulping could be used effectively in paper production. Biopulping is the treatment of wood chips with lignin-degrading fungi prior to pulping. Under experimental condition biopulping is mostly applied as a pretreatment prior to mechanical pulping of wood. This greatly eases subsequent mechanical and chemical pulping by improving penetration and effectiveness of chemicals during the cooking of wood chips for separating the cellulose fibres from the lignin. Consequently, biopulping reduces the demand for energy and chemicals, improves paper quality, and decreases the environmental impact of pulp production (Pullman *et al*. 1998). It has been reported that treatment of wood chips with lignolytic fungi like Phanerochaete chrysosporium before craft pulping gives more tensile strength. In biochemical pulping two steps are involved: primary refining or defibration and secondary refining. Biological step may be introduced before or after the defibration step. Treatment of coarse pulp with lignolytic fungi (e.g. Trametes versicolor, Pleurotus ostreatus etc.) has been shown to increase tensile strength and may reduce the energy requirement for secondary refining. For effective biological pulping, considerable research towards isolation of more lignolytic fungi and the most effective species and strain of the same, design and development of fermentation reactors and optimisation of conditions for scaling up of the fungal strain and mechanism of lignin degradation by fungi is essential (Gupta, 2004; Mohapatra, 2006). The paper industry is unlikely to use enzymes in the bleaching process because they are too expensive and enzymatic treatment takes too much time (Todd 1993). However, enzymes are already well established in processing of pulp and paper. For instance, enzymes are used in biobleaching of pulp to reduce chlorine consumption; pulp dewatering and deinking; removal of pitch; degradation of dissolved and suspended organics in concentrated effluents of mills; and enhanced fibrillation to give stronger paper (Eriksson 1997). Implementation of enzymatic processing in many cases has been driven by the savings generated by reducing the use of chemicals and energy and the improved quality of the product that is attained with their use. Energy savings occur due to elimination of processing steps, their simplification and reduction of the severity of treatment that are needed in the absence of enzymes (Gavrilescu and Chisti 2005). The development of genetically engineered trees to alleviate lignin separation from cellulose may save US$100 million y -1 , although such wood will increase costs as raw materials account for 45–65% of the final paper price (Tils and Sorup 1997).

Biomass, Bioenergy and Biorefinery

It is evident from various reports that, over the years, the requirement of biomass for food, fodder and fuel has been responsible for different types of environmental problems like deforestation, eutrophication, contaminated agricultural fields, etc. Afforestation in wastelands, social forestry etc. is some of the measures adopted for biomass production (Singh, 1999; Gupta, 2004; Mohapatra, 2006). Fast growing plants species for the production of fuel wood and grasses for use as fodder, and captive regeneration of biomass to reduce pressure on the natural biomass reserves, are being made popular at some discrete level. One of the most efficient and environment friendly technology for low cost biomass production that has emerged in recent years is the use of wastewater for freshwater aquaculture (Singh et al., 2011; Priyadarshani and Rath, 2012). Continuous research is going on to improve the performance and production efficiency of aquaculture systems, employing grazable algae or macrophytes. The most successful progress is observed in the use of wastewater/effluents for the production of value added products like single cell protein {(SCP) *Chlorella* or *Spirulina* biomass}, pigments, amino acids and polyunsaturated fatty acids. However, further research and technological developments are required for commercial utilisation of such processes (Singh et al., 2011; Priyadarshani and Rath 2012). Present day biotechnological methods are using microorganisms to produce liquid or gaseous fuels from plants, animals or microbial biomass. Attention is mainly focused on ethanol production from corn, wheat and sugar crops, as well as wastes from food processing industries. Cost effective strategy could be based on the production of liquid bio-fuels from fast growing trees and grasses. Currently, worldwide research is focused on the microbial production of bio-fuels viz. methanol and ethanol to support the global fuel demand. The added advantage to this technology is the use of agro-waste or agricultural-overproduce and the reduction of CO_2 emission (Singh, 1999;Chawla, 2002; Mahapatra, 2006). Biotechnology-based production of fuels continues to attract a great deal of attention. Bioethanol (Wyman, 1996; Roehr, 2001) firewood, biogas, biodiesel (Graboski and McCormick, 1998) and biohydrogen (Nandi and Sengupta, 1998) are examples of bio-fuels. Apart from biohydrogen, commercial and/or pilot experimental production of other types of bio-fuels is already established or emerging. Even though bioconversion of lignocellulosic biomass to sugars for ethanol production has been studied extensively but it still remains difficult (Aden *et al*., 2002). Till date, more successful and widely used method is the bioconversion of starch to sugars for the production of bioethanol. Likewise, fuel ethanol produced from residues of cane and beet sugar processing has been employed for several decades. Though in energy terms annual land production of biomass is about five times the global energy consumption, only 1% of commercial energy is derived from biomass at present (OECD, 1998). Organic waste from landfill sites and farms can be transformed in to biogas (approximately 55% methane and 45% carbon dioxide) through anaerobic digestion (OECD, 1998) and liquid hydrocarbon fuels can be produced from plant, animal and microbial oils. Prior to the 1900s, agriculture and forestry were the predominant sources of raw materials for energy, food and a wide range of everyday commodities. The industrial revolution led to mass production of goods by machines for our daily life. The industrial revolution was brought to fruition by the invention of combustion engines and the subsequent development of the fossil fuel and chemical industries. Nevertheless, fossil energy and chemical sources are not unlimited. Thus, there is an absolute necessity to switch over the current industry and human activities back to a sustainable track in such a way which assures that our way of life today continues on the path of improvement after the exhaustion of fossil energy resources (Liu *et al*., 2012). Biorefinery is a concept of converting plant-based biomass to chemicals, energy and materials that would sustain our civilization, replacing the requirements of petroleum, coal, natural gas, and other non-renewable energy and chemical sources. Combustion of biomass liberates energy, carbon dioxide and water. Sustainable harvesting and utilization of biomass does not negatively affect the environment and is carbon neutral (Liu *et al*., 2012). "Catch and release" (Amidon and Liu, 2009) is the key to biomass utilization. "Catch and release" conceptualize that in photosynthetic-consumption cycle, CO_2 is drawn from air and water, mostly from soil, generating O_2 and producing biomass by using energy from the sunlight. The biomass can then be reacted with O_2 to produce CO_2 and H_2O. This cyclic process produces no net CO_2 or H_2O. The net result is that solar energy and atmospheric carbon dioxide can be converted into energy and materials that can be utilized by humans. As the non-renewable energy sources used today will cease to be available in the future, it is essential to consider intensifying the production and use of plant biomass, especially forest biomass, as a sustainable energy and chemical source (Amidon, 2002). The utilization of renewable carbon does away with the fossil-derived carbon dioxide burden to the environment and reduces the greenhouse gas (GHG)-driven global climate change. Managed forests thus have significant potential for reducing GHG emissions through conversion of the forest material into liquid fuels, electricity and other products that are currently derived from non-renewable carbon (Amidon and Liu, 2009). The biorefinery plays a major role in ensuring the cycle of biomass production and utilization satisfying human needs for energy and chemicals (Liu *et al*., 2012). Thus, biorefinery concept is analogous to that of an oil refinery. The refineries take petroleum or crude oil, fractionate, process and blend all of the potential molecular feed stocks to generate the vast array of fossil-fuel based products that we use today. Cereal grains, nuts and oil seeds are direct food sources for humans and animals, and they are perfect raw materials for chemicals, energy and materials. To avoid any kind of contest with direct food sources for humans and animals, woody biomass can be utilized for the purpose. There are four chief classes of substances in woody biomass: cellulose, hemicellulose, lignin, and extractives. Fractionation and conversion of the lignocellulosic biomass can produce vast array of chemicals, energy and materials. Developing means to convert variety of plant-based biomass to chemicals, energy and materials is the foundation to shift the world economy back from fossil-fuel based growth to sustainable renewable biomass based development (Liu *et al*. 2012). Considerable effort and research in this line started long back and a few old industries have already taken a leap forward in augmentation of existing unit towards biorefinery setup. Various research reports and opinions are available about the feasibility and future prospects of the biorefinery. For instance, substantial amount of unusable, or unutilized, plant biomass from crops has caused experts to develop the concept of whole-crop biorefineries, in which products can be extracted and the remaining waste transformed into energy (Rexen and Munck, 1984). This technology has been considered non-viable for a number of reasons including the facts that it appeared to be too expensive and still underdeveloped, that the raw materials are too expensive, that the markets are inadequately developed, and that an organized production chain is lacking (Lévêque *et al*., 1992; Zechendorf 1999). At the same time, Borregaard in Sarpsborg, Norway is considered to be one of the most advanced biorefineries in operation today and has more than 40 years experience of running such a biorefinery (Rødsrud *et al*. 2012). Based on this experience and presence in many markets, new strategies for converting lignocellulosic biomass to biochemicals and bio-fuels in a sustainable and profitable way have been employed. The company is devoted to the biorefinery strategy of manufacturing the maximum amount of valuable products from the biomass resources. Examples of prospective new products are microfibrillar cellulose (MFC), water soluble specialty lignins from other sources than wood, lignocellulosic ethanol, proteins and sugar based chemicals. Both experience from the long history of running a biorefinery as well as the main development routes for future new bio-products is researched and analyzed. The basic strategy of maximizing the conversion of the biomass feedstock to specialty chemicals, leaving only minimal side streams to energy products, has proven well and will be the principle also for the future. The Borregaard plant in Norway is the largest producer of second generation ethanol from lignocellulosics today with a capacity of 20 000 m 3 (Rødsrud *et al*., 2012). The sustainability of biorefinery is based on the "Industrial Metabolism" as opined by many researchers (Octave and Thomas, 2009). The biorefinery concept based on the use of the whole plant can evolve to a generalization. The diminution of the wastes or by-products could be linked not only to one whole plant transformation but also to the utilization of several plants based on complementarities of different processes, different factories belonging sometimes to different companies. The wastes and by-products of the first one could be the initial material for the second one and a source of energy for the third one. Standardization of the flow of raw materials, of by-products, of energy among different industrial production units on a given site is a generalization of the concept of biorefinery through an actual ''Industrial Metabolism''.

Setting a Path to a Sustainable Future – The Bio-Based Economy

Biotechnology is an effective tool which provides a means of reconciling the need for economic growth with the need for environmental protection. The ecoefficiency of industrial bioproducts and bioprocesses can provide a basis for moving a broad range of industries toward more sustainable production. However, these applications are occurring as a "thousand points of light", that is, without a guiding principle or a strategic orientation. Such a strategic orientation is needed to avoid investing resources on incremental improvements in the cleanliness of industrial production systems which may never make it to "clean enough", i.e. sustainable. Shifting toward an economy more extensively based on renewable raw materials – a bio-based economy – does provide such an integrating principle. Continued use of conventional processes that are not eco-efficient in combination with non-renewable feedstocks results in continued pollution and exhaustion of resources. If conventional processes that are not eco-efficient are used in combination with renewable resources, they may lead to depletion of the renewable resource as the global economy grows and demand increases. If cleaner production processes are used on non-renewable resources they will extend the lifetime of those resources, but only postpone their inevitable exhaustion. Sustainability is most likely to be found in utilising renewable resources through cleaner processes that are eco-efficient. Developing a sustainable economy more extensively based on renewable carbon and ecoefficient bioprocesses (a 'bio-based economy') is one of the key strategic challenges for the 21st century. At present, the global economy depends to a large extent on energy, chemicals and materials derived from fossil carbon sources, mainly petroleum. Petroleum provides us with fuels for transportation and heating. It also yields synthetic chemicals for producing plastics, paints, dyes, adhesives and a wide range of other useful industrial and consumer products. These developments have contributed to strong economic growth and employment and have literally transformed our global society. But this has come at a cost. The Petrochemical Age has also resulted in massive pollution of air, water and soil as well as emissions of greenhouse gases responsible for climate change. Petroleum is also a finite, diminishing resource now subject to strong price increases and fluctuations. The present level of global energy consumption, production and industrial growth is ultimately not sustainable because it is only made possible by continued withdrawals from the stored "bank" of fossil carbon which is finite and not renewable. The world was not always dependent on petroleum. A traditional bio-based economy provided and continues to provide us with food, feed, fibre and wood. Before the 1920s, many of our industrial products were also bioproducts, such as fuels, chemicals and materials derived from biomass, primarily wood, and various agricultural crops. Cheap and abundant oil changed that. However, advances in technology, and biotechnology in particular, are making it economically viable and environmentally attractive to "go back to the future" and begin supplementing, and eventually perhaps, replacing petroleum with biomass, a renewable feedstock derived mostly from plants. Improved understanding of biodiversity, ecology, biology and biotechnology is making it possible both sustainably to increase biomass productivity in forestry and agriculture as well as to utilise that biomass and waste organic materials in a highly efficient and sustainable manner. Without such advances in science and technology, the move to a bio-based economy would result in rapid depletion of renewable resources and environmental degradation. Thus, advances in science and technology are making it possible to have an economy where industrial development and job creation are not in opposition to environmental protection and quality of life. Getting there will be a major challenge, requiring effective tools to assess technology, processes and products for sustainability and also policies that encourage sustainable production and consumption. The "bio-based economy" offers hope both for developed and developing countries. For developed countries, it presents the opportunity to use their technological capabilities for national energy security to head off major economic and social disruptions which will be caused by fluctuations in the availability and price of energy and petrochemicals as the supply of these finite, non-renewable resources continues to diminish. It will also help them diversify and grow employment in their rural economies. For a number of developing countries, it provides the potential to leapfrog (at least in part) the age of fossil-fuels and petrochemicals to the age of biofuels and biochemicals. These are less toxic and more easily biodegradable than their petrochemical counterparts and can be derived from locally grown feedstock, leading to local self-sufficiency, an improved economy and a better quality of life. However, if we are to see a move to such a future in the 21st Century then, despite the potential economic, environmental and social benefits, it is not realistic to assume that a new "green revolution" will sweep spontaneously over existing industries. Potentially, the move to a bio-based economy could be at least as big as that caused by the development of the petrochemical age during the 20th Century. But societal values are different in 2001 from those of 1901. The transition therefore will need to be carefully managed, not least because it will link such issues as biotechnology and GMOs, preservation of biodiversity, climate change, globalisation, economic growth, sustainable development and quality of life. The interplay of these issues could pose complex problems and policy issues for governments, industry and civil society as they try to optimise economic, environmental and societal benefits, while enabling and fostering the development of a bio-based economy in their countries. Visionary thinking is required among stakeholders if we are to identify proactively the key issues and policy decisions that will have to be dealt with along the way (OECD, 2001).

Conclusion

Biotechnology revolution has spawned new industries focused on manipulating human, animal, plant and microbial agents to create heretofore unattainable products and services such as fermented food products which have great potential as key protein, fatty acid and good sources of gross energy, therefore, condiments are basic ingredients for food supplementation and their socioeconomic importance cannot be over emphasized in many countries especially in Africa and Asia (India) where protein calorie malnutrition is a major problem. Biological organisms that are being used in most biotechnological processes are microorganisms, which are very small living things which are invisible to the naked eyes but can only be seen with the aid of a microscope. They play this vital role because of the simplicity of their genome, their short generation time, ease of manipulation, their use of synthetic medium for growth among other factors. The present molecular techniques such as cloning, genetic engineering, recombinant DNA technique and polymerase chain reaction (PCR), ribotyping, using restriction fragment length polymorphism (RFLP), and pulsed-field gel electrophoresis (PFGE), Random amplified polymorphic DNA (RAPD) or amplified fragment length polymorphism (AFLP) molecular marker systems involve genetic manipulations using microorganisms such as bacteriophages and bacterial plasmids as vectors and bacterial cells as hosts. This therefore implies that biotechnology occupy a very strategic position in the socio-economic advancement and development of the nation in particular and the world at large. Investments therefore should be made on more sustainable and renewable raw materials – a bio-based economy rather than the conventional or the traditional methods so as to provide a cleaner and healthier environment.

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