BIOMASS AND ORGANIC WASTE CONVERSION TO FOOD, FEED, FUEL, FERTILIZER, ENERGY AND COMMODITY PRODUCTS

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Summary

Our planet's abundant plant life is nature's storehouse of solar energy and chemical resources. Whether cultivated by man, or growing wild, plant matter represents a huge quantity of a renewable resource that we call biomass. Biomass represents a useful and valuable resource to man and nature's fauna. The value of the biomass content is related to the chemical and physical properties of the large molecules.

The challenge for the future lays in the establishment of biorefineries, where a combination of biological, physical and chemical sciences is able to replicate an "oil-refinery" with a "bio-refinery', replacing the non-renewable fossil resources with renewable biomass resources for the production of food, feed, fertilizer, fuel, energy, industrial chemicals and related consumer products. All future biotechnological and technological developments should be aimed both at improving the quality of life of our communities and sustaining our environment by using clean bioprocess technologies. This can only be achieved through a full exploitation of our natural renewable resources, reducing the risks to health and achieving sustainable, economical growth conducive to a higher per capita income for urban and rural communities.

It has long been realised that biomass consists of lignocellulosic and non-lignocellulosic materials, whereby the composition of the latter depends on the plant variety. This overview shows that basically all lignocellulosic as well as non-lignocellulosic materials can be used for energy, food, feed, fertilizer, fuel and commodity product formation. Production of food should never compete with feed, energy and commodity production and this can easily be avoided through careful agricultural practices. The examples demonstrate that starch, sucrose, protein and oil products fulfil these requirements, whether farms or industries or a combination of both are involved. The main target of each of these bio-refineries is therefore eco-efficiency and environmental sustainability. Such (regional) industries would directly benefit the farmer as the production of biomass would be maximised and the local economy, creating jobs for rural people, in turn stabilising the social structure of the communities and reducing migration into urban areas and large cities.

1. Introduction

Our planet's abundant plant life is nature's storehouse of solar energy and chemical resources. Whether cultivated by man, or growing wild, plant matter represents a huge quantity of a renewable resource that we call biomass. The chemical composition of biomass varies among species, but biomass in general consists of 25 percent lignin and 75 percent carbohydrates. The latter category of carbohydrates consists of many monomeric (i.e. single) molecules of sugar (mainly glucose) linked together in long chains referred to as polymers. Of these, cellulose, hemicellulose and starch are the most significant ones. Nature uses the long cellulose polymers to build the fibres that give a plant its strength and lignin to hold the fibers together. It is this combination of lignin and cellulose that gives plants their flexibility and which is referred to as lignocellulosic biomass.

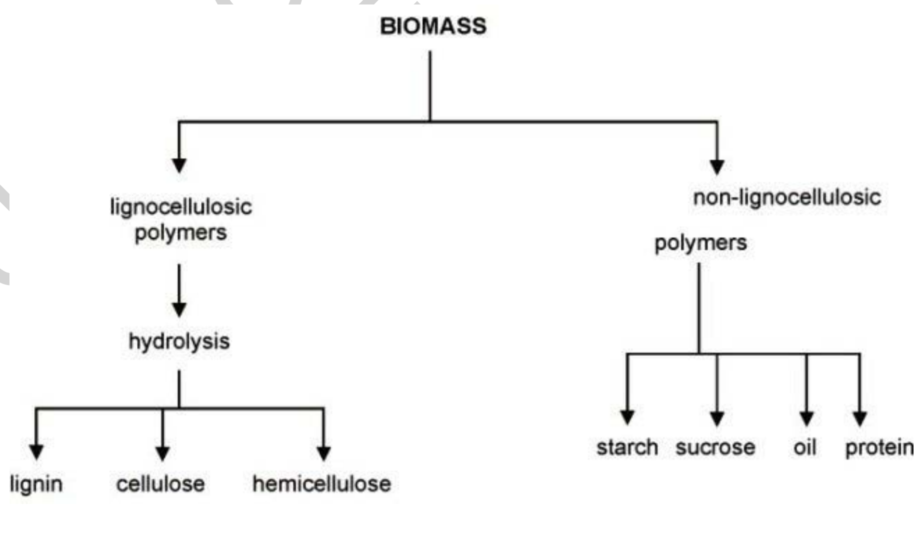

Figure 1. Biomass raw materials.

Biomass represents a useful and valuable resource to man. The value of the biomass content is related to the chemical and physical properties of its large molecules. For centuries humans have exploited the solar energy stored in the chemical bonds by burning the lignocellulosic biomass as fuel (e.g. wood) or as feed for animals (e.g. hay) and eating the non-cellulosic parts of the plant (i.e., crop) for better nutritional energy of their sugar, starch, protein and fat/oil content. The introduction of food, industrial and microbial processing of these non-cellulosic parts of plant crops for better and improved nutritional food and feed increased and varied the type of agricultural, human and animal residues, mostly referred to as waste, joining the natural cycles of matter via natural decomposition and composting (Figure 1). It soon was realised that the non-cellulosic parts of the plant were not only nutritional for humans and animals, but also for the enormous natural microbial flora important for the natural cycles of matter (see also chapter *Environmental Biotechnology*). Most of these microorganisms are beneficial for supplying nutrients to the plant and thus help in the production of new biomass, but many have also been found to be destructive to plants, humans and animals, and are referred to as pathogens.

2. Planning Strategies

2.1. Historical Development of the Clean Bioprocess Technology Concept

Technological developments in improving the quality of life for a community started with the Industrial Revolution in the late eighteenth century, and changed the pattern of consumption, land use, international trade and distribution of wealth. This still-prevailing industrial development style is characterized by production of goods and services aimed at satisfying ever-growing consumer demands of certain social groups with high purchasing power, within monopolistic and closed economies, regardless of the consequent negative impacts on the environment. Although these developments have resulted in a longer life expectancy, as industries developed better housing and sanitation, together with vaccines and antibiotics to combat diseases, they have also led to much urbanization, improved employment conditions, and so to a population explosion. Wealth and health are enjoyed by only a minority of the world's population, while a growing percentage of people, especially in the less developed countries, live on a very low per capita income.

This trend did not change with the introduction of the Green Revolution in the 1950s, aimed to help feed the rapidly growing population through increasing yields in crops such as rice, grains and many other agricultural products. In order to achieve this goal of higher production, large-scale mechanized mono-crop culture systems were introduced, forcing small farmers off the land into urban areas, and large-scale clearing of forest areas took place, to increase arable land availability. In order to maximize crop production, new chemical industries were established to produce the artificial fertilizers, pesticides and insecticides required to increase yields and combat pests. The application of these new chemicals led to a decimation of the soil microflora, resulting in decreasing soil fertility, and pollution of waterways through leaching and run-off, causing severe eutrophication and detrimental effects on our aquatic life environment.

These increasing environmental problems caused by the industrial and green revolutions, together with the realisation that 90 percent of all infectious diseases occur in developing countries, led to the call for strategies to sustain and improve our environment and agriculture. At the first environmental conference organised by the UN in 1972 it was recognised that the conservation of the environment was crucial for human life. Regulations were introduced for proper waste management or so-called “end-of-pipe” requirements. As a consequence, in terms of technological development, “end-of-pipe” technologies were commercialized for the treatment of municipal and industrial wastewater, along with remediation technologies for cleaning up contaminated soils, mainly in developed countries.

In 1987, the concept of sustainable development was introduced and defined as “Development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. This concept led to the launching in 1990 of the United Nations Program for Cleaner Production, which was defined as “the continuous application of an integrated preventive environmental strategy to processes, products and services to increase eco-efficiency and reduce risks to humans and the environment”. Its distinctive feature is that the entire life cycle of the product, from raw material extraction to the ultimate disposal of the product, is evaluated in order to reduce negative impacts. As a consequence, new factors such as globalization and competitiveness are moving industries into certification programs such as the Environmental Management System regulated by the set of international standards known as ISO 14000. These set standards are either for organizations and processes or for products. Their wide spectrum forces industries to seek new processes and products, in spite of the cost of new investment.

Despite the efforts and billions of dollars spent in the area of waste management and “new biotechnology” to help clean up the environment, poverty and infectious diseases are still prevalent in developing countries, where human and animal population growth is largest. Most clean-up procedures are implemented mainly in industries in developed countries. With the exception of a few countries in which environmental legislation is stringently enforced, most countries are still suffering severe environmental damage and health risks owing to increasing populations and subsequently animal production, lacking proper management. This situation can be explained by the fact that most industries are situated in urban areas while the plight of the agricultural and rural farming industry has not been attended to. This demands an extension of the more urban policies to rural industries. Such a development requires, however, a fundamental change in traditional industrial and economical thinking, as well as in community and governmental attitude, to a more socio-economical or socio-ecological development. It has also to be realised that processes which are economical for one nation or region may well be uneconomical and/or unsuitable for another, irrespective whether these are developed or developing regions

It should therefore be the aim of any future technological development to not only detoxify the results of the two previous revolutions, but also to reverse the trend of urbanization and develop sustainable strategies for urban and rural communities based on clean bioprocess technologies.

2.2. Future Planning Strategies for Urban and Rural Sustainability

In order to develop socio-economic strategies containing clean bioprocess technologies for urban and rural sustainability, it is very important to have a sound knowledge of the natural cycles of matter and the appropriate cultural heritage of the particular society. Furthermore, it is important to realise that these strategies, whether they occur in urban and/or rural areas, must be flexible and do vary from region to region. In addition, we have to be aware that microorganisms are the most powerful creatures in existence as they play an integral part in determining life and death on this planet. Some can cause disease and are known as pathogens, but at the same time the majority can be harnessed to sustain life. Over the past century we have managed to foster the killer-type pathogens through population growth and density, overuse of antibiotics and at the same time reduce and/or eliminate the beneficial type (e.g. soil microflora) through overuse of chemical fertilizers, pesticides, etc., and thereby reducing our biodiversity. This trend has to be reversed if we want to sustain life, i.e. our supply of food, feed, fertilizer, energy, and commodity products, without seriously affecting the environment and thus Nature's cycles of matter (Figure 2).

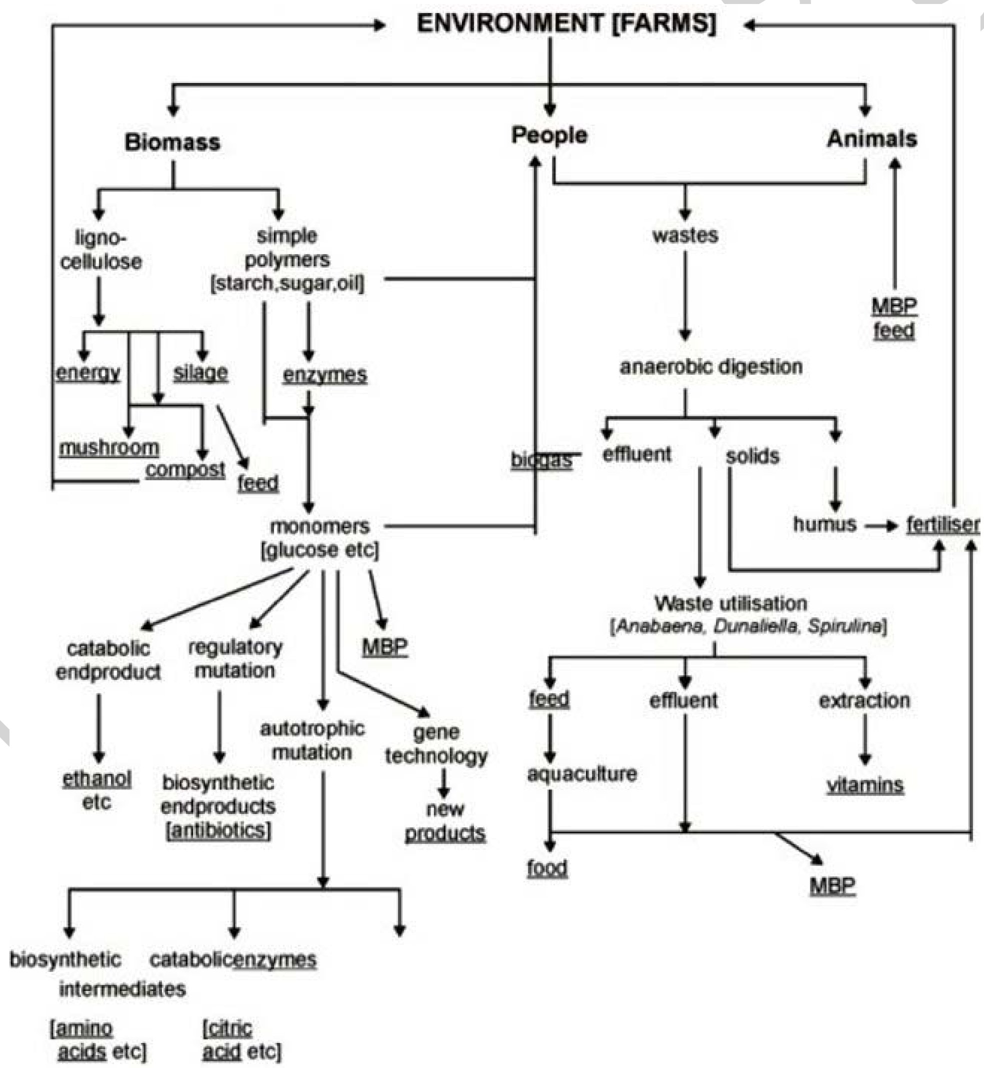

Figure 2. Processing of Biomass and Control of Pathogens Within the Concept of a Biorefinery.

We should also be aware that the production of biomass is about eight times the total annual world consumption of energy from all sources. At present, the world population uses only approximately 7 percent of the annual production of biomass, which indicates that we are only partially exploiting nature's abundant renewable resources despite the enormous expansion and expenditure in biotechnology over the past century.

2.3. The Concept of Bio-Refinery

In order to sustain life for an ever-increasing population of people, and consequently of animals, it is absolutely necessary to develop a sustainable agriculture together with optimum exploitation of the renewable resources available. It should therefore be the first priority of any region to establish so-called *bio-refineries* and/or *bio-industries*, whose raw materials are solely based on biomass and human plus animal wastes (Figure 3).

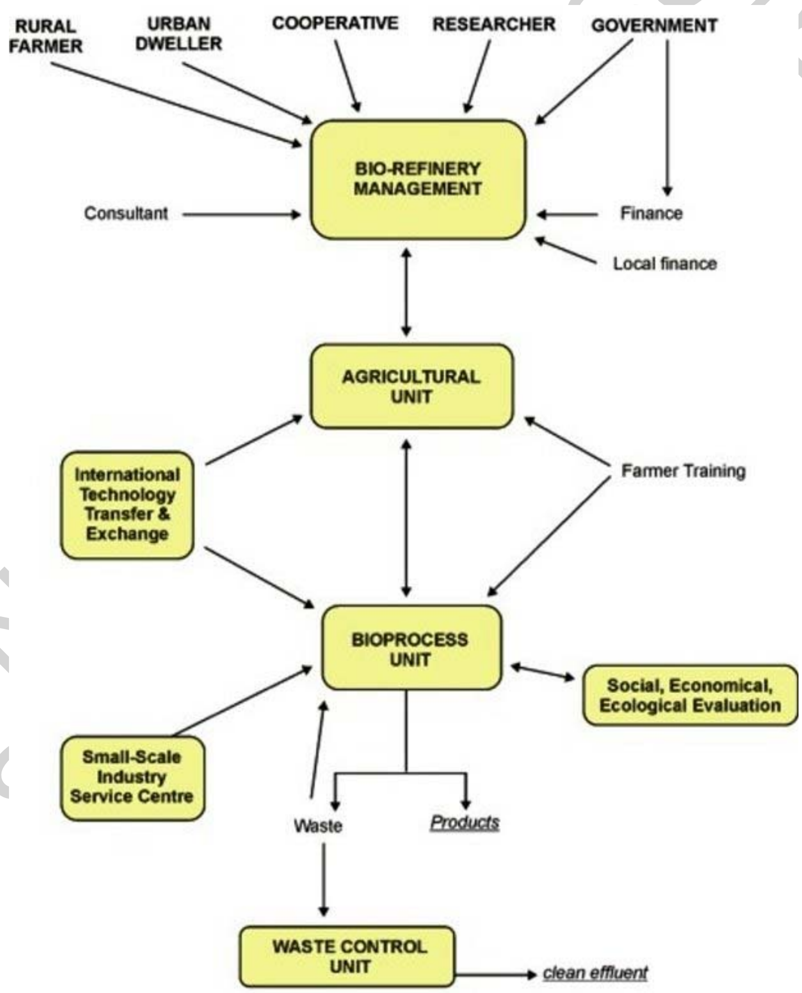

Figure 3. Concept of a Bio-Refinery Management.

The success and failure of any such bio-refinery concerned with food, feed, energy, fuel, fertilizer and organic chemical production depends, however, on the initiatives and involvement of local communities and certain government agencies. A perfect analog could be drawn with the past development and presently operational *oil-refineries* using non-renewable resources. Although the chemical composition of biomass and fossil fuels are different, it is possible to produce a similar range of endproducts from either source.

Each region should make certain that the established bio-refinery not only sustains land and environment, but also the life of people and animals in rural as well as in urban areas of that particular region. The marketing products will depend on the surplus obtained after this first priority has been satisfied.

Biomass in the form of plants and trees captures solar energy through photosynthesis (see also chapter *Cell Thermodynamics and Energy Metabolism*) and stores it as chemical energy in the bonds between the carbon, hydrogen, nitrogen and oxygen atoms that form lignocellulosic plant material and starchy, sugary, fatty as well as proteinaceous crops. Biomass is solar energy stored in a chemical form. It is the goal of each bio-refinery to use this stored energy for a sustainable development on this planet.

2.4. Bio-refinery Management

The ultimate priority of management should be to assure self-efficiency in food, feed, fuel, fertilizer and energy production for the region with a socio-economic marketing strategy. This requires a sound knowledge of

- land availability;
- biomass availability;
- biodiversity in crop production
- maintenance of high soil fertility
- maintenance of high crop yields
- population growth
- type of animal production (e.g. chicken, pig, beef, etc.)
- type and amount of any waste accumulation from the production unit, human and animal population

The bio-refinery management team should therefore consist of a “Board of Directors” representing the local communities, business, government and financial institutions, with expert advisers from local agricultural research institutions, who have expertise and knowledge on local biomass availability. Once the basis for the operation of a bio-refinery has been established, detailed crop and process development can commence.

Every bio-refinery will consist of a minimum of three basic units:

1. the agricultural production unit, which is mainly concerned with soil fertility, land utilisation, biomass production, crop yield and pest control;
2. the bioprocessing unit, which is mainly concerned with the utilisation of surplus crop and agricultural waste into value-added products; and
3. the effluent control unit, which controls and monitors all the effluent into the environment.

Any of these units may or may not consist of various sub-units and may or may not be connected with each other. It is important, however, that administration is kept to a minimum in favour of production. It is furthermore important to stress that these units should only be concerned with clean technologies, helping to sustain health of mankind and the environment, which in turn will improve the living standard of all people in urban and rural parts of the region.

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Bioenergy Information Network. *http://bioenergy.ornl.gov/*

Biofuels Program. http://www.biofuels.nrel.gov/economics.html

Biogas Forum. http://www.biogas.ch

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Biographical Sketch

Horst W.Doelle, born in 1932, studied biology at the University of Jena [1950-1954]. He studied for his doctorate at University of Goettingen [1955-1957] on antibiotic production. After receiving his doctorate, he worked in the wine and brewing industry in Germany before taking up an appointment with CSIRO in Australia in 1960. After 4 years wine research, he took up the challenge to build up microbial physiology and fermentation technology at the Department of Microbiology at the University of Queensland in Brisbane. He received his Doctor of Science in 1976 and his Doctor of Science honoris causa in 1998. He participated in and conducted numerous training courses in developing countries. After 29 years teaching he retired in 1992. His research area was regulation of anaerobic/aerobic metabolism, microbial technology [*Zymomonas* ethanol technology] and socio-economic biotechnology using microorganisms for waste management.