# Biotechnology and the Future of Human Existence

## Preamble

Mr. Vice Chancellor, Prof. Bartho Okolo, Deputy Vice Chancellors, Members of the Governing Council present, Principal officers of the University, Former inaugural Lecturers present, Distinguished professors, Other academic and non-academic staff of the University, Lions and Lionesses, Distinguished Ladies and Gentleman

I am delighted to have an opportunity to give this inaugural lecture. I thank the Vice Chancellor for the opportunity and remain ever grateful to God Almighty for His blessings and protection. I will use this opportunity to look at Biotechnology as a field that will, to a very great extent, determine the future of man on this earth and his relationship with nature. While highlighting this point, however, I will introduce what I have been doing and intend to do for the rest of my academic life.

## Definition

Biotechnology has been defined in several ways depending on the interests and objectives. For the purpose of this inaugural lecture, Biotechnology can be defined as "the application of scientific and engineering principles to modify and / or use biological materials to provide goods and services". This includes any process

in which biological agents such as organisms, tissues, cells, organelles, or isolated enzymes are used to convert raw materials to products of greater value or to degrade or remove waste materials from the environment. It also includes genetic modification of these biological agents (plants, man, other animals and microorganisms) to inculcate certain desired characteristics, thereby making them more useful or more efficient.

**Biotechnology and our future**

The pace at which the field of Biotechnology has been progressing is amazing even to Biotechnologists themselves. It is now obvious that the future of man on earth depends to a very great extent on Biotechnology because it potentially has solutions to all our problems and can also create problems that will be difficult for man to handle.

**Biotechnology has been helping to increase crop and farm animal productivity and has the potential of producing enough food to feed the world.** It is now possible to produce crops that are resistant to various diseases and pests; that can mature much faster and produce higher yields even on poor soils; crops that are more nutritious with much longer shelf-life, bio-fortified food crops, diet food stuff for diabetic patients and people that require special diets, edible vaccines from plant sources; farm animals that grow faster, produce better quality meat, cow and other animals that produce large quantities of good quality milk, birds that

lay more than two eggs every day, sheep that produce more and better quality wool etc. The application of Biotechnology has already led to several-folds yield increases in many plant species. Some of these crops/plant products have been commercialized, others are being tested in experimental farms while others are at various stages of development. It has been applied to crops like potato, rose, cotton, corn, tomato, rape seed, rice, wheat, barley, yam and tobacco. GM cassava is currently being tested in Nigeria. In fact, *in vitro* meat – edible artificial animal muscle tissue cultured *in vitro* has been developed. Even with all these developments, starvation is still a problem in the world today, partly because we do not seem to be prepared to accept GM foods as a solution to the world food problems. In order to completely become food sufficient, we must accept the technology and extend research to other crops and farm animals. The question now is how many more folds can we increase crop and animal yields? How can we increase the yield potentials (by genetic engineering) and actual yields by agronomic practices?

**Our environment can be made much cleaner and safer through Biotechnology.** It is now possible to genetically manipulate microorganisms to degrade almost any type of environmental pollutants. Plants have been genetically modified to fix more carbon dioxide and absorb other green house and acidic gases, plants that can grow under water stress have been produced and used to prevent desertification, Microalgae have been genetically modified for

increased bio-diesel oil, bio-gas and bio-ethanol production, genetic engineering has been used to produce second and third generation energy crops for efficient production of renewable energy which are environmentally friendly. In fact, most of our environmental problems can potentially be solved by Biotechnology.

**Biotechnology has been imparting positively on our industrial sector.** Most of our bio-industries can now be made more efficient by genetic modification of the biological agents used. Many metabolites of industrial importance can now be efficiently produced by genetically modified microorganisms. Continuous production of better quality wine, beer and other alcoholic beverages have been achieved by genetic modification of microorganisms and bio-process improvements. Sustained development of the world economy must be based on renewable resources for which Biotechnology is indispensable.

**The importance of Biotechnology in health care delivery cannot be overemphasized.** Microorganisms have been genetically engineered to produce human and animal metabolites such as insulin and human growth hormones. These were being extracted from cadavers and animals with the attendant risks. Many pharmaceuticals, drugs, vaccines, diagnostics and other metabolites of medical importance are now efficiently produced by microorganisms and genetically modified plants; Human gene has now been completely sequenced, making it possible to identify genes that are

responsible for various genetic diseases and those that predispose man to various diseases. Information from human genome project is now used to study and find cures for such genetic diseases as sickle cell anemia, tay-sachs diseases, cystic fibrosis, some types of cancer as well as some forms of infertility problems; Gene therapy which involves genetic modification of gamete and somatic cells is used for the treatment of various genetic diseases; Genes associated with aging have been identified and active work is currently going on, on how to slow down the aging process and prolong man's lifespan.

Like machines, our bodies experience wear and tear and as we age, some of our bodies are no more able to perform optimally. Furthermore sickness, strokes, and heart attacks can permanently damage some of our tissues and organs which must be replaced. Human organs are presently very scarce and expensive. However, Biotechnology has a great hope for us. Various human tissues and organs can now be produced artificially and transplanted to patients by a process of tissue engineering. Bio-artificial organs such as artificial heart valves, vascular tissues, skins (constructed from human skin cells embedded in collagen), blood vessels, bladder, bones, bone marrow, artificial liver device, artificial pancreas (which is used to produce and regulate insulin in diabetic patients), cartilage, and even nerve cells have been produced and used for the treatment of various diseases. In other words, Biotechnology has made it possible to produce

“human spare parts”. Efforts are now being made to extend the technology to other vital human tissues and organs (such as liver and kidney), to improve the efficiency of the already produced ones, and to make them cheap and affordable to people in the low income group. Production of human tissues and organs has been greatly facilitated by the discovery of stem cells. Unlike plant cells which are totipotent (any plant cell can be made to differentiate into any tissue, organ and whole plant), most animal cells are specialized and can produce only the same cells. However, animal (including human) cells, called stem cells have been discovered. Stem cells are undifferentiated cells with the ability to divide in culture and give rise to different forms of specialized cells. According to their source, stem cells are divided into "adult"stem cells which are multipotent, and "embryonic" stem cells which are pluripotent. Some cells are totipotent in the earliest stages of the embryo. Pluripotent stem cells can be cultivated and differentiated into more than 200 specialized cells such as skin, brain, cartilage, spermatozoa, liver, and muscle. These cells subsequently form tissues and organs which are used to repair diseased or damaged tissues. Use of human embryonic stem cell is controversial but adult stem cells are now isolated from brain, intestine, hair, skin, pancreas, bone marrow, fat, teeth, muscle and blood. These adult stem cells are used to produce vital organs and less controversial. Another Biotechnology advance that will help a lot in production of organs for humans is

cloning (this will be discussed later). Many pig organs are similar in function and size to human organs but the human body often rejects them because they contain sugar-producing genes. However, transgenic pigs without the sugar-producing genes have been cloned by using gene knockout techniques. Organs from such pigs are cheap and will save the lives of many patients who are waiting for organ transplants but cannot get human donors. Many women are not able to bear children because of defects in their womb. Some are using surrogate mothers, which has raised some ethical concerns. Research on artificial womb has reached advanced stages with various experimental animals. An artificial womb is a device that allows for extracorporeal pregnancy, (growing an embryo or fetus outside of the body of a female organism). It will be possible to "conceive" and sustain a baby in artificial womb until "birth". Genetic manipulation of embryo to produce humans with some desired characteristics is controversial but scientifically possible.

Cloning as used in Biotechnology simply means to make a copy of biological material. This can be a gene, a cell or even an entire organism. Gene cloning is less controversial since it does not involve embryo. On the other hand, cloning for the purpose of creating an entire organism or stem cells for tissue engineering has been controversial and will be discussed later. Various types of animals have been cloned from single cells. This is a technology whereby human or animal cells are fused into enucleated egg cells (eggs cells whose nucleus have

been removed) to develop into embryo. The embryo is then transferred into the uterus of a surrogate mother where it develops into a new baby. The new baby is genetically identical to the donor cell. Animals that have been cloned include sheep, rat, mice, kitten, cattle, mule, pig, deer, dog, goat, horse, rhesus monkey, buffalo and wolf. In fact, there are claims that human clones have been successfully born but such claims have not been confirmed since neither the identity of the babies nor the hospitals have been revealed for privacy and security reasons. However, if all the above animals have been successfully cloned, it can be equally assumed that the technology for cloning human beings is available. **In other words, we can assume that anybody who wants to make a copy or copies of him/her self can do so.**

**Genetic Engineering has also been used for production of biological weapons.** Highly virulent microorganisms can be constructed, mass produced and used as biological weapons. This has already been used and a lot of researches on development of biological weapons are still in progress. However, there are also many research projects on how to use biotechnology to combat bioterrorism. Biotechnology can be used to detect biological weapons, develop vaccines against them and drugs to treat or protect people against biological weapons.

Can we now imagine a world with sufficient quality food for all, a world where there is no energy scarcity; a world with very clean and safe environment with ready

cure for all the diseases threatening human existence now? A world where human beings can decide to design and "produce" the type of human he needs on earth? A world where man will be living for 150 years or even longer? Biotechnology is saying that it is possible and has demonstrated some of these. Efforts are being made to expand and improve the efficiencies. Biotechnology is indeed a key to our future. Biotechnology has the potentials of making the world a much better place for man but if not carefully controlled, it can equally destroy the world. The issue of bioethics and bio-safety will be discussed later but I wish to state here that **it is only a very small fragment of Biotechnology that raises much ethical questions. Most aspects of Biotechnology are unquestionably safe, ethical and desirable** and it is this aspect of Biotechnology that I have been researching on.

**My Research activities**

Recently, globalization of trade and establishment of free trade zones are being pursued vigorously. However, these free trade zones can only be sustained if all the participating countries have something to export so that no country will have negative balance of trade with all other countries. Each country must carve out a niche and specialize in areas where they have comparative advantage over other countries. In that case, what can Nigeria export apart from fossil fuel, which we know will one day be exhausted? Must she wait until her oil reserve finishes before developing other sectors of the

economy? Where does Nigeria have comparative advantage over other countries? How can Nigeria use her huge biological and human resources for economic and social development of the country? Where does she start from?

Nigeria's abundant renewable biomass resources can be efficiently processed or converted to various useful metabolites. Development of processes for the efficient utilization and processing of the agricultural products will definitely help in the country's economic development. Efficient processing of agricultural products into value-added products will create demand for, and thus boast the agricultural sector. Furthermore, Nigeria has good solar radiation and temperature that can support photosynthetic cell culture throughout the year. Photosynthetic cell cultivation can be used to convert the abundant and clean solar energy into many useful metabolites. This technology has been extensively explored in developed countries but in the whole of Africa, there is almost no industry that is engaged in commercial cultivation of photosynthetic cells. This is due to lack of appropriate technology that can be sustained in the region. Many fermentation and cell cultivation processes can be done without the need for very high-level technologies. Thus many bio-industries based on fermentation or cell cultivation can be sustained in developing countries.

Although most of my research works are centered on process development for efficient utilization of biomass resources and solar light energy, I have also done some

work on other aspects of Biotechnology as explained below.

**Agricultural Biotechnology**

Impact of Biotechnology on Agriculture is perhaps, the most visible in most developing countries. It is obvious that the only way of avoiding food crisis is to increase food production in proportion to increase in world population. This can be achieved by either increasing the area of land under cultivation or by increasing the yield per unit area of land. The former is difficult since land is a fixed resource and there is competition for land from other sectors. The later is therefore, the only feasible option but again improvement in agronomic practices is not sufficient to produce enough food for the ever growing world population. The only method of ensuring sufficient food for all is therefore to increase the innate ability of crops and farm animals to yield high and adapt to the ever stressful prevailing environmental conditions. Genetically modified (GM) foods are already used all over the world. These are foods from crops or animals that have been genetically modified for improved yield, increased resistance to biotic and abiotic factors, improved nutritional values, increased shelf life/keeping qualities, shortened lifespan, improved flavor and colour of the products etc. The safety and bio-ethics associated with GM foods will be briefly discussed later. Biotechnology can also be used to improve soil fertility through nitrogen fixation or production of organic fertilizers, as well as in the

production of bio-insecticides, growth hormones for farm animals, animal vaccines, and drugs.

I started my research career on Agricultural Biotechnology and worked on the physiological basis of crop improvement. The feasibility of hormonization of seeds for improved yields of Acha (*Digitaria exilis*), and cowpea (*Vigna sinensis*) were investigated (**1,2**) and the results demonstrated that simple pre-treatment of the seeds with various types of phyto-hormones such as indole acetic acid, indole butyric acid and gibberelic acid can be used to achieve several fold increases in plant yield. I also studied source-sink relationship in bambara groundnut and showed that the source (photosynthetic efficiency as represented by leaf-area index), the sink (pod initiation) as well as translocation of the photosynthetic products from the leaves to the young pods are all important physiological basis of yield determination in bambara groundnut. Unfortunately, my career in Agricultural biotechnology was short-lived as I moved to Japan and changed to the field of bio-process engineering.

**Bioprocess Engineering**

Bioprocess Engineering is a fundamental area in Biotechnology that deals with design, construction, optimization and scale up of bioreactors as well as design and optimization of bio-processes. It involves both upstream processes (cultivation of microbial, plant and animal cells and tissues for various purposes) as

well as the downstream processes (separation and purification of the products).

Immobilization of bio-catalysts and cells has many advantages over suspended cell cultures among which are: It allows for re-use of the bio-catalyst, it permits continuous cultures at high hydraulic retention time, high cell density can be achieved with consequent increase in the productivity, and it makes downstream processing very easy. I worked on optimization of cell immobilization by entrapment in polymeric materials such as alginate and carrageenan **(3,7).** The immobilization methods were optimized in terms of choice of gelling agents, concentrations of the polymers and gelling agents, loading cell concentrations and the length of incubation in the gelling agent. The optima conditions which we elucidated are now widely used by researchers all over the world. However, mass transfer limitation is a very serious problem in such systems since the gel layer serves as an additional barrier to mass transfer (transfer of the substrates and oxygen into the cell and transfer of metabolites from the cells into the culture broth and carbon dioxide out of the bioreactor). Mathematical models were used to evaluate oxygen and glucose distribution within gel beads of various diameters containing various concentrations of cells. The results showed that with the conventional large diameter gel beads, only a very small outer layer of the beads is under aerobic condition while the centre

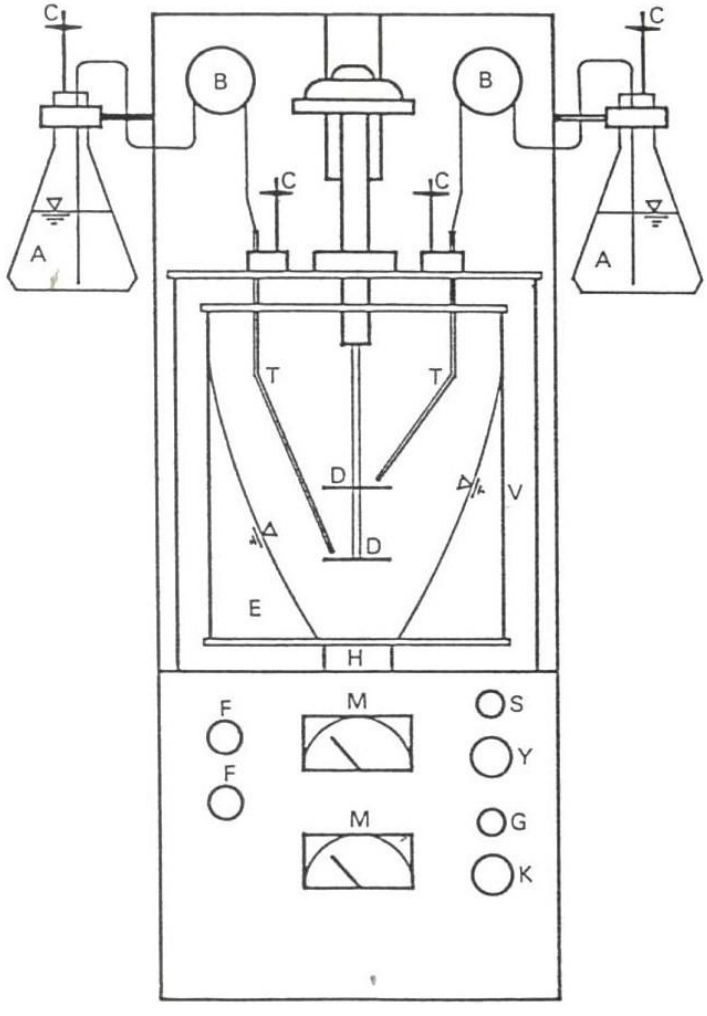



Figure 1. A schematic diagram of the rotating disk atomizer system. A: Na-alginate-cell mixture, C: Air filter; B: Peristaltic pump; F: Power switch for the pumps; D: Rotating disks; S: Power switch for the rotating disks; Y: Speed controller for the rotating disk; T: Feed nozzles; V: Glass vessel; H: Magnetic disk; G: Power switch for vessel rotation; K: Speed controller for the vessel; E: Vortex of calcium chloride; M: Speed meter

of the beads is under anaerobic condition. Thus uniform cells, substrate and oxygen distribution within the beads can only be achieved in very small diameter gel beads (micro-gel beads). As a solution to this problem, I developed and patented a system for production of micro-gel beads (**6, 8, 9, 53**).

The system comprised a rotating disk atomizer and a vortex of gelling agent. When a mixture of the immobilization carrier and the cell is dropped on top of the rotating disk, it is atomized into micro droplets which fall into a vortex of gelling agent produced by rotating the vessel. The droplets are gelled, resulting in micro-gel beads. The diameters of the beads are correlated with the flow rate, the rheological properties (viscosity and density) of the immobilization carriers while smooth and spherical beads are produced by reducing the surface tension of the gelling agent. The instrument is shown in Figures 1 and 2. It is now commercially produced by Marubishi Bioengineering Company, Japan. The instrument is used not only to immobilize aerobic microorganisms but the micro-gel beads are now used for drug delivery. Functional substances are immobilized in micro-gel beads and administered to patients for treatment of various diseases.


Figure 2. A photograph of the rotating disk atomizer for immobilization of cells in micro-gel beads. This was patented and is now commercially produced by Marubishi Bio-engineering, Japan.

Since most of the currently used carriers for cell immobilization are expensive synthetic materials and often not biodegradable, I did some screening of many natural fibrous materials for suitable cell immobilization carriers. It was found that loofa (*Luffa cylindrica*) sponge is very suitable for cell immobilization. I have successfully developed methods for immobilization of aerobic and anaerobic microorganisms; unicellular and filamentous cells, as well as flocculating and non-flocculating cells in loofa sponge. Photographs of the loofa sponge before (A) and after (B) immobilization of various types of cells are shown in Figures 3

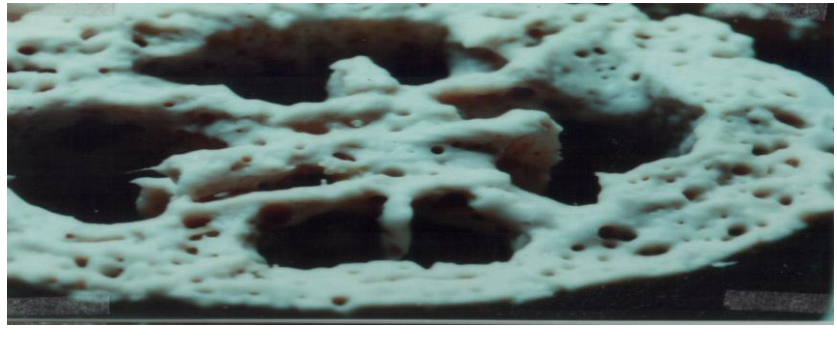
**3A**

**Loofa (*Luffa cylindrica*) sponge before immobilization**

**3B**

***Aspergillus awamori***

***Aspergillus terreus***



***Saccharomyces cerevisiae* strain IR2**

Figure 3 Photographs of loofa (*Luffa cylindrica*) sponge before cell immobilization (A) and after immobilization of various cells (B)

I have also developed bioreactors with cells immobilized in loofa sponge and a method for scaling up of bio-processes with loofa sponge as immobilization carrier (**17, 22, 31, 40, 49, 51**). Photographs of bioreactor with cells immobilized in loofa sponge is shown in Figure 4. Furthermore in order to use loofa sponge as an immobilization carrier in systems containing/producing cellulase enzymes, a method of protecting the loofa from cellulase by acetylation has been developed (**63**). The work on using loofa sponge for cell immobilization attracted grants from both Government and private funding bodies. It is interesting to note that loofa sponge is now used for immobilization of both animal and plant cells for production of many useful metabolites.

Contamination is a major problem in biological processes and the cost of sterilization and maintenance of sterility represents a significant percentage of the overall production costs. This is especially a problem in tropical regions because the relatively high temperature and humidity favour the growth of contaminants. Heat treatment is the most widely used method of sterilization but this is expensive and unreliable in Nigeria and other developing countries because of unsteady power supply. We did some work on development of fermentation processes under un-sterile conditions (**15, 16**). The system involves co-immobilization of the biological agent with vegetable oils and adding chemicals that inhibit the growth of

microorganisms but with high partition coefficient in the vegetable oil.

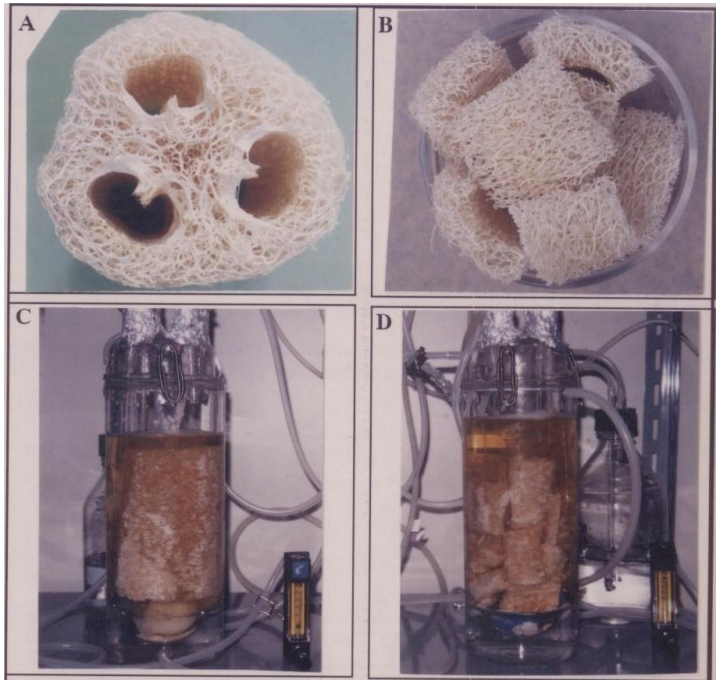



Figure 4. Photographs of cylindrical (A) and sliced (B) loofa sponges and bioreactors containing them(C and D) at the initial stage of fuel ethanol production.

Thus the inhibitory substances will inhibit the growth of free cells in the broth but does not inhibit the growth of the immobilized microorganisms. This is because the inhibitory substance is confined in the vegetable oil droplets while the immobilized cells are in the hydrophilic parts of the beads.

High density cell culture is very important because it leads to increase in the rate of product formation and also leads to decrease in the cost of downstream processing. I worked on high density cultures of an extremely thermophilic archaeon *Pyrococcus woesei* (the optimum growth temperature is $90^{O}C$) for production of thermo-stable enzymes **(10).** *E. coli* is a very important microorganism in Biotechnology because of its very simple DNA structure and very high growth rate. It is widely used in Genetic Engineering research and has been used as a host for expression of many genes for production of recombinant proteins as well as human metabolites such as insulin and human growth factors. I therefore worked on high density cultivation of this microorganism, using membrane reactors. I developed a nutrient-split feeding strategy to avoid wastage and maintain aerobic condition even at very high cell densities. A very high cell density of 183g-dry cell/L was achieved and to date, this cell concentration remains the highest reported for this microorganism **(11, 12, 14)**. Theoretical calculation based on cell morphology, water content and cell size revealed that the maximum cell concentration that can be achieved for *E. coli* is about 190g-dry cell/L.

Many biological processes involve a series of reaction steps that cannot be accomplished by a single microorganism. Such bio-processes require the use of two or more microorganisms (mixed culture) and it is often very difficult to analyze the role(s) of each of the microorganisms with a view to optimizing the process.

We developed a system for cultivation and analysis of mixed cultures using membrane reactors and hollow fiber modules **(32).** With such systems, it is possible to monitor the growth and activities of each of the microorganisms in the system and thus determine the optima conditions for the activity of each microorganism. Such a system is very useful for production of many useful metabolites as well as in the treatment of wastes that contain various contaminants that cannot be degraded by a single microorganism **(36).**

I have also developed various types of bioreactors including immobilized cell reactors, internally illuminated photobioreactors, tubular photobioreactors, circulating loop bioreactors, and an alternating liquid phase-air phase bioreactor. These bioreactors are explained and discussed under different sections.

**Industrial Biotechnology**

Simply put, Industrial Biotechnology is application of Biotechnology in Industries. In that sense, commercialization of research results from other areas of Biotechnology (Medical, Environmental, Food and Agricultural Biotechnology) can also be considered Industrial Biotechnology. However, here, I would rather restrict discussion on Industrial Biotechnology to use of Biotechnology to produce useful metabolites of industrial interest. With huge biological resources, Nigeria is in a position to produce many biotechnological products at competitive prices. However, there is a need to develop technology and

processes that are cheap, simple and sustainable in Nigeria. Biological agents in Biotechnology (microorganisms, plant cells, animal cells and their products) can be used to produce arrays of metabolites that are of industrial importance. Examples include enzymes, vitamins, amino acids, pharmaceuticals, functional proteins, food and beverages, organic acids, polymers, food additives such as, colourants, taste enhancers, and preservatives.

Potentially, Nigeria has a lot of biomass resources that can be converted into value-added products. Unfortunately, these biomass resources are not readily available in the right quantity and quality to support industrial transformation. For example, we all have the impression that we have a lot of fruits most of which rot away because of poor storage qualities. However, a pure fruit juice production company failed because of lack of orange and mango to feed the company. Maintaining consistent quality of the juice was difficult because the company depended on purchase of the fruits from various markets. There was batch-to-batch variation both in chemical/nutritional composition and state of ripeness all of which affected the quality of the product. There is a need to establish plantations of the same variety of fruits to maintain a fairly uniform quality of the fruits. Nigeria has remained the world largest producer of cassava since 2004 but cassava is still too expensive in Nigeria. The present average yield of 11 tons/hectare is still much lower than yields of more than 44 tons/hectare reported in China and Thailand. There is

therefore a need to increase our agricultural output through increase in the yield per hectare (improved varieties and agronomic practices) and increase in the land area under cultivation (less than 40% of our arable land is presently under cultivation). Those in the agricultural sector would argue that once there is demand for these produce, production will increase to meet the demand but the industrialists argue that they would not invest without being sure that the raw materials will be available in the required quantity and quality. Investing on biomass-based industrial production therefore requires long-term plan and collaboration between the industrialist and farmers.

I have done a lot of work on development of processes for production of useful metabolites from biomass resources. Processes for production of both distilled and non-distilled alcoholic beverages from pineapple, orange, sweet potatoes and yam have been developed. Some of the processes were based on immobilized cell technology which has been explained under the bio-process engineering **(4, 5)**. Sodium glutamate ("white maggi") is a taste enhancer that is produced by *Corynebacterium glutamicum*. Production of glutamate is an aerobic process, making the use of conventional immobilization by entrapment in polymer materials difficult. However, I have demonstrated that the microorganism can be entrapped in micro-gel beads and used for efficient production of glutamate. In the process, the ratio of glutamic acid to glutamine is affected by the nitrogen source **(8)**. Commercial

production of photosynthetic cell biomass as single cell protein or animal feed supplement is also very important and feasible in Nigeria **(26)** and the details are discussed under photosynthetic cell cultures.

Human beings are constantly exposed to various types of stress that lead to production of oxygen radicals which in turn leads to oxidative damage of tissues and organs. It is therefore recommended that we take sufficient amounts of antioxidants such as ascorbic acid (Vitamin C) which serve as free oxygen radical scavengers to remove/detoxify the oxygen radicals. Green vegetables are good sources of vitamin C. However, two common types of antioxidants that are commercially produced are tocopherols (Precursor of Vitamin E) and astaxanthin. Presently, commercial production of tocopherols is based on extraction from vegetable oils but concentration of tocopherols in vegetable oils is very low and the extract contains a racemic mixtures of α-, β-, and γ-tocopherols. Depending on the use, there is a need to separate and purify the most active α-tocopherol. *Euglena gracilis* is known to accumulate high concentrations of tocopherols and more than 98% of the accumulated tocopherol is in the α-form. I therefore worked on the development of processes and optimization of culture conditions for efficient production of tocopherols by *Euglena gracilis*. I demonstrated that heterotrophic cultures using various organic carbon sources **(29)** as well as sequential heterotrophic \ photoautotrophic cultures **(33)** can be used for efficient production of α-

tocopherol. In mixotrophic (photoheterotrophic) cultures, both heterotrophic and photoautotrophic metabolic activities function simultaneously. I demonstrated that under such conditions, cell growth is mainly controlled by heterotrophic metabolism while α-tocopherol synthesis is controlled by the photoautotrophic metabolic activities. It is therefore very necessary to control the ratio of the two metabolic activities in order to achieve high α-tocopherol productivity **(44, 45, 47)**. In such systems, improved productivity can be achieved by selecting appropriate carbon sources **(66, 67)**, as well as by addition of reactive oxygen species **(69, 70).** *Haematococcus pluvialis*, a micro-alga, can also be used for production of another important anti-oxidant (astaxanthin) and I worked on a two step culture system for efficient production of astaxanthin by this microalga **(41).** Furthermore, various useful metabolites such as ethanol, and lactic acid can be produced from cassava starch **(49, 51).** An alternating liquid phase-air phase bioreactor was developed for efficient enzyme production. Amylase enzyme production, for example, is an aerobic process and productivity is usually low in suspended liquid culture due to oxygen limitation. A system whereby the immobilized cells are cyclically exposed to the air to "breath" and submerged in liquid broth to absorb nutrients and extract the enzyme was developed. When this system was coupled to an immobilized yeast bioreactor for ethanol production (Figure 5), ethanol productivity remained very high for more than 600 h

I wish to emphasize here that Nigeria can be sustained as a nation by only Biotechnology Industries. We have the potentials to produce enough raw materials to feed the industries, the required technology is affordable and we have large market both locally and internationally. All we need is the will and determination to develop the sector.

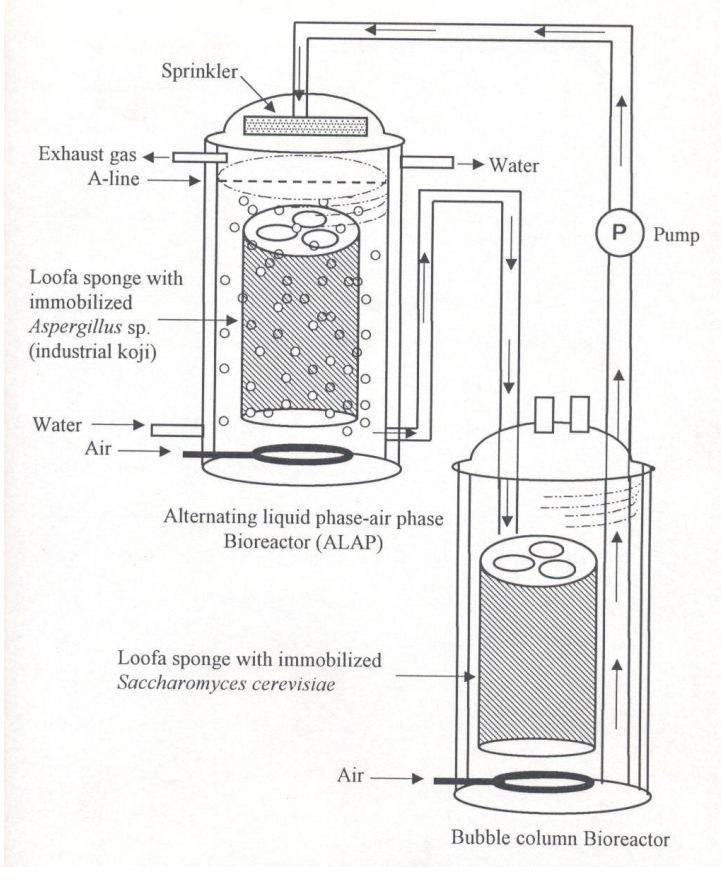



Figure 5. An Alternating liquid-Air phase bioreactor for efficient aerobic enzyme production.

**Environmental Biotechnology**

The current environmental problems facing the world are due to air, water, and soil pollutions resulting from human activities. Water and soil pollutions are often local in nature and there are greater commitments to their prevention, and when they do occur, government and people in the affected area are more prepared to deal with them. On the other hand, air pollution is global in nature because the pollutants are carried far away from the source and the effects (acid rain, global warming, ozone depletion, etc) are global in nature. Biotechnology can be used to minimize environmental pollution by producing environmentally friendly alternatives such as bio-insecticides, bio-fertilizers, bio-degradable plastics and bio-energy. Production of insect/disease-resistant crops and animals will also help to reduce the use of insecticides. Also the use of crop varieties that can yield well in poor soils reduces the use of fertilizers that are major sources of contaminants. Furthermore, Biotechnology is used for bio-remediation of polluted environments (air, soil and water) by *in-situ* (bio-stimulation, bio- augmentation, phyto-remediation etc) or *ex-situ* (as in the case of water, wastewater and air purification systems).

Although I am not an environmental Biotechnologist, I am interested in the environment and have tried to use the bio-processes I developed for environmental monitoring and remediation. For example, I developed a system for simultaneous

removal of organic acids, nitrogen and phosphorus from wastewater by mixed culture of photosynthetic microorganisms(Photosynthetic bacteria, Cyanobacteria and green algae) **(36)** and have also demonstrated that photosynthetic microorganisms can be used for environmental monitoring **(37).** Systems for efficient cultivation of *Bacillus thuringiensis* for control of mosquito have been developed and the efficacy demonstrated in Afikpo, Ebonyi State **(62, 63).** Lipase production for treatment of Palm Oil Mill Effluent (POME) have also been developed **(68)**.

Photosynthesis is the natural and still the most efficient means of reducing the atmospheric carbon dioxide concentration which is one of the most important green house and acid gases (in terms of volume). Although there are efforts to reduce them by afforestation/planting of trees, it is known that microalgae are far more important in carbon dioxide fixation than green plants. For example, the amount of carbon dioxide fixed by a photo-bioreactor with a working volume of $4.3m^3$ is equivalent to the amount fixed by one hectare of forest (assuming a productivity of 1g/L.d). Also depending on the species used NOx and SOx fixation can be efficiently done with the photobioreactors. Thus, most of the systems and processes I have developed for cultivation of photosynthetic microorganisms are good for carbon dioxide fixation. Details of these systems are discussed under solar energy utilization.

**Medical biotechnology**

Biotechnology is used to improve health care delivery. Some aspects of Medical Biotechnology are based on fundamental research on human being such as the human genome project, human cloning and stem cell cultures. Such basic research provides basic knowledge useful in the improvement of health care delivery. Specific examples include Reproductive Biotechnology (test tube babies, artificial womb), gene therapy, tissue engineering for production and transplanting of artificial organs as highlighted earlier.

Some of these aspects of Medical Biotechnology have generated a lot of ethical issues which I will discuss later. However, production of pharmaceutical and therapeutic agents, as well as biological control of pathogenic/disease carrier organisms are also considered as parts of Medical Biotechnology and it is on this aspect of Medical Biotechnology that I have done some research. Examples include production of tocopherols **(29, 33, 44, 45, 47, 66, 67, 69, 70),** production of astanxanthin **(41)**, and control of mosquito larvae **(62, 63).**

**Bio-energy production**

With increasing demand for energy, continuous depletion of the world fossil energy reserves, and various environmental problems such as climate change, global warming , soil, water and air pollution associated with the use of fossil fuel, there is an increasing pressure for development of renewable and sustainable

alternative sources of energies. The world fossil fuel reserves have been estimated to last for less than 50 years from now and there is urgent need to develop alternatives. The concepts of “green development”, and “sustainable development” have been conceived and vigorously pursued by various countries and organizations. Bio-energy (energy from biomass materials) has very good potentials as a substitute for the fossil fuels because they are renewable, sustainable and environmentally friendly (little or no pollution of environment).

Bio-hydrogen (hydrogen produced by biological processes) is the cleanest type of energy. Unlike other fuels whose combustion leads to production of acidic and greenhouse gases ($CO_2$, SOx, NOx etc), water is the only by-product of hydrogen combustion. However, production of bio-hydrogen is still expensive because the conversion efficiencies for all the known biological systems are still low. There is also the problem of transportation and storage of bio-hydrogen. One method of improving the efficiency of bio-hydrogen production is to develop efficient photo-bioreactors for photoautotrophic or photoheterotrophic production of bio-hydrogen. I have developed an internally illuminated photobioreactor with high light supply coefficient, and have demonstrated that it can be used for efficient production of biohydrogen because of uniform light distribution inside the reactor **(30, 38)**.

Bio-ethanol is another good alternative to fossil fuel. It was initially used as an octane enhancer but since the

oil-shock of the 1970s, bio-ethanol has been commercially produced as liquid fuel for various engines. Most car engines can run on gasohols (blends of gasoline and ethanol in various proportions) but some engines that can run on 100% ethanol have been developed. The raw material used for production of bio-ethanol depends on the region/country. For example, while most of the bio-ethanol produced in Brazil is from sugar cane, in United States, most of the bio-ethanol is produced from corn, India uses molasses, and sugar cane, some parts of Europe use sugar beet, while China uses corn and cassava. There is a general concern that food crops should not be used for fuel production because of its possible effects on food security. However, since the technology for bio-ethanol production from non-food crops is still inefficient, most countries are still using food crops as the substrates for bio-ethanol production. Whether food crops or non-food crops are used, the net result is that there will be competition for farm land and agricultural input. Thus, the important thing is the amount of bio-fuel that can be produced from a given land area and agricultural input. Furthermore, the choice of the crops will depend on the region and socio-economic conditions of the region. If our fossil oil is exhausted, we will not have any alternative but to produce energy from what we have. Presently, I think that an average Nigerian will suffer more from increase in the price of fuel (because the prices of all other commodities will increase) than increase in the price of one food item. It is obvious that

with the current crude oil price of more than one hundred dollars per barrel, the actual gasoline price in Nigeria would be more than one hundred naira per liter. In other words, the current official price of N65/L is due to the Federal Government subsidy and one should imagine the prices of other items in Nigeria if the official price of gasoline is increased to N100/L.

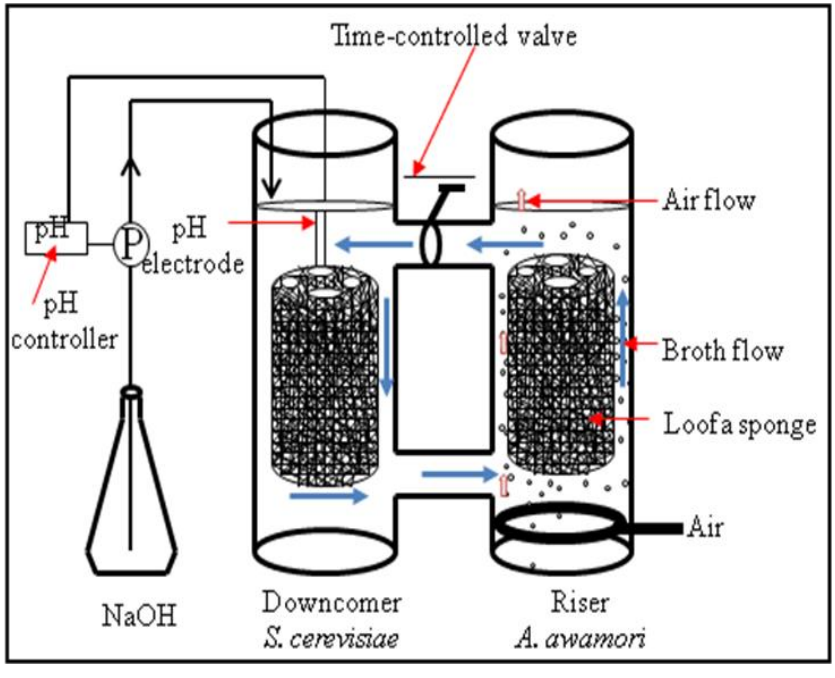



Figure 6. A schematic diagram of a circulating loop bioreactor with cells immobilized in loofa sponge for simultaneous aerobic and anaerobic processes

Nigeria has abundant unfarmed arable land which can be used for large scale production of high energy crops.

I have worked on fuel ethanol production from sugar materials by cells immobilized in loofa sponges **(25)** and developed a method of scaling up the process **(40)** with very high productivity of 6.5g/L.h. I also developed a circulating loop bioreactor for bio-ethanol production from cassava starch using immobilized fungi and yeast cells **(49).** As shown in Figure 6, *Aspergillus awamori* is immobilized in aerated chamber for amylase production while *Saccharomyces cerevisiae* is immobilized in the un-aerated down-comer chamber for bio-ethanol production. The amylase produced in the aerobic chamber hydrolyzes starch to glucose which is then converted to ethanol in the anaerobic chamber. I have reviewed the whole ethanol production process from various raw materials, as well as current technologies **(54, 55)**, and have made pragmatic economic analysis and highlighted the potentials of sustainable energy production from various materials in Nigeria **(74)**.

**Development of technologies for efficient solar light utilization**

Solar light energy is one of the most abundant natural resources in the globe. The total amount of solar energy reaching the earth surface is several times higher than the total energy consumed in the world today. Most of this solar light is concentrated within the tropics where the temperature is also favourable for outdoor cultivation of photosynthetic cells throughout the year. I have been working on development of systems for

efficient biological fixation of solar energy through photosynthetic cell cultivation. Many photosynthetic cells contain more than 60% protein and a lot of vitamins and minerals. Thus, they are excellent sources of many nutrients that are lacking in the diet of many Africans. Most of these cells are currently produced in many developed countries as health food, animal feed and for extraction of many fine chemicals and pharmaceutical products such as β-carotene, astaxanthin, and food colorants. The climatic conditions in most African countries are favourable for photosynthetic cell cultivation but unfortunately, most of the systems are either too expensive or not appropriate for tropical developing countries. Thus, I have been working on development of appropriate photobioreactors and systems for efficient cultivation of photosynthetic cells within the tropics.

I developed a photosynthetic cell growth index and proposed a concept of "light supply coefficient" as an engineering parameter for design of photobioreactors and evaluation of light conditions inside photobioreactors (**18, 19, 20, 39**). This index was found to be very good for photobioreactor design and scale up. Using this index, an internally illuminated photobioreactor was designed, constructed, and a method of its scale up proposed (**21, 27, 35**). A schematic diagram of this photobioreactor is shown in Figure 7. This scale-up method has been validated by scaling up a photobioreactor while maintaining the light supply coefficient constant.

Night biomass loss is a major problem when only solar light is used for photosynthetic cell cultivation. I have investigated night biomass loss and changes in the biochemical composition of cells under day/night cycles (**23**) and designed a system where the solar light energy is supplemented by artificial light. The illumination system switches automatically from solar light to artificial light whenever the solar radiation decreases below a set value (**34**). For cells with heterotrophic metabolism, I have developed a cyclic photoautotrophic /heterotrophic cultivation method by which the cells are cultivated photoautotrophically during the day and a specified amount of organic carbon source is added at night for heterotrophic culture. This system has been tested with *Chlorella* and *Euglena* cells (**28**). Furthermore, an integrated system of solar light, artificial light, and organic carbon source has also been developed for efficient cell cultivation in localities without steady weather and electricity supply (**42**). When the solar light intensity is high, solar energy is used but when the solar light intensity decreases below a set value, the system switches to artificial light or organic carbon source depending on the optimum light/dark ratio for the process.

As a means of improving the productivities of systems for production of metabolites whose syntheses are induced by light, I have developed a sequential heterotrophic/photoautotrophic cultivation process for photosynthetic cells. In this method, the cells are cultivated heterotrophically to high cell concentration

and then subjected to photoautotrophic condition for accumulation of desired intracellular metabolites (**26, 33**).

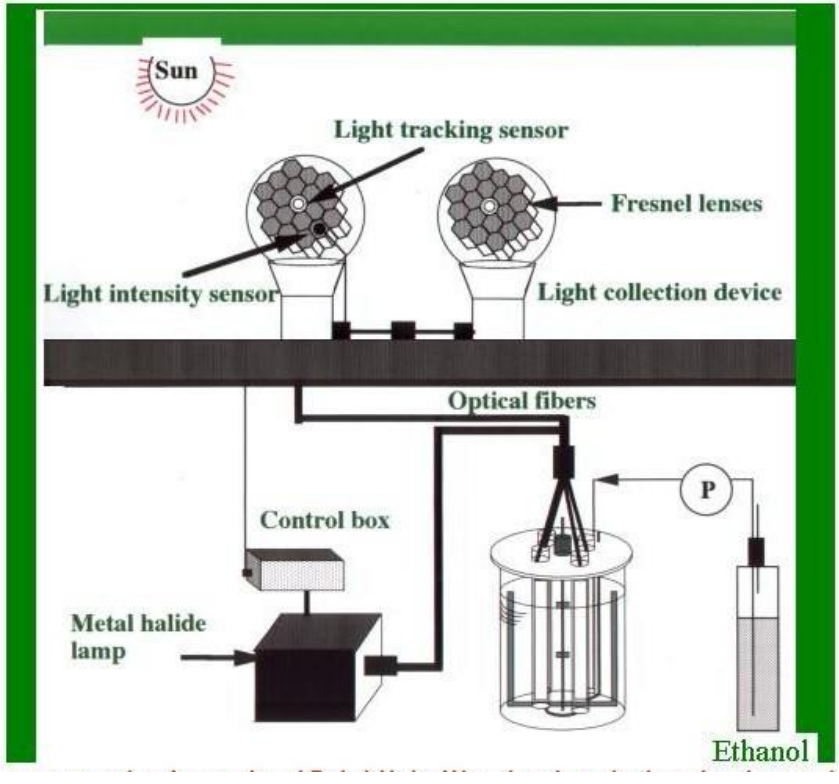



Figure 7. An internally illuminated photo-bioreactor . The solar light is collected by fresnel lenses and transmitted into the in-door photo-bioreactor through optical fibers. The solar light collection device is equipped with light tracking sensor which rotates with the position of the sun. The energy source to the photobioreactor changes automatically between solar light, halogen lamp and ethanol depending on the weather condition.

Another method of utilizing both the photoautotrophic and heterotrophic metabolic activities in photosynthetic cells is to simultaneously supply both light and organic carbon source to the culture (mixotrophic culture). In this system, it is very important to regulate the two metabolic activities (**44, 45**).

One major limitation of internally illuminated photobioreactors is the high construction and operation costs. Tubular photobioreactors are simple, cheap and efficient and are therefore suitable for developing countries. Various types of tubular photobioreactors have been designed, each of them suitable for specific location and product (s). However, mass transfer is a major technical challenge in designing tubular photobioreactors since carbon dioxide limitation and oxygen built up limit cell growth especially with increase in the length of the tube. We have demonstrated that mass transfer efficiencies in tubular photobioreactors can be improved by installation of static mixers (**46**), and optimized the static mixers in terms of shape, number, size and distribution of holes (**50**). The static mixers could be used to induce light/dark cyclic movement of *Synechocytis aquatili* for improved biomass productivity (**56**) and also used for efficient cultivation of *Chlorella sorokiniana*(**58**). A photograph of the tubular photobioreactor with static mixers is shown in Figure 8

**Future research plans**

Education is conversion of money into knowledge but innovation is conversion of knowledge into wealth. The extent of knowledge-based economic development is therefore determined by the innovation profit margin which is the amount of wealth generated through innovation minus the amount of money spent on education. Education without innovation can be likened to a trader who likes to stock his shop with various goods without bordering to sell them.

Figure 8. Photograph of tubular photobioreactor with static mixers for improved mass transfer.

We academics should therefore not be satisfied by just publishing our results. We must make effort to ensure that those results make it to the market. I hereby

propose a concept of "one man one product" where by an academic should aim at bringing at least one product (singly or in collaboration with others) to the market before he retires. Each academic, depending on the area of specialization, should aim at advancing the area sufficient enough to take a product, service or technology to the market. In other words, there should be practical application of at least one of his research results before he retires. This, of course, can only be achieved if there is a closer collaboration between the government, academia and the industrial sector. Collaboration among academics in different fields of research is also very vital. The government must play a role of a match maker, by facilitating collaboration between the academia and the private sector. The concept of impact factor is a measure of the extent research results impact on the society. Although presently citation index is the main index used to evaluate impact factor, there is a need for each country to develop a means of measuring the impact of her research results on the society, and in the case of developing countries, commercialization of research results is definitely a very good index which must be used to evaluate staff for promotion.

I believe that development of bio-industries is pivotal to economic development of Nigeria and will thus continue to work on development of various practical systems for efficient utilization of the abundant biomass resources in Nigeria. I have produced various types of alcoholic beverages from yam, maize and sweet

potatoes. The products are unique, tasteful and rated very high by those who have tasted them. Economic analysis has shown that commercial production of the alcoholic beverages from these crops is very feasible. I am therefore looking for investors/business men to start commercial production of "Yammy" alcoholic drinks produced from yam. It is also my dream to commercialize fuel ethanol production from our abundant biomass resources as well as commercial process for cultivation of photosynthetic cells for various purposes. These research projects are on-going and their commercialization will remain my research focus throughout my academic career.

**Bio-ethics and Bio-safety**

Biotechnology is a field of study that has been misunderstood by many people because of some ethical issues associated with some aspects of Biotechnology, especially those that involve human cells, tissues, organs and life. The relationships between Human being and God, Science and Religion are very sensitive and very often interpreted from different angles depending on who, what, where, and why.

Genetic modification of organisms has been occurring naturally and what Biotechnology is doing is to hasten the rate of such modifications. However, those who oppose genetic engineering of organisms argue that we should allow nature to continue at its pace. They refer to a statement that "nature has solutions to all its problems". In other words, there are natural solutions to

all natural problems. However, our nature is no more "natural" and the present world problems can no longer be left for nature to solve. The existence of Human beings on earth and his activities have created a lot of problems which cannot be regarded as natural problems. The present economic, social, health, environmental, energy, and food problems on earth are all directly or indirectly caused by humans. The problems of food and energy shortages are due to the steady increase in human population, and thus increase in demand for these vital commodities. Both local and global environmental problems such as depletion in ozone layer, and global warming are due directly or indirectly to human activities. The steady increase in atmospheric carbon dioxide concentration is due to excessive combustion of fossil fuels for transportation and other industrial activities. The birth rate in most developing countries is still very high. Even some developed countries with very low birth rates are seeing it as a problem because of the consequent aging of the society and shortage of working class population to man the economy. Thus, they are now encouraging couples to give more births by providing various incentives. Where such incentives do not produce the desired results, they adapt immigration policies that will encourage needed talented immigrants from other (mainly developing) countries. Yet, the average life expectancy has been increasing steadily and has reached well over 80 years in many developed countries. This is even expected to increase further due to better

healthcare delivery. It is therefore obvious that the world population will continue to increase with the associated problems. Sustainable development is now preached, which according to the United Nations is "development that seeks to meet the needs of the present without compromising the ability of the future generations to meet their own needs". Sustainable development requires both technological development .and more importantly, attitudinal change. It requires that we change our life style by consuming less and polluting less. Unfortunately, many of us are not willing to do that. In fact, the present world economy is sustained by "produce more and consume more", and every economy is pushing for increase in demand. On average, a car owner in Nigeria would use 20 L of fuel in a week (1040 L in a year) and emits 2.36 tons of carbon dioxide in a year (assuming that one liter of gasoline produces 2.27 kg of carbon dioxide). How many of us who can afford to buy a car would rather use a bicycle just to conserve our fossil fuel and reduce air pollution? The point I want to make here is that as long as man wants to multiply and live affluent life style, man must find solutions to the associated problems. Just as nature has solutions to natural problems, man must find solutions to man-made problems if he is to continue to exist and create the problems. Biotechnology is used to assist nature cope with the problems caused by man. If we do not use Biotechnology to increase food production, for example, which environmentally friendly and feasible alternatives

do we have? The only alternative we have is to reduce the world population and the quantity of food consumed by each individual. Are we willing to do that?

Ethics is simply a guide to distinguish between right and wrong or good and evil. It involves deciding what should be done, and the right way (how) they should be done. Based on ethics, there are: a) things we can do and should do, b) things we can do and should not do, c) things we cannot do but we should do, and d) things we cannot do and should not do. Scientists are worrying about those things they cannot do, studying and researching to know how to do them. However, bio-ethics is concerned with determining the things we should do, those we should not do and the best way to do those things we should do. Biotechnologists have demonstrated a lot of things they can do but the society does not seem to be sure whether they should be done or not. In the case of human cloning, for example, some people have described it as a "terrible knowledge", or "Science that frightens Scientists" The decision on whether or not to continue with some of the controversial advances in Biotechnology is very difficult because the society is often biased, myopic or un-informed about the science and their consequences. Decisions should be based on facts rather than emotional reactions. Thus, those who make decision should have a sound knowledge of the issues involved. Often a time, religion, politics and economic considerations dictate our views on ethical issues. Sometimes, selfishness is even highlighted in our views

on some ethical issues. For example, those who do not have health problems are likely to condemn xeno-transplanting, gene therapy and some Biotechnological approaches to health care delivery because they do not need them. Those who do not have fertility problems are likely to condemn some reproductive Biotechnology. However, it is very important that we follow the ethical guidelines on decision making. One of such guideline is "motive, action and consequences". Before we accept or reject any action, we must consider the motive, the action and the consequences of such an action. Two actions may have the same motives and consequences but one is considered ethical while the other is condemned because the actions are different. Again, a single action may be considered ethical or condemned depending on the motive. Another important thing on ethical decision making is that we must consider the effects on the first person, second person and the third person (which includes the environment, and even how God thinks about our action). Bio-ethics is not religion and it is very important that our stand on issues is selfless, and based on accurate information and knowledge – not based on sentiment, and selfishness. Presently, world organizations have condemned (at least for now, based on our present knowledge) some aspects of Biotechnology such as human cloning. Again based on the scientific knowledge, motives and consequences, some aspects of embryonic stem cell culture and gene therapy involving embryonic cells are condemned while others are encouraged. It is becoming obvious that there

are some "unwanted" knowledge. In other words, we should not make effort to know how to do those things that we should not do. We must guide science towards the enhancement of human dignity and thus should not pursue science that will de-humanize man or that tantamounts to playing God. At the same time, we should not hurriedly throw away the child with the dirty water. I wish to state here that based on the above ethical decision guidelines, **most aspects of Biotechnology are considered ethical, desirable and highly encouraged.** The world can no longer do without them, they can be considered a "must have" technology and Nigeria must pursue it before it is too late. There should be active interactive Bioethics forum for exchange of information and views on various aspects of biotechnology so that National decisions are taken based on sound knowledge of the science and the consequences.

The issue of Bio-safety is also of great concern in Biotechnology. The safety of the various Biotechnological activities, goods and services must be properly evaluated. Unfortunately, again, views expressed by some groups and countries on Bio-safety are apparently guided by politics, economics or ignorance. The issue of Genetically Modified (GM) Foods has been the subject of many conferences and workshops. Determining the safety of GM foods is straight forward if it is based on scientific knowledge but there is still controversy over labeling of GM foods. What is important in product labeling is the content of

the product and not how it was produced. Therefore if GM foods are substantially similar to non-GM foods, there is no need to label them since "GM" is an attribute of how it is produced and not what it contains. Again the concepts of "safe until proved unsafe" or "unsafe until proved safe" are both applied depending on who and what are involved. These non-scientific-based judgments bring a lot of confusion to the less informed population.

The question of whether to accept GM foods or not is more complex since aside from the safety, the effects on the environment, on bio-diversity, possible negative effects on our Agriculture, especially in terms of sustainable production (if we have to depend on other countries for supply of seeds, planting materials and farm animal breeds) must all be considered. A cartoon which I published in 2003 in one of the Biotechnology Magazines is shown in Figure 9. The cartoon does not imply that Nigeria or Africa should accept GM food just because of hunger. However, many people have hastily condemned GM foods without good scientific evidence or without due consideration of the safety and socio-economic implications of accepting or rejecting them. Ethical decision requires interactive Bioethics where the views of all the people affected by such decision must be considered and respected.

Those who are rich and can afford to pay much higher for foods are likely to reject any food that they are not sure of, without bordering to confirm the safety.

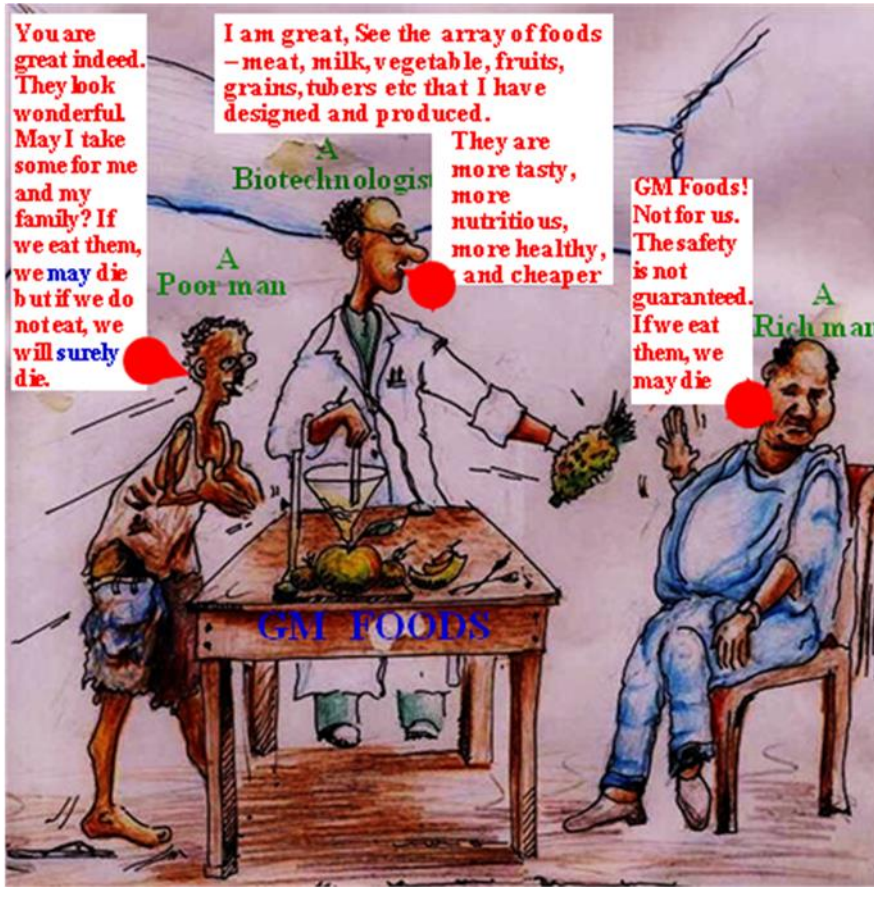



Figure 9. Ethical decision making on acceptance of GM foods

On the other hand, the poor ones would want to make sure that such food is not safe before rejecting them. Those who are involved in decision making should try to have the scientific facts and consider all those who will be affected by the decision before taking a stand. Again, we need to consider our peculiar situation and not accept just because other countries are accepting.

We must not allow ourselves to be left behind in the "Biotechnology race". It has been said that in the 19th Century, those who did not follow were left behind but in the 21st Century, those who do not follow are dragged along. It is never easy to be dragged along.

The world is becoming a global village, with free flow of goods across country boarders. Nigeria is said to have "porous boarders" and it has not been easy to prevent unwanted goods from entering the country. Furthermore, Nigeria does not yet have political and economic power to resist both domestic and international pressures to open her boarders for inflow of products and services that are judged safe and ethical in other countries. The safety (to humans and animals) of GM foods and their environmental impacts are global issues. Although different countries have different capabilities of tackling problems, it can be assumed (with reasonable degree of certainty) that what is safe for indigenes of one country is safe for indigenes of other countries; what is safe for one environment may be considered safe for other environments (there are some exceptions). There are very strict international/ national safety guidelines for release of GM crops/animals and GM foods that have passed these international guidelines can be considered safe for Nigerians as well. It is on this basis that Nigeria accepted trials of Genetically Modified Foods. However, the issue of the effects of introduction of GM foods on Nigerian food security must be addressed. Nigeria must not be completely dependent on foreign countries for

seeds, planting materials and animal breeds. For this, there is a need for strong Biotechnology R and D Programme in Nigeria. Nigerians should be involved in the development of GM crops/animals for Nigerian farmers.

**Biotechnology education in Nigeria**

There is a proverb that a goat fed by the public dies of starvation. Almost everybody in the Biological Sciences can claim to be a Biotechnologist. However, very few are actually committed to Biotechnology Education in Nigeria. Most of the people involved in Biotechnology education in Nigeria are more committed to their traditional subject areas/departments than in Biotechnology.

The importance of Biotechnology has been highlighted. However, for any nation to benefit from the vast potentials, there must be a solid education on the various aspects of Biotechnology. Unfortunately, there has been misunderstanding even among the Nigerian "Biotechnologists" as to whether there should be an Undergraduate Programme leading to a degree in Biotechnology. Some were of the opinion that, Biotechnology should only be taught as a course(s) at undergraduate level and offered as one of the degree options at postgraduate level in the Faculties of Biological, Pharmaceutical and Agricultural Sciences. This view is in sharp contrast to what is happening in the developed countries. For example, The Google Biotechnology Degree Guide lists more than two

hundred Universities in the US alone offering degree programmes in Biotechnology. Later some came up with the view of having it as an option in undergraduate programmes. This led to establishment (renaming) of some Departments such as Department of Plant Science and Biotechnology (University of Port Harcourt), Department of Plant Biology and Biotechnology (University of Benin), Department of Genetics and Biotechnology (University of Calabar), Department of Microbiology and Biotechnology (Caritas University), Department of Biochemistry and Biotechnology (Previously in Ebonyi State University), and Department of Applied Biology and Biotechnology (Enugu State University of Science and Technology). In these Universities, the curricula (courses offered) do not differ much from the curricula used in the traditional base departments, (only that a few courses in Biotechnology are added). However, many Universities have now established full-fledged Departments of Biotechnology. These include Ebonyi State University, Federal University of Technology Owerri, and Federal University of Technology Yola. From JAMB brochure, there are now 12 universities offering B. Sc. or B. Tech. in Biotechnology, 7 Universities offering B. Sc. in Plant Science and Biotechnology, 2 Universities offering B. Sc. in Genetics and Biotechnology, 2 Universities offering B. Sc. in Microbiology and Biotechnology and 1 university offering B. Sc. in Applied Biology and Biotechnology.

Although these Programmes have been given accreditation by NUC, there is not yet any NUC-approved curriculum/ bench mark (minimum academic standard) for Biotechnology Programmes in Nigerian Universities. The curricula used by these Departments differ widely. NUC constituted a committee to draft Biotechnology curriculum but I do not know the outcome of the committee. I championed the establishment of Biotechnology Programme in Ebonyi State University and sent a copy of the curriculum to NUC but I do not know if they are making use of it or not. Biotechnology Society of Nigeria also constituted a committee to draft a curriculum which could be recommended to NUC. I was the chairman of the committee and a copy of the curriculum has been forwarded to NUC. We are still awaiting NUC's reaction and hope that they will approve a curriculum as soon as possible. Biotechnology deserves a full-fledged Department or at least a degree programme as is the case with many Universities overseas. Introducing a few Biotechnology courses to the curricula used by the various Departments in the Faculties of Biological Sciences and other related Faculties is definitely not sufficient to produce graduates that will pilot Biotechnology Research and Development in Nigeria. The scope is wide, and there are many fundamental and core courses that cannot be integrated into the existing curricula of other Departments. Furthermore, Postgraduate curricula are already too narrow and specialized to accommodate most of those core courses

in Biotechnology. I am therefore looking forward to the time NUC will approve an undergraduate curriculum for Biotechnology in Nigerian Universities. Nigeria urgently needs NUC-approved curriculum and minimum academic standard for Biotechnology Programmes in Nigerian Universities.

**Conclusion**

It is clear that no Nation can develop or maintain its present state of development without investing much in Biotechnology Research and Development. The developed countries have been spending a lot on Biotechnology Research and Development. For example, United States alone spent more than sixty billion US dollars on Biotechnology Research and Development in 2007, while in 2005/2006 Canadian Government's 861 million dollars expenditure on Biotechnology Research and Development represented about 9% of all her expenditure on Science and Technology. Most other developed and even some developing countries have been steadily increasing their spending on Biotechnology Research and Development. Nigeria is still lagging far behind even among the developing countries in Biotechnology Research and Development. Nigeria is making commendable efforts on policy issues (Bio-safety Bill etc) but much is expected on Research and Development.

The only people in this hall who have not benefited from Biotechnology are those who have never eaten garri, popcorn, or bread, those who have never taken

beer, wine, or any alcoholic beverage, those who have never taken antibiotics, antioxidants, or drugs of plant, animal or microbial origin, those that have never been immunized against any disease. Those who do not want to advance Biotechnology R and D are those who do not want sufficient quality food; cheap, sustainable and environmentally friendly energies, safe and clean environment, better health care delivery, and thus longer healthier and happy life.

**Acknowledgments**

Finally, I wish to use this opportunity to acknowledge the Educational Institutions, teachers, colleagues, students and family members who influenced my academic carrier in various ways.

I started my Primary School in January, 1965 at St Peter's Primary School Umachi, but my primary school education was interrupted in 1967 by the Biafran civil war. After the war in 1970, those of us who were in Primary 3 in 1967 were all advanced to Primary 4. In July, 1971, I lost my mother so when I completed Primary 5 in 1971, I went to live with my uncle, Late Mr T. C. Onyeke who was then a teacher in St Mary's Primary School Aji where I did Primary 6 and obtained the First School Leaving Certificate in 1972. I wish to thank all those who taught me in Primary school, more especially Mr. William Nwugwu, Mr. Cypriel Agbedo, Mr. Raphael Idoko, and Late Mr. C. Agbaji. In January, 1973, I gained admission into the then Igbo-Eze Grammar School, and obtained the West African

School Certificate in June 1977 in Division One. Mathematics and Physics were my favorite subjects and I did not like Biology at all. In fact, I dropped Biology after class three but was forced by our form master to register it for the WASC examination. I therefore had to study it again during my class 5 because I did not want to have a "fail" or "absent" in my result. I wish to thank **all** my secondary school teachers, more especially the Principals of the School during the period (Mr. Ezekwe, and Mr. C. J. Ogbuka), Mr. J. Ogbu (Mathematics teacher) Mr. J. B. C. Okonkwo (History teacher), and Mr. K. Amadi (Physics teacher). Mr. Amadi influenced my initial decision to study Land Survey at University of Nigeria, Nsukka, which I gave up because of sickness. He is now the Surveyor General of Enugu State. I was having sleepless nights and my father, who was not literate, was told that the cause of the sleepless nights was because I was doing too much mathematics and he believed. Another school of taught was that somebody around us poisoned me and had sworn that I would not have a University Education. My father then made it clear that I could go to the University only on two conditions: 1). That I should not study anything that would involve calculation, and 2). That I must leave Nsukka area so that the man who poisoned me would not be seeing me. I then spent one year as an auxiliary teacher in the same Igbo-Eze Secondary School where I had just graduated. I did not like it but my Principal then, Mr C. J. Ogbuka specifically requested that I should be posted to the school to show other students

the importance of studying hard. In 1978, I gained admission to study Botany (I was able to convince my father that Botany did not involve any calculation) in University of Jos (which was far away from Nsukka). Having met the two conditions given by my father, he agreed to pay my school fees. I graduated in 1982 in First Class honours and the best graduating student in my set. I really enjoyed my stay in Jos – thanks to my lecturers and mates. In a special way, I want to thank Prof J.K C Berrie, Prof C. O. Akueshi, Prof. C. I. C. Ogbonna, Prof. M. O. Iwunze, Prof. Chiweite Ejike, and Prof. P. G. Abraham.

I did my NYSC primary assignment in University of Ilorin and even though the Head of Department of Biological Sciences encouraged me to apply for a graduate assistant position, I did not apply because I was promised the same position in University of Jos. Unfortunately, University of Jos did not employ me after the Youth Service. All the efforts made by the then Head of Department, Prof. C. O. Akueshi failed. I then taught in Boys Secondary School Aji for a few months before I got a job with the Federal University of Technology Yola (FUTY) in October, 1983. In 1984, FUTY was merged with University of Maiduguri and I came to University of Nigeria, Nsukka for a Master's degree Programme in Crop Science. I had completed the course-work, and the laboratory/field research work under the supervision of Late Prof Ezedinma when I got a scholarship to study in Japan. My special thanks go to Late Prof. Ezedinma, Prof. Obi, and Prof. Asiegbu of

the Department of Crop Science, University of Nigeria Nsukka. They were wonderful lecturers. I travelled to Japan in October, 1985, studied Japanese language for six months at Osaka University for Foreign Studies and passed Entrance into the Graduate School of Engineering to study Fermentation Technology in Yamanashi University, Japan in April, 1986. During that period, I also did basic and intermediate courses in Computer programming, which became very useful in my research in Bio-process Engineering. In fact, one of the courses I enjoyed teaching most in University of Tsukuba was Basic Programming and Bioprocess Simulation. I completed the Master's degree Programme in March 1988. With First degree in Botany, Master's degree Programme in Crop Science (though not completed) and a Master's degree in Engineering, I was confused as to what I would do as a researcher. After attending a conference in Biotechnology, I became interested in the Biotechnology, as an interdisciplinary field cutting across Biological Sciences, Agriculture and Engineering. I also learnt that Biochemistry was very important in understanding metabolic pathways which is the basis for genetic engineering. It is only with good knowledge of the metabolic pathway that one will appreciate the reaction step(s) that one wants to suppress or enhance, the enzyme(s) catalyzing the reactions and the genes that code for the enzymes. I then opted to study Biochemistry so as to become a Biotechnologist since there was no degree Programme in Biotechnology then.

The Programme was not offered in Yamanashi University so my supervisor, Prof. Y. Amano contacted his friend, Prof. H. Tanaka of Tsukuba University who said that I could be admitted into their Ph. D Programme provided that I passed the entrance examination and was willing to take some core courses in Biochemistry. I passed the entrance examination in April 1988 but was assigned to Prof H. Kataoka who was the head of the Bio-process Engineering laboratory in the Department of Applied Biochemistry. Although I had wanted to do my Ph. D research project in metabolic engineering, I was forced to work on Bio-process engineering because of my field of study in the M. Sc. Programme. I obtained a Ph. D in Applied Biochemistry in 1991. Here, I want to thank my lecturers in Japan. Prof. Amano had so much confidence in me that I had no option but to work hard to meet his expectations. It was very difficult initially because of language problem and I had even planned to go to the University of Leeds that had offered me admission in 1987. However, Prof Amano was always telling people that I was very good and fast in Japanese language so I did not want to disappoint him. I am very grateful to him and to Dr. K. Nakamura who was then an assistant Professor. I also want to thank Prof K. Kataoka, and Prof M. Matsumura, my Ph. D supervisors. Prof. Matsumura, then an Assistant Professor was an action man who was pushing me hard while Prof. K. Kataoka paid attention to every detail. They formed a very good combination. After the Ph. D programme in

1991, I went to the Institute of Bio-process and Biochemical Engineering, Technical University of Hamburg-Harburg, Federal Republic of Germany for a Post doctoral Research. There, I worked on Membrane Bioreactors and high density cultivation of cells. My hosts, Prof H. Maerkl and Dr. Ralph Poetner were very nice to me and my family and they have remained very good family friends. After the postdoctoral research in 1992, I went back to University of Tsukuba and took up a job as a Research Associate in the laboratory of Cell Cultivation and Bioprocess Engineering, Department of Applied Biochemistry. I was converted to Assistant Professor in 1993. The Head, Prof. H. Tanaka was working on plant cell culture while Prof. M. Matsumura in Biochemical Engineering group had started working on Animal cell culture. I was then told to concentrate on microbial cell cultures. That is how I specialized on microbial cells and now in the Department of Microbiology. Prof H. Tanaka is a very wonderful and open hearted man and I thank him very much. He made my stay in Japan very enjoyable. Also I want to thank Dr. Aoyagi for his support. He is still my contact in University of Tsukuba and has been facilitating the academic linkage between the Faculty of Biological Sciences, University of Nigeria, and the Graduate School of Life and Environmental Sciences, University of Tsukuba. I also want to thank other friends in Japan, more especially Mr. and Mrs. Fukazawa, and all the members of Fukazawa Kai. They have been always there for me and my family. In 2002, I decided to return

to Nigeria for family reasons but both the Japanese colleagues and myself were afraid as to whether I would be able to adjust to life in Nigeria after 17 years. The Department then granted me sabbatical leave which was an opportunity for me to make a final decision as to whether I wanted to resign my job in Japan or not. I took up a job in Ebonyi State University, Abakaliki and made up my mind to return finally to Nigeria. In 2003, I went back to Japan, resigned my job and returned finally to Nigeria. I was in Ebonyi State University till 2006 when I joined the service of University of Nigeria, Nsukka. I want to thank Prof. F. Ogah, the then Vice Chancellor, Ebonyi State University for offering me the job and providing a very good conducive environment for me to work. I also want to thank the entire staff of Ebonyi State University for their friendship.

The Head of Department, Prof I. M. Ezeonu and all the staff (both academic and non-academic) of the Department of Microbiology have been wonderful and I thank all of them. In a special way, I want to acknowledge the contributions of Profs C. U. Iroegbu, (the then HOD), Bartho Okolo, J.A.N. Obeta (retired), J. Okafor, and J. O. Ugwuanyi. They all facilitated my employment in the Department.

I want to thank all my students both past and present. They are too many to be listed here. Most of them have been very wonderful and I could not have done much without them. More especially, I want to acknowledge the contribution of the first two M. Sc. students I supervised – Mr. H. Yada (Japanese) and Dr. Y. C. Liu

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My special thanks go to the Vice Chancellor, Prof Bartho Okolo, the immediate past Vice Chancellor, Prof C. O. Nebo (who approved my employment), the chairman of Ceremonies, Prof Obi Njoku and his team. You all directly or indirectly made this inaugural lecture possible.

Finally, I want to thank my parents, Late Mr. Ogbonna Onyeke Nweze and Nwada Eke. They sacrificed so much for us and it is most unfortunate that they died without seeing the fruits of their labour. I want to thank my dear wife Dr (Mrs.) Christy Ogbonna. Her patience, encouragement and support cannot be qualified. She is just a wonderful gift from God. My children – Jude, Sochi and Chizie have all been great friends and I thank them for their understanding, especially when I selfishly decided to return to Nigeria. I want to thank the entire members of Onyeke Nweze family for always being there for me.

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