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BIOTECHNOLOGY IN SOUTH AFRICA

Prof JE Rollings

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Of

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JAMES E. ROLLINGS was born in Mankato Minnesota, United States of America on Feb 13, 1950. He graduated valedictorian from Orono High School. Long Lake Minnesota. His undergraduate degrees were obtained from the Univ. of Minnesota in Biochemistry and Chemical Engineering. He did graduate work under Professors G. Tsao and Martin Okos in M. S. Food Engineering and Biochemical Engineering at Purdue University, obtaining his Ph.D. in 1981 studying the conversion of maize starch to sugars. In 1985 he was awarded the Presidential Young Investigator Award from President Ronald Regan for his work on biopolymer characterization and in 1989 he received a W. K. Kellogg National Leadership Fellowship, examining intercultural differences in entrepreneurship. He worked in Kenya, East Africa from 1972 to 1975 teaching high school chemistry and biology as well as in Ecuador, South America from 1990 to 1995 assisting both environmental protection and new business developments. He speaks Spanish and Swahili and is learning Afrikaans. He has held positions as Associate Professor of Chemical Engineering at Worcester Polytechnic Institute, a consultant for over two dozen biotechnology companies in the United States, and a member of the U.S. Peace Corps Kenya in Kenya, East Africa. He is a member of several scientific societies and has held offices in the American Chemical Society, the COBIOTECH of International Council on Scientific Unions, New England Biotechnology Association, and the Institute of Biological Engineering. He is also a member of the SA Institute of Chemical Engineering. He has authored over 40 scientific publications and spoken at over 100 national and international symposiums. He currently serves as associate editor for Separation Science and Technology. Tonight he will speak on Biotechnology in South Africa.

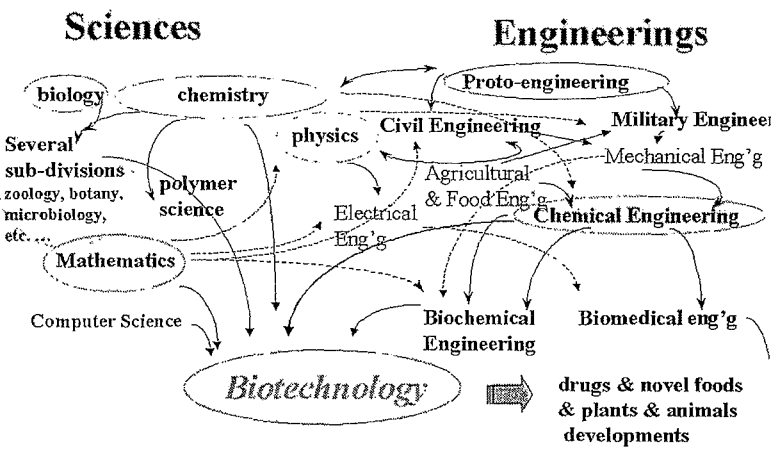
Thank you for the kind introduction.

I'm a person of this past half-century! Born Aquarian ... "head of Tiger" (in the Chinese zodiac). I think that I might be the last Professor to give an inaugural lecture this year.

I'd like to talk to tonight about my field of research, but in the broadest context: BIOTECHNOLOGY. My own specific research (biopolymer characterization) is more of a "pinhead" piece of science, as my graduate students know, and is a "building block" required of some parts of the biotech R&D efforts, but to speak of my specific research would be too boring. Biotechnology is a broad field, requiring input from several different technical fields as well as business, marketing and government and public oversight.

Tonight, I am not going to limit the word "BIOTECH" to gene-jockeying (as some might), but rather use a broad definition; " Making money with biology!!" At the risk of someone in this gathering getting upset, from my perspective genetic "engineering" is no more than a set of recipes wherein restriction enzymes and DNA binding domains are admixed to induce genetic alterations or alternatively vectors such as hyberdomas are introduced to induce similar cellular responses. With the use of modern computers to reassemble the wealth of data so collected, these are powerful methods, no doubt, and are currently being used successfully to unravel the mysteries of the human genome .The rough draft of the human genome may be available next year. I heard a report earlier this week that the human genome project will produce more genetic information in one year (2000) than has been collected in all of recorded history to this date. Interesting thought!

Evolution of Science Engineering disiplines

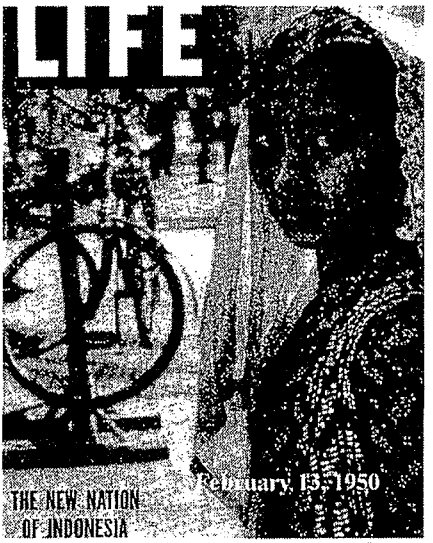


There is more to biotechnology than molecular biology. Biotechnology will take input from several disciplines - many disciplines. A possible scheme is displayed here. This is only a current "snapshot", my snapshot. Academic disciplines, like all other parts of nature, evolve. The structure of nature as known 100 years ago is different than we think today and will be different in another 100 years. All societies throughout history have thought of themselves as "modern".

Biotechnology has its roots in several contributing disciplines. And with this introduction I should really drop the place name "South Africa " from the title because, as I'll discuss, Biotechnology has few disciplinary boundaries and no national boundaries.

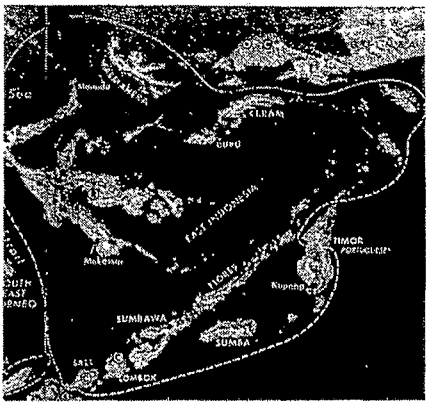
Biotechnology/bioengineering is a very broad field of disciplines. In thinking about the bioengineering, one could imagine a matrix that, along one side of which are all the fields of biology and along the other are all the fields of engineering. The applications that arise out of this matrix are virtually limitless. This linear/matrix is not a good representation, as it's too masculine - biology is more feminine, requiring nurture. The field of bioengineering is even more than this, for as we move into the next century, there is clearly a need for a true integration of biology and engineering, just as we have integrated chemistry and physics into engineering practice. This later integration formed the basis of all engineering ... civil, mechanical, chemical, and electrical engineering, and the first generation of natural science applications. These developments have led us to send people into space,

design micro-circuitry, and brought about the dawn of the information age. In fact, what we are proposing to do with biology today could not have been thought of without the use of large computers and other parallel advancements.



However, the template for the next future lies in studying the past.

A friend of mine who frequents used bookstores found a copy of this LIFE magazine that was issued onto newsstands the day I was born. The feature article was on Indonesia. You can see by this map from this edition of LIFE that East Temor was at that time in Portuguese control. And now it's independent again, or soon will be. I hear that several other islands or island groups of this complex archipelago are also asking for independence from past oppressive rulers (Dutch, Portuguese, Indonesian and indirectly American). Life does go full circle... sometimes. A fundamental question that each of these potential new nations must ask themselves is, "Will it be economically viable?" Now, this is an important question! Several years ago, a scientific study in the United States found that coconut oil was unhealthy for some reason (it affected blood cholesterol, I think). Never the less, the cookie and cake manufactures in the Western nations, reacting to public pressure, removed coconut oil from their formulations, finding a synthetic substitute and stopped purchasing coconut oil from the tropics. The oil constituted less than 0.02% by mass of the cakes and cookies, but this in turn destroyed major coconut plantations in the South Pacific, upsetting several local economies, including Indonesia's. There were never any reports of these economic upsets in the Western press that I ever saw.



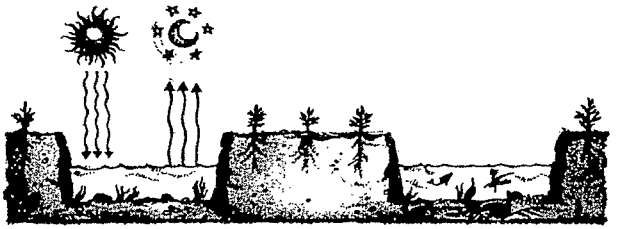
The advertisements from this LIFE magazine of 1950 reflect, in some ways, the social values of the US four years after World War Two. I find it interesting to look back on the changes that have occurred in the past and from this historical vantage point, envision to see how the next half-century will progress in biotechnology, in South Africa and elsewhere. Let us examine the past, then, as a means of looking forward into biotechnology's future.

In 1950, you must remember, the United Stated as a nation was undergoing rapid change at that time. There was a boom economy. There were lots of new housing and cars, plastics became common place, super highways were invented, television was broadcast, infrastructure was being laid down. I am classed as a "baby boomer". The returning servicemen remembered basic biology.

Here is Dad and Mom at their wedding. That's dad and his two older brothers and mom and here two younger sisters. Dad and his brothers didn't have suits, so they wore their military uniforms. The gowns, though were not military issues.

Television told us about WWII and we all knew about the Soviet challenge (the Cold War), fallout shelters and fear of the A-bomb. Sputnik's launch by the Soviets in 1957 sparked reforms in the U.S. educational system, whose stated mission was a lot like South Africa's curriculum 2005,i.e outcomes-based. I am a product of "new" math and "new" science. During that time, we all somehow gained an added appreciation and consciousness of our society and the greater world around us. We knew we were economically better off than many of our global neighbors, but to what end?

Bioengineering has historical roots that extend back centuries. Western education taught us that agriculture started in the Middle East 12 000 years ago, but some historians might debate this. The Inca tribes in South America devised intricate agricultural schemes that employed micro-environmental changes (caused by altitude differences in these mountains) and unique use of water to control thermal changes to develop more cultivatable crops than Europe had at the time of their conquest by the Spanish. The Chinese developed integrated agricultural schemes as well, specifically in their rice paddies. Rice plants, fish and waterfowl live in symbiosis with the rice farmers.



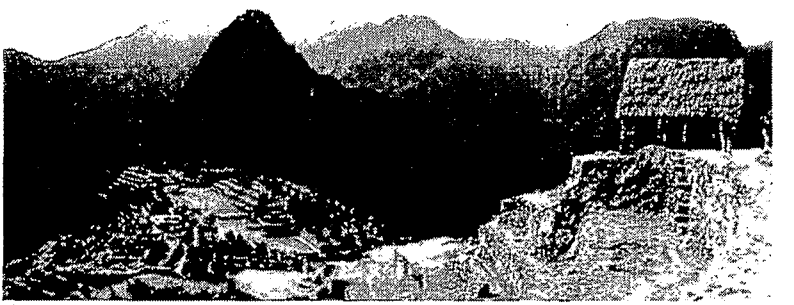
A colleague of mine (Steve Gliessman) is studying indigenous, agricultural techniques, generally non-mono-culture which, although more labor intensive, are generally found to be more environmentally friendly and therefore more appropriate to developing nations. Although this Inca scheme was over 1000 years old, the agricultural methods were in many ways far more advanced than existed in Europe at the time of the conquest. The National Academy of Sciences in the States published this book about "Lost Crops of the Incas". The basic thesis here is that there are unexploited plant materials with great commercial potential yet to be developed. After all, where would we be today without maize, potatoes, tomatoes, peanuts, and several dozen other common crops, all of which came from the Americas? Several that I've heard of are being developed (mostly fruits) in New Zealand. New Zealand markets mainly to Japan and North America. As South Africa develops markets in these regions, we shall follow this lead. The key is rapid transportation to the consuming markets. SAA has currently expanded air travel routes to the IS, targeting tourists, but the entrepreneurial biotechnologist should look for more commercial markets as well. I heard yesterday that this past quarter 's export earnings were up 3-4% due mainly to fruit exports from the Cape. The movement of plant materials around the world in the century and a half after Columbus caused the greatest upset in the balance of nature that the world has ever seen! Biotechnology will be the next major upset!

In modern times, we can list bioengineering contributions of Robert Hooke, L. Euler, Thomas Young, and many others that assisted the development of engineering in general, and saw their developments applied to biology. I have specific interests in W. K. Kellogg's contributions on flaking corn due to a special fellowship I had that first brought me to South Africa. You should know though, Native Americans in Mexico developed the original technology. Kellogg rediscovered it, scaled it up and made money.

Early forms of biotechnology have been used to add nutritive qualities, texture and taste to food. Microorganisms are added to food to ferment beverages such as beer, to culture milk as yogurt, and to rise bread. Modern biotechnology is contributing new food-processing techniques, broadening the range of food products that can be produced from agriculture and other sources, and enhancing opportunities to add nutrition, taste and quality to food.

I come from the so-called "heartland" of America (Minnesota), a lot like the Northwest Province of SA (agriculturally based) and from good pioneer stock as my Dad would tell me. Their family moved up from southern Illinois in 1915, just after there had been an Indian massacre near Mankato MN, 4 miles from the farm. Prairie Home Companion or Little House on the Prairie was my grandparent's myth! As a consequence, I don't know much about indigenous African cultures and native cures, etc. There are people in this room that know far more than I and this should be left to the experts, but, as an analogy, I'll tell you a few stories from across the pond (the Atlantic).

Another friend of mine (Jack Weatherford) is an anthropologist at MacCalester College in Minneapolis and studies the cultures of native Americans. Minnesota had many native Americans, for example, Sioux, Cree, Chiawa,



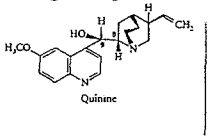
Ojbwa, Dakota, etc.

How many of you saw the movie, "Dances with wolves", with Kevin Cosner? Did you know that this was the only all-American film with subtitles? Two different Native American languages were spoken in that film, in addition to American English. As a Catholic, I will admit to an original sin committed by my white culture on those indigenous peoples of the Americas. Jack Weatherford is trying to correct part of that wrong by collecting stories and native wisdom of these peoples, or at least what's left. There are other researchers doing similar studies here in Africa. I find it great that in the East Coast of the United States, the Piquot Indians and the Pinopsquot Indians have begun casinos on their "native" lands (those given to them from the "great White Father") selling the bangles back to the white man! Manhattan Island cost the Dutch the equivalent of $25.00.
I cannot tell this story on biotechnology without mixing past and present and future, because all of these technologies are mixed as well, like tribal knowledge and modern science. Jack Weatherford presents a thesis in his earlier book (Indian Givers) that the Inca were experimenting with potatoes and other seed corn on thesis terraces (Machu Pichu) when Pizzaro assassinated their king and destroyed their culture. Here, small variations in microclimates changed the "optimal crops" for each of the various altitudes

and moistures (ground and air). In other words they (the Inca, not us) created agricultural biotechnology. They understood which microclimate was best for which seed crop. When Pizarro conquered the Inca, he destroyed a lot of scientific knowledge. "Civilization" (Western civilization) destroyed culturally gained knowledge that may never be regained. Biotechnology now must try to relearn these secrets of nature or reinvent alternatives. Interestingly, when the potato and tomato were introduced into Europe, there were people that argued that these foods should not be eaten, as they were not mentioned in the Bible.

Biotechnology is currently making great strides in medicine today. But first another story.

It was Europe that introduced malaria into the New World and this disease, together with small pox, leprosy, the plague, turburculosis, and other Old World afflictions killed an estimated 90% of the Native American peoples. Interestingly, a Peruvian bark was found to cure malaria symptoms. The Inca (actually Quechua) peoples of the Andes knew well the medicinal powers of many native plants in the Andes as well as in the Amazon jungle. Quina means "bark" in Quechua and "quina-quina" means" bark of barks" and this is where the word" quinine "originates. In 1630 quina-quina was introduced into Europe. By 1671, quina-quina was introduced in North America (Virginia) and malaria was cured in the New World English colonies. The etiology of malaria was not understood until very early this century, and this discovery earned Sir Ronald Ross the Nobel Prize for medicine in 1902 - fully 300 years after the Quechua Indians found the cure! Malaria probably killed Alexander the Great and it killed Oliver Cromwell. The funny story about this later death is that a Jesuit priest named Father Calancha described the healing properties of the tree bark (quina-quina) in the "Chronicle of St. Augustine". And Jesuits throughout Peru began to treat Malaria with an extract of this bark. In 1645 Father Bartolome Tafur took some bark back to Rome where its use spread among clerics. Cardinal John de Lugo wrote a leaflet to be distributed with the bark. Peruvian bark was introduced into England in 1654, but British Protestants were reluctant to try a Catholic cure. Cromwell, who refused to be "Jesuited" with the bark died in 1658. Twelve years later, a young aparthecary named Robert Talbor gained fame in London by curing malaria with a "secret" cure. This cure saved the life of Charles II as well as the son of Louis XIV, and after the death of Talbor, the formula was found to be the Peruvian bark. Introduction of quinine marked the beginning of modern pharmacology.



Quinine

There are many other stories such as how scurvy led to the discovery of vitamins, and curare (the poison on Amazon jungle Indian's blowguns) led to

discovery of muscle relaxants and treatments for heart disease, and how goiter was found to be an iodine deficiency, cured by consuming a specific seaweed, etc. All of these have Native American connections. But the point is that when cultures share biological information, all people can benefit.

This century has seen an explosion in biological developments, including the appearance in 1902 of the term "immunology" first appears. Sir Ronald Ross earned the Nobel Prize in medicine for determining the etiology of malaria. The term "genetics" was introduced the same year as Einstein published his theory of relativity. AIChE created the discipline of Chemical Engineering. The term "pH" was coined to deal with acid/base conditions in aqueous solutions. All of this happened in the same two-year period.

The first cancer-causing virus was discovered in 1911. Four years later Phages, or bacterial viruses, were discovered. 1919 saw the word "biotechnology" first used by a Hungarian agricultural engineer. The next year, the human growth hormone was discovered. Fleming discovered penicillin, the first antibiotic, one year before the stock market crash of 1929. In 1940, Avery demonstrated that DNA is the "transforming factor" and is the material of genes. The US entered the Second World War the same year that Jost first used the term "genetic engineering". During WWII, The electron microscope was used to identify and characterize a bacteriophage - a virus that infects bacteria. Waksman isolated streptomycin, an effective antibiotic for TB.

In 1946, genetic material from different viruses was found to be combined to form a new type of virus, an example of genetic recombination. The same year that millions were first reading Alan Paton's book "Cry The Beloved Country", Pauling showed that sickle cell anemia is a "molecular disease" resulting from a mutation in the protein molecule hemoglobin, a common affliction here in Africa. Artificial insemination of livestock using frozen semen (a longtime dream of farmers) was successfully accomplished the same year I was born.

The quinine story was central to WWII battle plans of the United States in the Pacific Theater where my father served. It turns out the seeds from a particular variety of Cinchona trees (botany only recognizes two species, whereas native healers of the Amazon recognized 40 species that exist in different microenvironments) were stolen by the Dutch in 1861 through an Australian botanist named Charles Ledger. Ledger first tried to sell these to the British, but they didn't trust him (I guess he was a rugby fan) and Ledger sold these seeds to the Dutch. The Dutch used these seeds to set up plantations in Java, Indonesia (do you see the connection with the LIFE magazine?). As these trees matured, Dutch scientists discovered that these seeds contained a bark that was 13% quinine! By 1930, the Dutch plantations in Indonesia were producing 22 million pounds of bark, yielding 97% of the world's quinine. In 1940, the German army captured the entire

world's repository of quinine when they captured Amsterdam. When the Japanese conquered Indonesia in 1942, the United States and its allies were completely without a source of quinine. The small reserves of quinine held in Manila were airlifted out with the last dignitaries as Mac Arthur exclaimed, "I shall return!"

I actually "fell into" this field we call biotechnology.

I finished my first "B" in biochemistry. And after my first "B" I went off to Africa by joining the U. S. Peace Corps in Kenya. They called us "Kennedy's Kids" in those days (JFK started the Peace Corps in 1961). I was Kenya X. There is a current South African Peace Corps volunteer in this audience, who is working in the Northern Province on AIDS related educational projects. Sam raise your hand! I think you are South Africa IV ... right?

I learned a lot from my experiences in Kenya. But I realized that if I was going to make a difference, than "pure" science was not enough, I needed to apply it. So, upon my return to the States, I did my "B" in ChemE and looked for a graduate program in Food Engineering, as I became interested in assisting the solution of world food problems. To make a long story short, I received offers to grad. school, took the offer made by Purdue University, and received by M.S. and Ph.D. from there over the next five years. I worked on the conversion of maize starch to sugar, a very large industry in the States today. African Products uses this technology here in South Africa. You have all consumed the product in cool drinks and most prepared food products. During that time, the field of biotechnology was formally created and I was one of the first dozen biochemical engineers to be granted a doctorate in this field in the United States.

In many ways then, my dream, "working on world food problem solutions" did come true. Except, of course, it became known as "biotechnology". That word (a modern word) was acceptable to the discipline of chemical engineering, a standard bearer of the established industrial complex. It has been said, "If you are not a socialist when you are 20, you have no heart. But if you are not a capitalist by the time you are forty, you have no brains" That is what happened in chemical engineering. My altruistic dream became commercial. But working in the States proved to be too distant from where the world's food problems exist ... so I moved back to Africa, more specifically, South Africa, the "new" South Africa.

"Biotechnology is already transforming medicine as we know it. Pharmaceuticals such as human insulin for diabetes, interferon and other cancer medications, antibiotics and vaccines are all products of genetic engineering. Virginia Polytechnic Institute is processing drugs from milk from genetically altered cows. One new drug has the potential to save hemophiliacs from bleeding to death. Six hundred animals are all that's needed to treat the entire human population who has this affliction. Scientists are also looking at bananas that may one-day deliver vaccines to children in developing countries. Imagine, a banana containing an anti-malarial drug!

I was three years of age when Nature published Watson and Crick's manuscript describing the double helical structure of DNA. This marked the beginning of the modern era of genetics. At the same time, large-scale immunization of Salk vaccine was being used to combat polio in the United States and this disease is still prevalent in tropical Africa. By the time the Beatles came to the States, Systemic fungicides had been developed; the steps in protein biosynthesis were delineated. Interferons were understood, as were the first synthetic antibiotics. Messenger RNA was found in 1954. And the International Rice Research Institute in the Philippines started the Green Revolution with new strains of rice that doubled the yield of previous strains.

Ten years later saw Harris and Watkins successfully fused mouse and human cells - the same year that Star trek TV series was first broadcast. The genetic code was cracked in 1966, demonstrating that a sequence of three nucleotide bases (a co-don) determines each of 20 amino acids, the building blocks of proteins. The next year the first automatic protein sequencer was perfected. The 1960s also witnessed the development of synthetic enzymes and expanded knowledge in metabolic pathways.

The first complete synthesis of a gene was accomplished in 1970. And also in the 1970s, Stanley Cohen and Herbert Boyer perfected genetic engineering techniques to cut and paste DNA (using restriction enzymes and ligases) and reproduce new DNA in bacteria. The National Institutes of Health formed a Recombinant DNA Advisory Committee to oversee recombinant genetic research. The Asilomar Conference (moratorium on genetic engineering research) occurred. The first monoclonal antibodies were produced. The tools of recombinant DNA were first applied to a human inherited disorder. Queen Elizabeth sent the first royal e-mail. Yeast genes were expressed in E. coli bacteria about the same time that TV arrived in SA. DNA sequencing was discovered: the first expression of human gene in bacteria. Methods for reading DNA sequence using electrophoresis were discovered. Recombinant human insulin was first produced. Human growth hormone was first synthesized. The first commercial company was founded to develop genetically engineered products. The discovery of polymerases was made. Techniques for rapid sequencing of nucleotides were perfected. Gene targeting and RNA splicing were developed.

In the 1980s an U.S. patent for gene cloning was awarded to Cohen and Boyer. Researchers successfully introduced a human gene - one that codes for the protein interferon - into a bacterium.
Transferring genes from other animals into mice made the first transgenic animals. Chinese scientists became the first to clone a fish - a golden carp. The "internet" had had only 213 hosts at this time. There are over 10 million today..
H.I.V was "discovered" in 1981. Humulin® was approved for the treatment of diabetes. The Polymerase Chain Reaction (PCR) technique was conceived

in 1983. The first genetic transformation of plant cells by TI plasmids was performed. The first artificial chromosome was synthesized. The first genetic markers for specific inherited diseases were found. The DNA fingerprinting technique was developed and used in court. The first genetically engineered vaccine was developed. The entire genome of the HIV virus was cloned and sequenced only 6 years after the virus's discovery. Genetically engineered plants resistant to insects, viruses and bacteria were field tested for the first time in the 1980s.

Recently, Scottish scientists reported cloning a sheep, named Dolly, using DNA from adult sheep mammary cells. They named it Dolly, after Dolly Parton. Oregon researchers have cloned two Rhesus monkeys. University of Hawaii scientists cloned three generations of mice from nuclei of adult ovarian cumulus cells. The age of biology is clearly upon us! But what might this mean to us here in South Africa?

Let's think about this hypothetical situation for a moment:
Let's suppose that the salad you ate today was made with a new carrot from SA/Club Farms, cc. Farmers grow the new carrot on fewer hectares because it yields more, and it's less expensive because it does not require any fertilizers or pesticides and can be harvested totally mechanically. In addition, it has more vitamin A & C than traditional varieties and stays crisper longer and keeps its fresh taste longer. "But, because this carrot does not require as much labor, the farmers have laid off hundreds of employees. While it does not require any chemicals to flourish, this new carrot does affect the environment by making it difficult for other crops or plants in close proximity to survive. And though it's cheaper to begin with, it's only available from one company, which could result in a considerable premium over regular carrot seed. And what's the secret to this hypothetical new carrot? It's the latest advance from biotechnology - produced with a gene from kakiebos, an invasive weed here in South Africa.

Sound far- fetched? It probably shouldn't. Remember the flavor-saver tomato, the one with a three-week shelf life? You can buy it in town at the Spar or Pick 'n Pay, or maybe not? It was introduced 5 years ago in the States and has taken over the market. Growers who didn't adopt this tomato are now playing "catch up" (or making ketchup). Maybe there are members of this audience that remember when hybrid maize was introduced (or heard stories from your parents or grandparents). That event early in this century began the first green revolution of the 20th century. Biotechnology will create the next green revolution of the 21st. But there are questions that we must ask.

How many of you have heard of the so-called terminator gene, which can keep a plant from reproducing? Farmers will not be able to grow their own seed corn. Today, nearly half the soybeans in the U.S., the stuff that is crushed and made into salad and cooking oil and that feeds most of the livestock the US, are produced from a variety that increases the plant's resistance to certain pesticides. Genetically engineered corn (maize) with

certain pest resistant characteristics is also rapidly displacing more traditional varieties in the United States and has been introduced here as well. And, it gets even more interesting when you consider that researchers are looking at genetically modified mosquitoes that cannot carry malaria or alternatively carry the anti-malaria prophylaxes. So, what do we think about this new carrot? When does nature belong to one company, and when does the invention belong to all life forms?

Are we concerned about the environmental effects we still don't fully understand by introducing this carrot? What about the farm workers who are now unemployed? Should one company have a monopoly on this carrot? And finally, are you concerned about these issues and about how it is produced? Would you still have eaten it if you knew about the kakiebos gene? Should you have been told? Would you buy it? There are many more questions that haven't yet been thought of, much less answered. I wonder if any of these questions were asked 500 years ago, when the European explores were bringing plants back from the Americas.

Agricultural biotechnology has enormous potential to help combat hunger. Genetically modified plants have the potential to resist killer weeds that are, literally, starving people on this continent and other parts of the developing world or to cure diseases that have afflicted humanity for all of recorded time. Combined with appropriate traditional agricultural technologies ,environmental problems may be combated.

Biotechnology can help us solve some of the most vexing environmental problems: it could reduce pesticide use, increase yields, improve nutritional content, and use less water. We're currently employing bio-engineered fungi to remove ink from waste paper in a more environmentally sensitive manner. Newsprint is yet to be recycled here in Potchefstroom and other places in SA.

We might look back over the advancements in biotechnology on this timeline. Here we have a scale of advances vs. logarithm of time. The scientists and engineers will recognize that the slopes will give us a kinetic constant of changes in biotechnology. Humanity had a slow growth rate until plants started to be shared between cultures. And we see a more rapid growth rate earlier this century as modern agricultural techniques started the first green revolution. We now can envision a time when sufficient food will be produced that no person on earth needs to go hungry or die of diseases that we can immunize.

But, as with any new technology, the road is not always smooth. Right now, in some parts of the world there is great consumer resistance and great cynicism toward biotechnology. In Europe protesters have torn up test plots of biotechnology-derived crops and some of the major food companies in Europe have stopped using GMOs (genetically-modified organisms) in their products, driven by an uninformed public.

The promise and potential of biotechnology are enormous, but so too are the questions, many of which are completely legitimate and need to be debated, scientifically and publicly.

Today, on the threshold of this revolution, we have to grapple with and satisfy those questions so we can in fact fulfill biotechnology's awesome potential.

Thank you.