Food and Agriculture Organization
of the United Nations

Proceedings of the FAO International Symposium on the Role of Agricultural Biotechnologies in Sustainable Food Systems and Nutrition

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Chapter 1

Opening plenary session

1.1 Welcome address

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Italy

Dear Ministers; Excellencies; Honourable keynote speakers; Distinguished delegates; Representatives from Civil Society, Private Sector, Research Institutions, Academia; Ladies and gentlemen;

Welcome to this International Symposium on "The Role of Agricultural Biotechnologies in Sustainable Food Systems and Nutrition".

I am delighted to see representatives of governments, civil society and private sector, as well as eminent experts, opinion leaders, research organizations, cooperatives and development partners, gathered here at FAO for this three-day event.

Thank you for coming in order to share your views, experiences and lessons learned on such an important issue.

As you all know, we have many challenges ahead by 2030 to eradicate hunger, improve nutrition and make food systems more sustainable.

And these challenges are surrounded by uncertainties and complexities, especially in the context of a changing climate.

We are constantly facing new and unexpected situations that emerge as a national, regional or global threat. The Zika Virus, in the health sector, is just an example of such unexpected scenarios.

It reminds me of the words of Lord Keynes, which I quote: *"There is no scientific basis on which to form any calculable probability. We simply do not know what may happen".*

I am afraid that the challenges posed by climate change to the world food security should be considered under this Keynesian perspective. Because we simply do not know much about what has been called the "new normality", in order to make calculations on the most probable scenario in the coming years.

The huge amount of information and sometimes mere speculation circulating today increase the uncertainties even more.

Professor Bertrand Hervieu has recently addressed this issue in Paris. Let me quote:

"The events we are experiencing refer to the obvious uncertainty of the course of history and the complexity of the world. This uncertainty and complexity are enhanced by the immediacy of information, which leads to fragmentation, preventing any development of perspectives, explanations and understandings of the world and of the time we live in.

You can be sure", said Professor Hervieu, *"that the year 2016 will be at least as uncertain and complex as 2015 was. So, let us wish for each other the intellectual strength and courage to penetrate this complexity, and, if possible, to control it. Let us not give up to the hardships of our times. Let's try to master them".*

Ladies and gentlemen,

I am using these words to highlight the importance of considering every possible solution to achieve world food security for all in the years to come.

We must count on a broad portfolio of tools and approaches to eradicate hunger, fight every form of malnutrition and achieve sustainable agriculture in the context of climate change.

As a neutral forum, FAO has been promoting debates, dialogues and exchange of information in order to enhance our knowledge of these tools and approaches.

We held an international symposium on agroecology in 2014.

We helped launch the Global Alliance on Climate Smart Agriculture in the same year.

And we have just released a new edition of "Save and Grow in Practice", FAO's model of ecosystem-based agriculture.

Now it is time to discuss and analyse what agricultural biotechnologies have to offer.

This symposium aims at showing the many possibilities and benefits of applying biotechnology in the agricultural sectors, including crops, livestock, forest and fisheries.

Showing, for instance, how it can help to transition to an agricultural production that relies on fewer inputs with less negative environmental impacts.

And, ladies and gentlemen, let me state this loud and clear: this symposium is not only about genetically modified organisms. Agricultural biotechnologies are much broader than GMOs.

Biotechnology gives us options and improves our capacity to act and respond in many different areas.

We will address fermentation processes, biofertilizers, artificial insemination, the production of vaccines, disease diagnostics, just to name a few.

I look forward to hearing stories on how biotechnologies can accelerate the development of improved and locally-adapted crop varieties. And can permit the rapid diagnosis of diseases and pests.

We want also to investigate and give examples of how modern biotechnology can be compatible with principles of agroecological approaches.

Knowledge and innovation are also key to address complex challenges:

- knowledge and innovation that are grounded on sound evidence and science;
- that leads to better integrating different concerns and perspectives of women and men of all ages;
- that can facilitate transfer of technologies and practices, and promote collaboration, including through South–South cooperation.

Ladies and gentlemen,

We cannot lose sight of the fact that biotechnology, knowledge and innovation must be available, accessible and applicable to family farmers. Otherwise, they will have a limited impact.

We must find means to remove the barriers that prevent their availability to family farmers.

They are responsible for the largest proportion of the food we eat.

I hope we will be able to identify new, better and innovative ways to make agricultural biotechnologies accessible to those who could benefit most.

Ladies and gentlemen,

The symposium is planned around three main themes:

- climate change;
- sustainable food systems and nutrition;
- people, policies, institutions and communities.

We will have a high-level segment where government representatives shall express and exchange their views.

There will be also a special student interactive session to provide an opportunity for the young generation to interact.

The symposium will be webcast live on the FAO homepage. That enables everybody, especially those not present in Rome, to follow the proceedings.

This event is another critical step in our efforts in order to reach zero hunger, improve nutrition and promote sustainable food systems.

I thank the members of the Advisory Panel who worked very hard with FAO in developing the programme.

Once more, thank you all for coming and participating in this symposium. I wish you fruitful debates and a successful event.

Thank you for your attention.

1.2 The state of knowledge in biotechnology

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Mr Director-General, distinguished delegates, dear colleagues and friends, it is a great pleasure to stand here again in the Green Room. And for a subject that is so dear to my heart and that we have been discussing at FAO for at least 20 years, if not more. A subject, I think, which more than any other current issue is fraught with difficulties, with misunderstandings, with great hope, with missed opportunities and with wonderful challenges. So let us see where we are today and where we can go from here.

Since the dawn of agriculture, men and women have been selecting species or individuals from species in terms of the most favourable characteristics for human use: bigger apples, stronger animals, fuller ears of corn and wheat. It was actually only one and half centuries ago that visual, phenotypical, selection led to something else, to a better understanding of the laws of inheritance, starting of course with Gregor Mendel. It took a long time for statistics to slowly come into the equation in regards to the probability of inheritance. It was only about 60 years ago when we started to unravel the mechanism of inheritance with the discovery of DNA. The molecule that actually is, in a way, the blueprint of life and the blueprint of inheritance. And then, things changed rapidly. The 1980s saw molecular biology and synthetic biology, and in the 1990s the first work in genetic modifications began. It was, and still is, a revolution as well as a continuity of men's working with nature.

To understand what we have done so far means understanding how genetics actually work, and that unfortunately is complicated, so bear with me. Now this conference is about biotechnology, and biotechnology, as the Director-General said very clearly, is not the same as genetic modification. To put it very simply, biotechnology is an enormous toolbox with lots of different tools that somehow, in some way or another, enable us to understand and unravel the genetics pertaining to the characteristics that make up the actual plant or animal and determine its performance. Genetic modification is a subset of that. It actually allows the introduction of, if you will, alien or foreign DNA into the DNA of the desired individual. You cannot do that without understanding the genetics. And the real breakthrough actually only came in this century and that is when we started to sequence entire genomes of plants and animals. Starting with humans in 2003, the last decade or a little over a decade has seen tremendous progress in getting this full genome sequence. So that means actually understanding the whole of the DNA. Not understanding it in the sense of knowing every characteristic, but we know now the DNA, the genome, of all the major cereals, apples, plums, tomatoes, cocoa and banana. About 80 crops are now fully known in terms of their genome. And for animals it is even more, about 140 types of animals that we have now sequenced. From horses to cats and dogs, but, of particular relevance here, also goats, pigs, chickens, you name it. Starting with chicken in 2004, we achieved all of this in only ten years. It is a marvellous achievement because it is like knowing a dictionary; it is like knowing the letters of a language. It is only through genomes that we can be far more precise and target the different characteristics that we want to know.

Genetic improvement exists only if there is variability; if there are different individuals with different characteristics. Otherwise, if everybody was identical, there would be no genetic improvement. So biotechnology is a combination of techniques that allows us to better target the kinds of characteristics we want. Let me make that clear through a number of examples that are immediately relevant to small farmers and poor consumers. I think that the thing that is foremost in our minds is, of course, nutritional quality; enhancing nutritional characteristics. The most famous example of that, which you probably know, is golden rice. A genetically modified (GM) crop which contains a fragment of DNA that actually codes for a precursor of vitamin A. Simply put, it has a yellow colour and vitamin A which was not there before. Currently, work is also being done on these characteristics for cassava, and getting a GM cassava is probably around the corner, if it has not happened already. Why is this necessary? Why can we not do this differently? We cannot, because rice does not contain any coding for vitamin A and it has to be found somewhere else. And it can only be found in crops or in plants that are quite different, so you have to introduce a different piece of DNA. In the case of cassava there is an additional complication which makes genetic tools necessary. Cassava does not flower very well at all, so it is very difficult to get new generations with new characteristics. In the case of poor flowering or null characteristic in the original crop, GM techniques (genetic modification) are the tools you need to use. In terms of terminology let me just say that there is a great deal of confusion. Genetic modification yields transgenic plants, transgenic being different from the original genome. Sometimes it is called manipulation but that is, I think, not the term scientists like me would like to use.

Now, another interesting aspect in nutritional improvement is the recent case of the purple tomato. Tomato, as you know, contains lycopene, which is an essential set of ingredients and antioxidants. But interestingly enough, tomato also contains genes for two other antioxidants. However, these are silent and this is something that happens in the genome that we did not know about before. Sometimes the genes are present but they need to be opened in a way. It is like opening the pages of a book. So by using genetic techniques to wake up these genes, we get a purple tomato with much better quality. The result is not a genetically modified tomato. It is a tomato that has undergone a kind of genetic transformation, if you will, only to wake up genes that it already had. So it is still the same genome. We will come back to that difference later.

The most important application, however, is not in regards to nutrition. It is regarding pests, insects and disease resistance. Viruses, bacteria and fungi greatly hamper yields, especially for small farmers. We have seen a surge in applications the names of which all started with Bt. Bt is derived from a soil bacterium, *Bacillus thuringiensis*, which actually confers quite a few properties that protect a plant against certain insects. A good example is papaya in Hawaii where half of the plantations at one stage were wiped out by ringspot virus. GM papaya, this is genetic modification because a piece of the bacterium was actually introduced into the papaya genome, has helped tremendously to revive the plantations. I should hasten to add that, sadly, this was not acceptable everywhere and to everybody, so the case of papaya is in many ways on hold. We have more examples and the best example for African farmers is, of course, Bt maize which has now been introduced in countries such as Sudan, Burkina Faso, and South Africa and has been a big success.

Another case, an example of what these genetic tools can do, is the potato. You remember the story of potato crops being wiped out by *Phytophthora* in the nineteenth century causing the death of one third of the Irish population. That disease is still around. It is very difficult to find a resistance. The resistance does not exist in the potato that is grown normally, but the resistance exists in a wild progenitor of potato, say a wild relative, an uncle, if you will. And through a process that is called cisgenesis, a piece of the DNA of that wild potato is actually put into the potato and that has had tremendous results. It means that after 50 years of trying to breed for a resistance, we now suddenly have three types of resistance, three genes, if you will, that help to protect the potato and help the potato to win the race against *Phytophthora* which is an extremely difficult disease.

Another example of the types of applications that we can think of is regarding the flowering of fruit trees. Now, you know if you want to improve a tree it often takes generations. Not just generations of trees but generations of humans to actually get the right tree. By using a gene from a plant, actually a model plant, *Arabidopsis*, we can actually shorten the number of generations by inducing early flowering. So instead of thirty years of fruit tree breeding, we can bring it down to about five years. After that period, the gene can be taken out of the fruit tree again so that the fruit tree itself and its fruit are not genetically modified. It is then the last generation that you allow to grow.

In animals we have similar types of results. One important area is, of course, disease resistance, for example in porcine pests. But there are two other areas that you might not realize. One is the defining of the sex of the chicken already in the egg by introducing a gene from the jellyfish, luminescence gene, which allows you to see the sex of the chicken embryo through the egg shell. What does this mean? You can eliminate all male embryos and therefore you do not need to kill all the male chickens after they are born, because male chickens, as you know, do not produce eggs. This is a very simple, more humane, and more animal-friendly technique. Another vast area of application is in the area of vaccine production. The introduction of genetic modification in the virus itself, such as for bluetongue or Rift Valley fever, allows a vaccine to be produced that is not dangerous, but confers resistance to the animals. So there are indeed many applications, including new areas in which we are not just looking at animals and plants but also at bacteria in the gut of animals, such as helping to reduce the greenhouse methane emissions from the stomachs of cows. Another area is the use of waste. Waste, as you know, contains lots of fibres, particularly cellulose and lignin, which can be broken down by bacteria. Genetically modified bacteria help to make your waste more palatable as animal feed.

So how have small farmers benefited? Well, first of all, let me say that of the 18 million farmers that are using genetically modified crops, which is a subset of what we are talking about, 90 percent, nine-zero, are small farmers, according to FAO definitions. And what have they mostly benefited from? From pest and disease resistance, Bt crops which also lead to a reduction in pesticide use, improvements in nutritional quality, and improvements in shelf-life and storability of products so that they can be brought to the market. What has not been very successful yet, but is in progress, is work on improved taste, complex nutritional qualities, and the issue of climate change in particular.

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Yes, we have drought resistant maize that has been successful in recent years, but the entire issue of climate change has not been addressed very well.

Now before I go on, I need to explain something about the breeding techniques themselves. So far we have talked about a toolbox and genetic modification, but there are some extremely exciting, very new developments that are extremely relevant today to small farmers but also to regulatory agencies and countries that are here today. We have three ways of doing our breeding. One is just classical crop or animal breeding – you cross the lines and you hope for the best in the next generation. The other one that we just discussed is genetic modification – you introduce a piece of DNA from somewhere else and you get a transgenic crop or animal. But the third way actually supersedes that and changes the story completely and that is what we call "new breeding techniques" or, as I like to call it, precision genetics. It is actually using a pair of scissors which allows you to extremely precisely and efficiently cut the DNA at the place you want and to introduce changes. Introducing changes in such a way that the end result is not a genetically modified crop. Remember my example of the purple tomato? There is no strange DNA. It is only waking up silenced genes or it is using genes for a while and taking them out later in the process. So sometimes, technically speaking, we have a mutation but it comes from the DNA itself and sometimes there is not even a mutation but only, as I call it, the waking up of genes.

Now, I know some of you might be bored by this time but this is an extremely important difference because it means that we have a process to actually conduct changes in the DNA without producing genetically modified organisms. And that is very important for everything that has to do with regulation. That technique is called CRISPR and sometimes is called CRISPR-CAS. CAS is the related protein, but that does not matter so much. To give you an idea, genetic modification is like

MS-DOS on an old computer. CRISPR is like supercomputing or Windows 10 and beyond; it is a completely different ball game. It is precise, it is exact, and it is efficient. And more importantly it can be used in any organism's DNA. Interestingly enough, the CRISPR itself, that is the protein sequence, is part of the natural immune system of bacteria. It was actually a way for bacteria to protect themselves from viruses and that is why it is so precise. But now we find a dilemma, and the dilemma is how can we regulate this? We suddenly have a third category of biotechnology that does not fit the regulations we have so far.

Now I need to add one other complication to that, and that is the issue of food safety which is so dear to our hearts. Risk assessment can use some of these precise techniques to see whether a product going to the consumer is actually genetically modified or not. It can also look at whether something is contaminated with other types of viruses or toxic products. So the assessment techniques actually also evolve and that is very important for poor consumers, who often have poor quality food. We have a number of unresolved problems here. And they are not technical or scientific as much as they are political, and that is why I need to bring them to your attention. One is the whole issue of intellectual property. Who actually owns the results of this work? And this is a tricky issue because apart from farmers and scientists who have done their work, it is obviously companies, particularly large companies, that have a stake or that have done a lot of the research. We have here two opposing political and legal regimes that some of you may be familiar with: breeders' rights and intellectual property rights. In a way, they are opposed because breeders' rights allow scientists to continue with the results of research while intellectual property and patenting does not allow this unless a fee is paid. Now breeders, obviously, want some protection and governments that do not allow that protection will see that breeders will be more hesitant to bring their products to market. On the other hand, obviously, they also need access to what is considered, in a way, the inheritance of mankind. So this is an unresolved issue.

This issue is related to something else: the speed of the whole process. At the moment, it takes about 14 years in pre-regulation processes and maybe another ten to get the regulation organized elsewhere. That is far too long. That is a whole generation of farmers. Now, one of the problems in regulation is that we have, again, two opposing regimes here. We have regulatory agencies that look at the process. Has DNA been introduced or not? If so, is it GM or transgenic? Or they look at the end product. Is the end product GM or not? That is the difference between the United States of America and European regimes and many countries are somewhere in between. This is something that we need to resolve quite urgently because if we do not resolve this, the risk is that national regulation will actually re-do some of this process.

The bottom line is that we have a very complex process here, which is political as well as technical. And it comes as no surprise that it is so difficult for society to follow these huge steps that science is taking and for politicians to have the political courage to move forward in an area which seems very risky in many ways. What are the societal concerns that we should address? First of all, there is a sense that big companies dominate the market. If you want to use a loaded phrase, this is a plot, a neo-liberalist plot, to keep small farmers and poor countries out of the market. I am not talking about my ideas but rather the general perception as this is a big issue. It is true that small companies are only just emerging in this field, particularly in Asia and to some extent in the U.S. Secondly, the perception is that this technology is not very useful to small farmers. I have indicated that there are many areas where small farmers benefit, but there are some areas where the focus is not on small farmers and the results are only indirect. In particular, the concern is that small farmers will depend on seeds which will create an even greater dependency on the market. That is not exactly true because farmers are used to using hybrid seeds so that problem can be laid to rest to some extent, but it is still the prevailing perception. Then there is the concern about transparency and labelling. Now this a difficult issue. We can do this even better with the new techniques, but big companies are loath to do this very often. Additionally, there is ample evidence that providing more information on labels does not necessarily lead to greater understanding.

There are also a series of other risks that we addressed even in the past here in FAO: human health, animal health, and environmental health. So far, there is no evidence from a scientific perspective that there are any risks, and I choose my words carefully here, that there are any risks with this type of biotechnology that are greater than the normal risks that we accept in classical plant breeding. But no evidence of risk is not proof that there is no risk. I hope you see the difference. But we are a long way from 20 years ago when the first GM herbicide-resistant soy and maize came to the market, for large-scale zero tillage production. As I said, 90 percent of the farmers that are benefiting are small farmers. But still, four crops dominate and they are all feed crops. Food crops are following slowly, particularly rice, potato and tomato. There is a great deal in the pipeline. But it is fraught with difficulty when it comes to regulation which can take 20 years or more.

So the issue is urgent. What can we do to make sure that poor consumers and poor farmers actually benefit? What needs to be resolved? Let me give you a few ideas here which I hope you will discuss.

First of all, I think we have to understand that with the delays, the current delays, and even future delays, we are targeting not today's small farmers but the next generation of small farmers. And that generation needs to be more entrepreneurial and more professional because young people will not want to remain small farmers if they can help it. So this technology needs to be part of a far larger package of agricultural development.

Secondly, we need to resolve some of the biosafety issues, particularly with CRISPR. This new genetics allows far better targeting for small applications, local applications but it needs to be able to come to the market.

Thirdly, we need to do something about the controversy between breeders' rights and patenting. This is an unresolved issue for many reasons, I know, but still, we cannot go on this way.

Next, we need far more public–private partnerships. This cannot be only a government issue or only a private sector issue. This needs collaboration, especially to help smaller companies with local clients and targets get to the market. And we need more research, long-term focused research, on the needs of small farmers and poor consumers, on the issues of climate change, and on nutritional quality. We need to acknowledge that some of these techniques are still neutral. They are applicable, like Bt, to small and big farmers but we need a far longer commitment and more funding to really do the trials and do the work in the fields. We need a systems approach.

And then we need a social dialogue. This is an issue with a great deal of misunderstanding because it is complicated and we need to resolve this. This is not a matter of us scientists coming out of our ivory tower, it is a matter of working together to identify the issues and to try and resolve them. The social dialogue is as important as the science today.

And then, we need to resolve things in an international forum, and that is my last comment. I think, that it is extremely appropriate that we are here at FAO. This is the heart of FAO's mandate. It also requires us to think about the international agreements that we have that touch upon this. Think of the Convention on Biological Diversity, think of course of FAO's own bodies, but also other bodies that are relevant here in some way or another. And maybe what we need to think about these days is a kind of platform to bring different parties together and to talk about what kind of regulation is needed in the future. Both unqualified optimism and severe pessimism are wrong in this case. The devil is in the details. It is probably the most important issue for the future of food and nutrition. We have to resolve it politically and technically. The future is already here but it is not evenly distributed. We must make sure that everybody has access to technology that betters his or her life. Thank you very much.

1.3 Biotechnologies in action in Brazil

Maurício Antônio Lopes[1] and Pedro Luiz Oliveira de Almeida Machado[2]

[1] President, Brazilian Agricultural Research Corporation (Embrapa), Brasilia, Brazil.

[2] Coordinator, Embrapa Labex Europe, Montpellier, France. The keynote address was given by Dr Machado.

Brazil is one of the largest countries in the world, with an extensive surface of continuous land, a large supply of freshwater, abundant solar energy and a rich biodiversity. The wide range of climatic conditions, from temperate to tropical, together with advanced capacity in technology development, allowed considerable diversification of agricultural systems in the country, which has become one of the world's largest producers of food, feed, fibres and renewable fuels. In this presentation, we will evaluate the impact of research and innovation in the process of agricultural modernization in Brazil, with emphasis on advances in biotechnology and related fields.

The presentation is divided into three parts as follows:

a) A summary of the constraints to agricultural development in Brazil, the key drivers for agricultural innovation, that led food security and enhanced export capacity in the short span of 40 years;
b) A synthesis of the development of modern biotechnology in Brazil and its role in the recent development of Brazilian agriculture, and
c) The new wave of biotechnologies and their potential impact in the nascent bioeconomy and sustainable agriculture and food production in the country.

Brazilian agriculture, after the 1970s, is a story of success. In the past 40 years the country was able to transform its traditional agriculture into a dynamic and competitive agriculture strongly sustained on science and its wealth of natural resources. Besides its 8.5 million km^2, Brazil has also a significant supply of fresh water (15.2 percent of the world's renewable water resource), large availability of arable land (13.5 percent of the world's equivalent potential arable land), abundant solar energy and a rich biodiversity. Among the 250 000 species of higher plants, nearly 60 000 are native to Brazil. In addition to the world's largest tropical forest, the country has over 200 million hectares of savannas (known as Cerrado in Brazil), which had its immense agriculture and livestock production potential unleashed through a science-based approach starting in the early 1970s.

During the past 40 years, Brazil has been able to successfully use its natural resources endowments to effectively become a world leader in the agricultural sector and more effectively boost backward and forward linkages in the economy. The traditional agriculture that prevailed in Brazil until the 1970s was progressively transformed in the following decades into a modern and highly competitive agriculture based on science and technology. Overall, such outcomes have made Brazil the world's largest producer of citrus fruits, frozen concentrated orange juice, sugar cane and coffee. The country is also a serious global competitor for many other products — soybeans, tobacco, poultry, corn, beef, biofuels — and self-sufficient in the production of most agricultural goods.

One common feature throughout this period was the huge agricultural research effort that generated important spillovers of knowledge and technology to farmers with an ample array of positive outcomes to Brazil and other countries in the tropical belt of the world. The Brazilian approach to develop autochthonous science and innovation for agriculture allowed for increased agricultural productivity, production and exports and decreasing food prices to consumers. The development path of Brazilian agriculture, especially from the 1990s onwards, was strongly based on productivity gains. Overall productivity gains in Brazilian agriculture have reflected a range of policies that varied markedly in the past 40 years. This virtuous growth path in Brazilian agriculture explains the country as a world's top agricultural producer at the same time it maintains over 60 percent of its territory preserved. In spite of this progress, it is necessary to recognize some localized drawbacks among agricultural production, environment and social claims, and the need to move even further in this sustainability path.

The key drivers for the tremendous advances achieved by the country can be summarized as: a) improvement in fertilizer recommendations and acidity control; b) availability of quality and certified seeds; c) governmental commitment and public policies for agricultural development; d) a landscape available for mechanisation; and e) availability of mineral resources. Ironically, with the acidic soils that dominate the landscape of the Brazilian Savannah, there is a plethora of limestone mines. The last and most important driver is by far the will and the entrepreneurship of our farmers that migrated from the south and embraced the huge challenge of developing advanced agriculture in tropical Brazil.

Institutional building and strengthening is also at the root of these developments. Brazil has developed a large and complex agricultural research basis, which is composed of public institutes, universities, private companies and non-governmental organizations. This capacity stands as one of the most comprehensive and most efficient in the tropical belt of the world. Beginning in the 1970s, Brazil improved its structure and capacity substantially, developing a two-tier system of federal- and state-based agencies. This so-called National System for Agricultural Research and Innovation (SNPA) has developed and promoted a wide array of technological innovations that triggered the expansion of agribusiness over the past four decades.

The SNPA is responsible for organizing, coordinating and implementing research that objectively contribute to the development of agriculture, sustainable use and the preservation of natural resources. Implementation of the SNPA concept led to the strengthening of agricultural research and development (R&D) capacity in Brazil, with improved infrastructure, human capacity, management mechanisms and support policies on a national scale. Embrapa is by far the largest component of the Brazilian SNPA system. A semi-autonomous federal agency administered by the Ministry of Agriculture and Food Supply, Embrapa is the largest agricultural R&D agency in Latin America in terms of both staff numbers and expenditure. The agency is headquartered in the capital Brasilia and operates 46 research centres throughout the country.

Given this background, we want to explore the importance of research and innovation in biotechnology for Brazilian agriculture. Despite the advances achieved in the past four decades, the challenges arising from global warming, the consequent climatic extremes, and an increasing world population make sustainable food production a key issue for the tropics. To maintain productivity and sustainability of agricultural systems, it is crucial to be alert, informed and acquainted with new technologies that could change production and consumption concepts, standards and paradigms. Scientific revolutions are happening in various fields of knowledge, in biology with genomics, in physics and chemistry with nanotechnology, in information and communication technology, with innovations that increase our ability to respond to risks and challenges.

In recent years, biology has produced tremendous advances which allow us to broaden our understanding of complex mechanisms in plants, animals and micro-organisms. New biotechnologies are already impacting agricultural diversification, specialization and value aggregation, besides increased productivity, safety and quality of food. Using advanced biotechnologies in agriculture to confront the challenges ahead is strategic not only for Brazil, but for the world. Among the wide range of biotechnologies available and in development, genetic modification of crops stands as one of the most successful to date.

In the past decade, Brazil has become the second largest user of genetically modified (GM) crops, with an area greater than 42 million hectares during the last crop season (2014/15). As of July 2015, there are 45 GM events approved for commercial cultivation in Brazil, of which 25 events for corn, 12 for cotton, six for soybeans, one for dry edible beans, and, most recently, one for eucalyptus. GM events with herbicide tolerance traits lead the adoption rate with 65 percent of the total area planted followed by insect resistance with 19 percent and stacked genes with 16 percent.

The adoption of biotechnology products in agriculture definitively helped the country to reach its current production level, even with the late adoption of GM crops, due to a “non-official moratorium” caused by legal disputes from 1998 to 2005. Only after the implementation of the new Biosafety Law was the use of GM plants officially endorsed in a trustable legal framework, essential for the stability of any economic sector. Several public and private, national and foreign institutions conduct research and development in Brazil to produce GM plants with several agronomic traits and/or characteristics that add value to the agriculture product.

The majority of GM crops being grown in Brazil are soybeans, corn and cotton, all belonging to the first generation of transgenic plants, which are insect and/or herbicide tolerant. As is the case in the rest of the world, the biggest share of GM crops being produced commercially in Brazil were developed by private companies such as Monsanto, DuPont Pioneer, Syngenta, Bayer and Dow, among others. However, the local research community has the capabilities to prospect genes of interest, “proof concept” of novel genetic engineering strategies, test it in controlled and real field conditions and take the developed product to the market.

Research institutes, universities and Embrapa have been developing various GM plants with different traits of interest. Embrapa developed and deregulated the first GM bean (*Phaseolus vulgaris*) with resistance to the golden mosaic virus to be produced commercially in Brazil, and, in a joint venture with the German company BASF, developed and deregulated a herbicide-resistant soybean. The new variety, which has resistance to imidazolinone herbicides, was released commercially in the 2015/16 growing season under the trade name “Cultivance.”

In addition to soybean, corn and cotton, various other GM crops are being tested in advanced development stages in field conditions in Brazil. Rice, passion fruit, eucalyptus, cowpea and sugar cane are examples of species being tested in actual field conditions for different traits such as yield improvement, drought tolerance, fungus resistance, oil quality and wood density. It is undeniable that there was a rapid increase in the utilization of genetic engineering technologies in Brazilian agriculture after the new Biosafety Law, in 2005. The unification of laws, rules and guidelines by all agencies involved in the biosafety legislation framework allowed, undoubtedly, the rescue of the confidence by investors, researchers, private/public institutions, and by all other stakeholders involved in Brazilian agribusiness.

In the area of animal breeding, several Brazilian companies have expanded the use of biotechnology tools to develop new cattle breeds well adapted to the tropical climate using genomics, artificial insemination and animal cloning and are exporting improved genetic material (semen, embryos) and live high-performance animals to developing and developed countries, such as Mozambique, Costa Rica, India and the United States of America. As a pre-condition for further export, sanitary protocols are being discussed by the Brazilian Ministry of Agriculture with Angola, Bolivia (Plurinational State of), Colombia, Ecuador, Mexico, Panama, Paraguay and Venezuela. As much as in breeding, biotechnology tools are helping to improve the sanitary conditions of the herds by making possible the production of a number of vaccines.

From the microbial world, one of the most interesting biotechnologies developed in Brazil has been the use of nitrogen fixing bacteria, which began with *Rhizobia* in soybean some 40 years ago and has now been adapted to help the growth and production of sugar cane, corn and other legumes. In the tropical world this is a very important tool to help in the mitigation of climate change. The development of biological nitrogen fixation for soybean, which allowed this crop to be grown without mineral nitrogen fertilizer, had a major impact in the country. Today, Brazil cultivates over 30 million hectares of soybean without the need for chemical nitrogen, saving farmers about US$ 5 billion every growing season.

Also, cloning and micropropagation are widely used for several ornamental plants, fruits such as banana, pineapple and strawberry and forest species such as *Eucalyptus* and *Pinus.* And biotechnology tools are also helping to develop new biological control formulations to be used in integrated pest management – a most welcome concept used more and more in sustainable agriculture.

Brazil is also investing in biotechnologies that can connect its agricultural system to the nascent bioeconomy. Among the major routes considered in the pipeline are the metabolic processes of organisms (plants, animals and micro-organisms) with focus on the production of materials and substances of high value, targeted to multiple uses (chemical and biochemical, medical, pharmaceutical, nutritional, energy, etc.). Multiple efforts for development of plant biofactories, genetically modified and cloned animals are underway. And biomass and biorefinery technologies are being developed to meet the demands for sustainable energy, chemicals and new bio-based materials. The growth of the bio-based economy can generate multiple opportunities for economic growth and creation of new jobs, including in rural areas.

New cutting-edge biotechnologies will become more and more important for Brazil for obvious reasons. More efficient technologies will be necessary to supply the needs of food to Brazilian society, besides the production of exportable surpluses to the world, thus fulfilling expectations of the country's contribution to food and nutritional security, globally. Technological advances will have to facilitate preservation of natural resources such as soil, water, forests and biodiversity. Add to that attention to global warming and its potential effects on agricultural production. More research is needed to mitigate effects of extreme weather events and to allow adaptation to new presumptive scenarios of biotic and abiotic stress intensification, as well as energy insecurity.

Despite the scale of the challenges, one must also recognize that the technological progress in several fronts is impressive, increasing chances of successful response. It is also important to think beyond the wonders of biology and modern biotechnology. Innovations in the fields of information technology and communications, remote sensing, advanced instrumentation, automation and robotics indicate that precision agriculture will emerge as common practice in agriculture in the near future. These tools and processes will allow smarter use of our natural resource base, ensuring more productivity, efficiency and sustainability in production systems. Nanotechnology, with innovations in the scale of the billionth of the meter, also promises to revolutionize the development of multiple products, processes and instruments. Advanced sensors will enable the monitoring of production systems with great precision, and new materials and processes will allow development of machines and equipment that are more efficient, accurate and durable.

All these innovations will have enormous implications for the future of agriculture. In order to benefit from them, and to remain competitive, countries will need to invest in training of human resources and sophistication of processes, methods and instrumentation. Information and communication technologies also promise to further revolutionize methods of managing agricultural production, access to markets, logistics and the relationship between producers and consumers. New information and communication technologies have also the potential to change behaviour, requiring increasing attention to consumer demands and to perceptions of society in relation to agriculture.

Conclusions

The agriculture of the future will be impacted by concepts, methods and multi-functionality far beyond conventional. Technological standards of the global agriculture are now being changed by the introduction of new technologies resulting from very recent advances in scientific knowledge.

The challenges ahead indicate the need to adjust and change agriculture and food production in ways that ensure improved sustainability and a healthier and more nutritious food supply. It involves, necessarily, the increased use of advanced technologies, with special emphasis in creative uses of genetic diversity – modern biotechnologies, following the development of the bioeconomy. Despite the scale of the challenges, one must also recognize that the technological progress in several fronts is impressive, increasing the chances of successful response.

In recent years, biology has produced tremendous advances, which allow us to broaden our understanding of complex mechanisms in plants, animals and micro-organisms. From such advances will innovations arise to agricultural diversification, specialization and value aggregation, besides increased productivity, safety and quality of food essential to assure a more sustainable future for humanity?

1.4 Breakthroughs in resource productivity

Gunter Pauli

Founder,
Zero Emissions Research and Initiatives Network,
Japan

Let me, first of all, thank FAO for inviting a rebel like me to come to this podium. The Huffington Post calls me the Steve Jobs of sustainability but my friends in Latin America call me the Che Guevara of sustainability. I think it's very important that in this debate we enlarge discussions of the very narrowly defined biotechnologies which only seem to look at a few plants and a few animals. Ladies and gentlemen, "bio" depends on "eco" – ecosystems. We need to understand the ecosystems as such and find the greatness of the ecosystem which gives us solutions we can never imagine in a laboratory. And let me just give you a first example when it comes to golden rice.

Income, malnutrition and control over seeds

In the Rio Grande do Sul State in Brazil, we have studied how to enrich vitamin A in food, especially for the malnourished children. We quickly concluded that there is no need to genetically manipulate the rice. You only have to harvest the microalgae that grow in the water that you use for irrigating rice paddies. Lo and behold, we found out that there is 12 times more vitamin A and beta-carotene in the microalgae in the rice water than you could ever get genetically into the kernel. So my question is: do you want something that is poorly designed, controlled by one company, and in the end not so efficient, or do you want to double the farmers' income and use local biodiversity? To me, the key priority is to ensure that there is income for the farmer, and that we fight malnutrition with what is locally available and ensure wide access of the benefits to everyone in the community, not just the one company that owns the intellectual property.

Ethics at the core

We have to put ethics at the core of this. I ask each country to never permit any company to operate in the nation if farmers are forbidden by contract, and even taken to court, to keep seeds from that specific plant variety. Excuse me, ladies and gentlemen, that is ethically incorrect. We have to permit the farmer to do what the farmer has always been doing: keep seeds for the next season. Therefore I am very firm and I disagree with the arguments sometimes forwarded by multinational companies, mentioned by a previous speaker, whereby governments of developing nations are corrupt, have inefficient bureaucracies and lack scientific knowledge when the seed companies cannot sell their engineered seeds to farmers.

"Think tank" and "Do tank"

In 1994, I was invited by the United Nations in Tokyo and the Japanese government to assist in the design of business models that would have zero emissions, hence still the name of my organization. We created over the years a network of 3 000 scientists that I call the "think tank". We have, on the other hand, 850 implementers – we call them the "do tank". We combine the thinking and the doing. It is a tremendous honour to know that while 20 years ago we were considered to be dreamers imagining a world of no waste or emissions, we now have 200 projects implemented, US$4 billion invested and 3 million jobs generated. At the end of the day, if we don't keep the generation of jobs as a top priority – especially in shanty towns and rural areas – in whatever we do we are not serving society.

Biodegradable is not necessarily sustainable

The biotechnologies must be at the service for all. I set up 12 corporations myself. Two failed. One of these corporations took on Proctor and Gamble, Henkel and Unilever for the production of biodegradable soaps. The company was very successful. We took market share without advertising. When these fast-moving consumer goods producers don't see advertising they don't understand how it works. But, as shareholder and CEO, I had decided to invest the near total of a three-year budget for advertising in the first zero emissions factory, a factory that had no waste. In 1992, the company's car fleet was running on biofuels. We were early. But, I had become the biggest buyer of palm oil and the Indonesian government hosted me as a VIP in Kalimantan, I realized that, while I was this green entrepreneur and had this ecological factory, unfortunately I was destroying the rainforest. I was destroying the habitat of the orangutan and the dwarf elephant.

It is very important to accept that when we want to do business, we can never foresee all consequences. Innovations will always result in unintended consequences. Now, as long as you didn't know it had this consequence then it is unintended, and you have a clear conscience. But, the moment you know there is the negative impact and you knowingly continue, then it becomes collateral damage. That's ethically not permitted. Unfortunately, industries today, backed by major investors, particularly hedge funds, are not prepared to take responsibility for their unintended consequences. Worse, these companies want fast-track approvals for any innovation be it chemical or biological. Therefore, in my view, the world has to redefine their license to operate and accept that quick fixes are not necessarily long term solutions.

Bamboo vs eucalyptus

Unfortunately, I had to realise that biodegradable palm oil is not sustainable. It is very unfortunate since it is more than the palm oil. There are these plantations – which I call empty forests. Nothing grows in there except a genetically modified (GM) tree. You know, how could we ever sustain a growing need for food and jobs in this world if we create empty forests? I must say that I do not understand this obsession for GM. For example, the recently approved genetically modified eucalyptus trees in Brazil. Why? Because Brazil has the world's largest biodiversity in bamboo and we have demonstrated to Embrapa that on one hectare you can generate 60 times more fibres over a 100 year period than you can ever do with a GM eucalyptus that grows to maturity in eight years.

Bamboo grows to maturity in three years, does not need replanting for at least 70 years, and has a much higher incidence of fibre per acre. Bamboo simply is much more efficient. The only reason why GM eucalyptus reigns is the prevailing institutional, technological lock-in of the paper processors with forestry companies, due to locked-in investments in millions of acres of planted empty forests. Even when the efficiency for the earth, the nation and the people on all counts from jobs to water are in favour of bamboo, the industry will insist on "business as usual" refusing to rely on "nature's best".

Ladies and gentlemen, sometimes we have to look reality in the eye. We have to say what is not popular and some will even tell that it is not politically correct. Doing less bad is bad. If I'm telling you that I've been stealing, I'm called before the judge and I'm promising him that I'm going to steal less, do you think the judge will consider me a good citizen, qualifying me for an early release from prison? Of course not. But, when we have companies that pollute and contaminate and don't want to take risks beyond the very narrowly-defined logic of risk by their core business, and they are committing to reduce risk and pollute less, then I must say you are still polluting. Polluting is polluting. Polluting less is polluting. Stealing less is stealing. How can we sustain a double moral along those lines and even offer these less-polluting companies environmental awards?

Blind search for productivity

Therefore, I must sometimes say that I am ashamed at how we have developed our food industry. I do not understand how we have come to the stupidity and, to me, even the insanity to have one-day old chickens flown around the world on jumbo jets. We don't want to have a male when it should be a female and don't want to have a female when it should be a male. I mean, ladies and gentlemen, why don't we let the males and the females live? One for the meat and one for the eggs. But we don't do it because we have genetically transformed those chickens to the point that the males that come from the egg-laying chickens cannot even walk. So what do we do?

Should I herald it as a breakthrough when scientists are injecting molecules derived from an octopus in order to see early on if it's a male or a female chicken because that is considered an improvement from the shredding of chickens, which is still the standard today. Ladies and gentlemen, we are shredding millions of chickens every day. We don't realize it, we don't want to know it. After a major outcry in the social media in 2015, the German Government suggested that instead of shredding, producers should gas them to death. I don't get it. Now we just have to ask ourselves a question: how come we don't succeed in leaving both of them alive? How come we can lose sight of this 50 percent all for the sake of productivity?

A new model for fishing

If you give a man a fish for a day he will not be hungry. If you teach him how to fish he will overfish! So the hard reality is not only that we overfish, we enjoy eating the eggs of these fish. Can you imagine that a farmer goes with a cow to the butcher to slaughter it while the cow is going to calve in a few weeks' time? I think that in many countries the butcher and the farmer would be put in jail. We would not tolerate it with animals, but we enjoy it with fish all the time. Is it because the animal is hairy and has four legs? I mean how can we have a fishing system where fish eggs are a delicacy? Now if you kill the females with eggs, plus overfish, how sustainable is your fishing technique? Now do you think GM tilapia is going to solve that problem? I wish you good luck. Because then you get into the hands of a feed business that has only one interest, to sell feed. We have this persistent drive to cut costs and go for the cheapest option. We have to start looking at generating more revenues with what we have, and we need to have a persistent drive to respond to the people's needs. May we put it as a priority? This is the United Nations right? May we have the interest and the benefit for society as a priority in policy-making and technology decisions? That requires new business models combined with different priorities for technology and innovations. We've heard from three speakers one type of technology, genomics and genetic modification. Permit me to share what we do.

You know how the whales fish their krill? With air bubbles. The whales are capable of designing an envelope of air bubbles around krill that permits them to catch all the krill. Smart! How come we can't do that? Well we can. I have not only been involved with a team of about 20 researchers to design this but the first tests have just been done in Peniche (Portugal) where the fishermen tested fishing with air bubbles. When the fish float, thanks to the air bubbles, we scoop them into the boat and then check if the females have eggs. The females with eggs are returned to the sea. Doesn't it make sense? Tests for two years in El Hierro (Canary Islands, Spain) allowed fish stocks to jump to the level of 1974. Why? Because we don't kill females with eggs. Are we ready to do that kind of research? Is there money available for that? This research and development is privately funded because the governments think that this is not the way to go.

We have now gone into the next phase which is the design of the boats. Because if you fish with air bubbles then you have to have a catamaran. Catching pelagic fish with air bubbles is easy. Now if you don't need to pull the nets and you don't have to freeze the fish, you save 80 percent of the required energy. That means this boat will be a cheap version of the Tesla for the fishing industry. Why? Because we can now process every fish on the boat, and we ensured that all females with eggs will continue their life cycles. We redesigned the fishing logic, not just the technique. Everything is done with seawater, eliminating freshwater. These fishing vessels save 250 000 litres of fuel per year per boat. When I met with the Minister of Marine Resources and Fisheries of Indonesia in Jakarta, she indicated that the nation needs at least one boat for every island. That's 17 000 boats. When you share a vision and make it clear that there are opportunities to change our food base, our protein search, and generate new industries, including shipbuilding, that work with the ecosystem and display a regenerative capacity, then we are contributing with technologies that empower fishermen.

Recover the mangroves and the shrimp farming

In Indonesia, as well, I would like to share that partnership of the government with the private sector is regenerating mangroves these days, where there used to be shrimp farms. You remember there were massive investments in shrimp farms and then the white spot virus attacked bankrupting the areas where the mangroves once stood. Seventy-five percent of the business evaporated and the European Union, rightfully so, objected to the use of antibiotics. The Indonesian Government, under the leadership of its Ministry of Marine Resources invested years to regenerate mangroves along the coast of East Java, outside of Surabaya. Here, channels in the newly planted mangroves are rich in shrimp which no one has to feed. Shrimp which you don't have to feed? Do you think this business model is competitive?

Salt resistant rice

Since we know there are rising sea levels, because of climate change, the encroachment of the seawater into the land is very plausible. Therefore, we need to look at the opportunity to propagate a natural hybrid salt resistant sea rice, which grows in China. Ladies and gentlemen, there is the first harvest of 158 hectares of sea rice in Zhanjiang City, Guangdong Province where land had been encroached by the sea. Biologist Chen Risheng and the Chinese government have been leading this research and seed propagation. The world should be happy to learn from this fundamental progress.

From 2D farming on land to 3D farming at high sea

Across the Atlantic Ocean, we are witnessing another breakthrough in food production. We need to rethink farming the sea. Whereas on land we can only exploit the surface and a thin layer of fertile soil (two dimensions), we have to embrace the revolution of exploiting the full water body, which is recently called 3D sea farming. We suggest to apply the same logic as with the mangroves. The goal is to regenerate the ecosystem of the sea. This strategic approach allows us to harvest without having to feed. Humans have the responsibility to create the conditions conducive to the generation of food, feed and raw materials for industries as diverse as pharmaceuticals, cosmetics, energy crops, chemicals and textiles. The aim is nothing less than to restore Nature and put Nature back on its evolutionary path so that we can respond to the basic needs of all with whom we share this planet with what is locally available.

Brent Smith operates a 3D sea farm in New Haven, Connecticut. The farming system is simple. To restore a bay or a coastline that has been overfished with nets being pulled time after time over the bottom to the point that nothing grows anymore the starting point is to reintroduce the bottom of the food chain including kelp, seaweeds, sponges, sea urchins, scallops, mussels, and oysters. Once this ecosystem has been reconstructed then fish will return, and traps are added on the bottom. Everything works. The advantage is a low investment cost: the biggest expense is the ropes and the buoys. No need to put any money in feed. This means that we relieve the pressure on the world stocks of sardines and herring which are overfished to feed salmon. The operational costs are so low that most of the people think it's not possible. I know most of you are going around and saying that what Professor Pauli is saying cannot be true. Let me invite you to come and see. I'm not prepared to debate the science of what we are doing. I'm prepared to show the results of what has been done on the ground and in the sea.

Research to mainstream the bottom of the food chain

Regeneration of the sea focuses on a few basic species at the bottom of the food chain. This reduces the cost of operations. 3D farming is a third of the price. It is important to state at this moment that I am not against anything in this world. I am in favour of what is better in spite of the established interests and the fierce lobby for a *status quo* with marginal improvements at the fringes. The research required to mainstream these new food, feed and industrial feedstocks must be mainstreamed. We have emptied the top of the food chain like tuna and spent a disproportionate amount of money to artificially produce the fish at the top of the food chain. We need to start rebuilding the oceans from the bottom and this is will ensure food security and a healthy diet for generations to come.

Dr Ronald Oringa, Professor at Wageningen University, has gone on record stating that with 180 000 km^2 of 3D farming we could feed the world with all the protein we need. That is the area of the territorial waters off Washington State in the United States of America. We have a capacity to generate nutrition beyond what we know. Now, how much research is going into this? Very little. What we have been able to share, is that 3D farming is not just into scallops, mussels and seaweeds. It is securing the supply of the feedstock for cosmetics, animal feed, fine chemicals and textiles. It is timely to remind everyone that this type of farming requires no inputs, no pesticides, no herbicides, no fertilizers. Ultimately, this frees farmers of the dependency from feed or seed companies. It is quite a different business model than the one that dominates farming on land.

Coastal defence against rising sea levels

The seas and oceans bring us food, but also challenges. We need coastal defences against rising sea levels. What I shared is not only a new model for agriculture and fisheries, these models also mitigate climate change. The ecosystem we can regenerate creates the real biotechnologies. The insights and how this works offer opportunities not just to get food and jobs but to improve resilience. How do we regenerate coastal systems where the rising sea levels are going to dramatically affect us?

First we need to tackle plastic waste in the sea – or also called plastic soup. This is what I call an unintended consequence. No one knew this was going to happen. But when it happened, and even as the science emerged, none of the companies who made this mess of plastics take any responsibility. Amazing isn't it? Where have the ethics gone? What we see is that by 2030 and at the present rate of discharge of plastics in water bodies, there will be 250 million tonnes dispersed as tiny pieces smaller than one millimetre. Nature Magazine ran an article in 2015 confirming that already 100 million tonnes float in the sea and that we are adding every year another 8–12 million tonnes. There is no strategy to remove it.

Now if we collect plastic soup composed of seven different types of plastic, it can be converted at low temperature pyrolysis into fuel (80 percent), carbon black (15 percent) and syngas (5 percent). New research at the University of Washington in Seattle has indicated that when you have these plastic beads there is a surface tension with a positive and negative charge that generates a tiny layer of freshwater. In nature, whenever there is freshwater and saltwater there are dynamics because everything gets stressed leading to more nutrition, different types of nutrition. So algae grow around the plastics because of the freshwater film generated by these plastics. This research is not yet described in numerous scientific papers. Unfortunately, for many, this makes this innovation invalid for most readers.

The freshwater–saltwater interface

Freshwater in the ocean attracts a whole range of micro-organisms which are unique and therefore the fish eat them, not because they like the plastics or they are only confused by the plastics but because there are so many micro-organisms living on the plastics thanks to this freshwater–saltwater combination. We propose to turn this around because these are the micro-organisms that extract phosphorus from the sea. This is interesting because in agriculture we know that we can process nitrogen and potassium in nearly unlimited quantities, but phosphorus is running out, with the exception of Africa.

Therefore, we are focusing on how we could clean up the plastic soup while harvesting phosphorus without destroying the bottom of the sea. That's the kind of work that my organization's members get excited about. The plastics get harvested while harvesting phosphorus. A pioneering company "The EVP Group" based in Taiwan, which developed the technology known as "R-One", has been running a two tonnes per day installation for two years. We support innovators who take their insights out of the laboratories and into the real world. Now, when 100 tonnes plastic soup can generate 85 tonnes of fuel combined with the generation of 50 m^3 of upwellings per second through this saltwater–freshwater combination that gives us 100 tonnes of phosphorus per year at very low energy cost, while we are recovering the minute plastic beads that are risking our food chain.

Now these projections are not large-scale yet. Do you know of any research programme funded on this? One day in a distant future we can imagine generating fuel on the high sea that could supply fuel to the ships en route. You need to have that multiple cash flow and that is the big change from the core business model logic based on a core competence that students are taught at business schools all around the world.

Tea and park management

Let us look at the logic of tea in the northeast of India. Assam is home to the Kaziranga National Park, the largest natural park which is recognized as a world heritage where you have 1 200 wild elephants, 2 500 rhinos, the largest group of rhinos in the world, an incredible collection of 120 wild tigers and, next to it, you have tea plantations. You can only imagine the chemical run-off from these plantations into the park. The owner of the plantation decided to have the whole plantation converted to organic. This is the largest organic tea plantation in India.

The bad news is that since this plantation has been farmed for over 100 years, there is less than 1 percent carbon in the soil. So, as a result, if you extract the chemicals from the equation of production, then the plantation's output drops overnight. I was asked by the owner whether we could double employment within three years because the financial people want to cut costs and put 1 500 people on temporary contracts. Since the harvesting of tea is limited to seven months per year it makes sense with the decrease in tea output to cut employment costs. You know what temporary contracts, working for 7 months instead of 12 months, means? It means increasing the risk of poaching.

So, building on the great work initiated by the Indian teams, we started to imagine where we can increase income and value, instead of cutting even further, and the first results are quickly visible provided one goes beyond the core business of tea. This is tea plantation under a canopy. Every tree is now growing pepper vines. The plantation now produces pepper which potentially brings a 20 percent increase in jobs. Then, tea bushes are pruned to foster a fresh flush. All the tea pruning are used to farm mushrooms. It is possible to generate more tonnage of mushrooms than tonnage of tea, using what the tea plantation has. China has been farming mushrooms on agricultural waste for more than 12 centuries. There is no reason this cannot be successfully introduced in Assam.

In order to alleviate the irregular supply of water due to the erratic monsoon rains, 18 retention ponds were created. These are water reserves that are also used to farm fish. The Kaziranga Park is based on the Brahmaputra River, the largest brooding region of the world after the Amazon, providing fish protein for an estimated 400 million people. Building on the existing biodiversity of the region, the tea plantation can increase protein output through fish farming with local species, increasing jobs. This tea plantation could soon make a profit and be on track to double employment around the tea plantation. This is the best protection for wildlife.

These are ecosystem-based innovations. Use what you have. Generate more with what is available. Use the five kingdoms of nature not just the plants and animals. The fungi are very efficient protein producers as well we all know. And let's not forget the microalgae. This Hathikuli tea will be launched internationally as a special brand generating higher returns. What is important is the increase in employment, the protection of biodiversity and the capacity to compete on the international market. At the end of the day we need to be competitive. How can the tea in Assam be competitive in a world market when the drive is a ferocious cost-cutting drive only without any generation of additional value? Now a new form of tourism can emerge and thrive.

The panda vs the cockroach

The problem we are facing is the concept of the core business characterised by an obsessive focus by scientists and business on one subject only. I tell them they behave like pandas. You know the panda! We love the panda. They're plushy, they're nice, they're lovely and you know the pandas are endangered. Why? Because we encroached on their land and now they don't have the bamboo to eat. But is it not true that the panda is part of the problem because it only wants to eat bamboo. I mean if the panda was ready to change its diet it would survive anywhere in the world. But the panda eats bamboo or nothing else.

That is exactly how business behaves these days. They consider it a risk if they have to go outside their core business. They consider that adaptation to new realities in the world is not permitted. They want to take companies and governments to private courts under a very special regime whenever the framework conditions change. I don't understand it. Why don't we simply behave like cockroaches? Cockroaches eat everything, anything, anytime. They have been around for 100 million years. They will be around for another 100 million years and if you try to kill them, you succeed with one or the other but you never kill them all. This is a need for a new mind-set of how we operate and let me exemplify that with coffee chemistry.

Coffee chemistry

The next example will surprise with all you can do with coffee. Do you realize the inefficiency of coffee drinking? When you drink a cup of coffee in the morning you basically only ingest 0.2 percent of the biomass that the farmer harvested. Can you imagine? A whole supply chain is organised for 0.2 percent of the biomass. Everything else is thrown away. That implies that coffee as a hard wood is a great substrate for mushrooms then we start mushroom farming. There are over 3 000 entrepreneurs in cities and rural zones that have started mushroom farms on coffee waste. We think there is space for at least 1 million. Mushrooms are cholesterol-free. It's the kind of food that we should be having. It is rich in essential amino acids, it can compete on protein dry-based basis with meat. Better, the spent substrate of mushrooms is enriched with amino acids and provides a great chicken feed.

This is the first value chain from coffee residues. Now coffee particles are mixed in clothing. Ladies and gentlemen, outdoor clothing like Patagonia, Adidas and Hugo Boss use special yarns produced with a 6 percent coffee content, micron-sized coffee mixed in polymers for textiles. Why would one put post-industrial coffee waste into the textiles? Because it absorbs odour. Timberland now puts it in its shoe soles. Twenty percent of the Timberland's sole is coffee. What does it mean for the farmer? What is the price for a functional chemical like coffee in the sole or coffee into clothing? It is US$2 500 per tonne. How much do you think you get for coffee these days? You don't even get US$500. We are increasing the revenue for the farmer by a factor of five. Coffee particles are mixed in carpets. Now we can add it to methyl diphenyl di-isocyanate (MDI) to make polyurethane with coffee. Coffee can be added to paint because coffee is also a natural UV protector. The latest research shows that coffee is an efficient storage medium for methane and hydrogen. The value of the total chain of coffee can be increased by a factor of 500. That is the real bio-economy. That is high tech because it brings food and nutrition as well as functionality. Do I have to add that genomes and genetic modification are irrelevant in this proposal? After all, these technologies may reduce cost and increase output of the core crop, but it is dwarfed by these ecosystem-based business models that provide income for the farmer and build on local biodiversity.

Thistle chemistry

In my last case, permit me to talk about Italy. The thistle is not very well liked because it is considered a weed. In Europe, we have an estimated 20 million hectares of these weeds growing because the European Union pays farmers not to farm. If you pay farmers not to farm what do you get? Thistles! On the island of Sardinia under the leadership of Dr Catia Bastioli, who is the CEO of Novamont, thistles are converted to the building blocks of bioplastics, including pelargonic acid and azelaic acid that can be formulated into herbicides. Novamont extracts lubricants. The coffee capsules of Lavazza in the future will be biocapsules. The waste from this process could be formulated as an animal feed. By the way, Novamont can extract enzymes from the thistle flowers which have been traditionally used to produce goat cheese. FAO is based in Rome. I suggest you visit Novara or travel to Porto Torres in Sardinia and see how this is being implemented. That is a new form of competition. On top of that, this is being processed in the former petrochemical facility of ENI which was transformed into a biorefinery.

Conclusion: Education

To conclude: if we only teach our children what we know our children will never be able to do better than we do. Therefore, I translate everything that has been successfully developed into children's stories, fables. I am very grateful to the Chinese Government because the Ministry of Education and the Ministry of Environmental Protection of China have approved these fables for distribution to all children in China. This is a gift I could never have imagined. We are in need of inspiring a new generation about the technologies and the business models where ethics is at the core, where serving society is the priority. If we are not inspiring the next generation what are you doing here on this earth? Ladies and gentlemen, with the wise words of Nelson Mandela I would like to close: "It always seems impossible until it's done".

And let me send you an open invitation to please come and see any of the projects that we have implemented. From there on, let's enjoy this great future that we all have. Thank you.