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New Life Sciences: Linking Science to Society

BioVisionAlexandria 2012

Ismail Serageldin & Mohammed Yahia
with
Mohamed El-Faham & Marwa El-Wakil

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OPENING WORDS

The Knowledge Revolution Today

Ismail Serageldin

I am honoured as it has become regionally traditional, if I may say so, to inaugurate the BioVision proceedings with a technical presentation, not just the words of welcome that I made at the beginning.

Today I will speak about the knowledge revolution that we are living through. I will take you throw seven points that will serve as an introduction to a changing world. The seven pillars of the knowledge revolution.

I genuinely believe that we are living the third global revolution and I believe that it is a very special one.

The first revolution was the agricultural revolution. It allowed human beings to move from being just hunters and gatherers and to have surpluses of food, which allowed them to be creative and gave rise to civilizations – mostly near the banks of rivers.

The second global revolution was the industrial revolution, which transformed production modes and methods of movement. This was done not just by inventing machinery, but by also changing the relationship between the human beings and the output of work. In the past, artisanship was the norm, where one person produced a product from start to finish. The industrial revolution shifted the paradigm so that humans became specialists, working in a factory and each doing a particular job. At the end, they all, working together, produced a product.

The third global revolution has been referred to as the information revolution and the knowledge revolution. I prefer the term knowledge revolution and will tell you why in a moment, but I think that this knowledge revolution is very profound. Where the past revolutions were driven by machinery and mussel, now it is brain power that impacts all these outputs that we think of.

The revolution that we are living right now is still young, this is the end of the beginning. It affects all aspects of science, technology and innovation.

We should recognize that in this field today, biology is taking enormous new steps and we can genuinely say we are on the verge of an enormous transformation of the biological sciences and their impact on our society and our living.

I remember in 1997 when Dolly the Sheep was first cloned. She made a huge impact back then, but it was all part of the steps leading us to where we are today. There was a lot of media attention at that time but fundamentally, the biological sciences are just beginning to come into their own now. They are about to start opening a lot of new doors in practically every field of human existence.

My colleagues throughout this conference will be addressing how all of this is linked to society in the areas of health, agriculture and food, the environment and industry. I will talk about something different. I will talk about the knowledge revolution itself – not how knowledge in the biological science is going to impact this field or that.

When you organize data it becomes information. When you explain this information it becomes knowledge. But how do you use that knowledge in society? This requires wisdom.

Wisdom is different from knowledge. It requires knowledge, but it is knowledge coupled with judgment and a pattern of experience to arrive at an understanding of the consequences of the actions we take in the deployment of science and technology throughout our societies.

It is an important classification, as the great poet T.S. Eliot wrote a century ago: Where is the Life we have lost in living? Where is the wisdom we have lost in knowledge? Where is the knowledge we have lost in information?

Sometimes you drown in information but you do not have knowledge and sometimes you have knowledge but you lack wisdom. I think it is an important distinction.

I will move to the fact of why I think we are living in a vastly changing world. A world that we all know, but one that has been transformed profoundly, far more profoundly than anybody could imagine, by the new information and communication technologies: An ICT world.

More importantly, I will talk about the seven pillars that make up this transformative revolution which is more profound than anything we have lived through in knowledge and throughout human history. I rate it close to the invention of writing, which was essential to cumulate knowledge and transfer it across space and generations.

Today, the scale of the revolution is of similar size and magnitude. We know and feel that we have moved through different stages of the Internet. The initial model was that someone would produce knowledge, someone would post it, and everybody else read it. Now we enter the age of Web 2.0, where everyone is both a producer and a consumer of knowledge.

Social connectivity is also being transformed, who could have predicted 10 years ago the impact that Facebook would have? Even Mark Zuckerberg himself could not have expected it. We are moving from connecting information to connecting people. Today, we have a very high degree of connectivity when it comes to knowledge.

More changes are already on their way. They are already starting to use modulated light to send data. This could allow transfer rates of up to ten GB/second. This would be enough to download the equivalent of a high definition DVD movie in less than 30 seconds, provided that there is a way of doing so legally! This is an example of the transformation taking place and beyond tomorrow, who knows what is going to happen?

I believe that what makes this revolution the most profound transformation since the invention of writing are these seven pillars that I will present.

The first pillar is what I call parsing. It is how you divide knowledge itself into living and dead. Throughout history, whether we are writing on tablets or scrolls or books, whether they are written as manuscripts or published, we parsed knowledge like building bricks in a wall. We build an edifice.

Today the parsing is done on websites with webpages. Now the distinction is very important, because the question is whether it is dead or alive? What I mean is that if we hold two copies of a book and you look up page 157 and then I look up page 157 the first line in my book will be the same as yours. I can tell you please look up such and such a book and such and such a page and you will find it. Ten or 30 years from now you will find it again and it shall be that way until there is a new edition of that particular book.

On the other hand, if I tell you look at such and such website then by the time you go there 10 minutes later it may have changed. It may have been updated. It is a living, constantly updated reality out there and that is why we have our little robots that photograph all the pages on the Web to create the Internet archive.

Yesterday, the documents were dead. Knowledge had a well known structure. Today the documents are alive and can be updated constantly. Instead of presenting material through introduction and arguments we look through a site map where we search and browse.

We are already starting to inject images and videos into websites and tomorrow the parsing which has already been reduced by the webpages hypertext will continue. Different concepts will emerge into the text itself such as 3D interactive images. There will be advanced search tools for this material across a semantic Web.

Language will no longer be a barrier because everything will be automatically translated into the language of your choice with this new Web. All of that is not that far away, we can see it coming. The transformation in the manner in which we produce and communicate knowledge, how we change that knowledge and how we search for it is going to change itself.

Instead of the bricks, instead of the few people talking to each other, instead of posting text on the Web, we are really talking about a living, vibrant, changing, interconnected knowledge base that connects people throughout the planet. All this is happening instantaneously. It is a living, pulsating being — almost like one giant brain with neurons firing off in all directions across the whole planet.

The second pillar is image and text. If you look throughout history, we have mostly relied on text rather than image, partly because it was difficult and expensive to produce images. Now, everybody is photographing and shooting videos and putting them up on the Web. Images call on different parts of our brain. Human brains are much more efficient at processing images than they are at processing text. You can describe in great detail what a cone looks like or you can just look at a picture of the cone.

Imagine you open a door to a room and close it again in a fraction of a second. Your mind has captured a reality of the room. You can say how big it is, approximately how many people are there, the carpet's colour, the ceiling's colour, what did the chandelier look like, there was a table, people sitting there, two women, four men, if there was something on the table or not, the table was made of wood or of metal — all of that has been captured and processed in a fraction of a second.

I imagine trying to communicate the same thing in text, the effort it takes is very different because text uses a different part of our abilities. It has three layers of abstraction. There is the abstraction of the letter itself, the abstraction of the word composed of letters and there is abstraction of the sentence composed of words. Thus the reader, unlike the person who simply receives the image, has to interact with the text and build their own mental images.

Images enable us to do things which we could not do before using new technologies. We can use images to go down to things that we cannot even see with our naked eye. We have the possibility of going beyond the visible light or use thermal imagery to capture images using temperature to see things we cannot normally see. We can visually communicate things that we could never communicate before.

The notion of image and text as a way of structuring and communicating knowledge is changing because images are becoming so easy to use. I have never been in space but I have vicariously enjoyed the experience of astronauts through the images that they were taking and communicating back to Earth. All of this enables us to expand our horizons, whether we go deep underwater or out into space. We are seeing things we could not see before. Images made available through new technologies are going to enable us to communicate in ways we could not before.

The third pillar is really about the relationship between humans and machines. I believe Kevin Warwick will be joining us again. I think he is the first human cyborg who actually imbedded a chip into his arm and communicates directly.

We now have brain-computer interfaces that make all kinds of new interactions possible. With the exception of pure math and some areas of philosophy — such as reflections on the purpose of life and the meaning of the universe — in every other field of knowledge, such as social sciences, literature, geography, history, etc, it will be impossible for human beings to search, find access and collect this information without computer assistant.

We will need machine mediation. It is not good or bad – we just cannot access information anymore without machines. We need a lot more machines because of the vast amount of information which is consistently changing. Therefore, now if I want to write about topic "A", I must find out what other people have said about topic "A". That involves an enormous capacity of search that only machines can do. It is not the ubiquitous computer but it is being replaced by a supercomputer and handheld devices.

There is currently some machine translation, but it will be much more effective in the future and it is coming very soon. All this is going to expand the brain reach beyond anything our parents could imagine and this is really the tipping point that justifies calling it a true revolution. On the flip side, there is the other side of machine human interface. It is not just to be able to read the thoughts of humans, but also whether we can and how far are we willing to go towards building artificial intelligence and the emergence of qualities of consciousness.

People say that today the human brain is about a million times more powerful than the most powerful computers. Well, computers are gaining power every day, what happens when the computers are a million times more powerful than human brains? Who knows what will happen?

The fourth pillar is complexity and chaos. I think we all recognize that our lives are now incredibly complex. Thus we will probably need new mathematics to deal with it. It is also chaotic — chaotic in the scientific sense that it has nonlinear feedback loops and therefore makes the prediction of a particular position of a system at a certain time in the future extremely difficult or subject to enormous uncertainties. These new mathematical tools will be required for the next round of innovations.

This brings me to the fifth pillar, which is computation and research. I believe that this new revolution is not just about the mathematics or the understanding of science, but it will give rise to new concepts and theorems along with tools from computational sciences. Information theory is going to be injected into the scientific research paradigm.

Let me give you an example. In the past, we have always been building data collections in science, but now we are increasingly changing our approach. Now, we are looking for connections between collections of data. This requires alternate ways of thinking and new tools. Our colleagues in the computer sciences and information theory fields have been thinking about this for a long time.

As with statistical concepts, some of these new technologies have found their way to physics and quantum physics everywhere. I think these ideas and theorems of computational sciences will increasingly find their way into the natural and social sciences. They are already leading to new ideas. Everything from new computer architectures to new pathways, new clusters to new network controls, neural nets, multidimensional manifolds, virtual communities, real communities, and who knows where tomorrow will take us with things changing so fast.

The sixth pillar is convergence and transformation. At one point, we used to have chemistry and biology. We now have biochemistry which is easy for anyone to relate to. I believe we are living the era of BINT — which in Arabic means girl — but in fact stands for bio-info-nano-technology.

These sciences are starting to converge and thus become new exciting and fertile ground in which new ideas can take root and grow. It will present new concepts and technologies that are going to impact our societies in major ways.

The second part is what I called transformative research. UNICEF actually used that term to describe research that changes the paradigm in some fields. In biology, for example, the discovery of the structure of DNA is rightly held as a transformative discovery and a milestone. Today, synthetic biology might be the next area for transformative research.

The question is whether, with all of the other tools I was talking about, we will be able to promote transformative research and not just let it happen when it happens. I believe that transformative research can be nurtured if we understand the way the structure of knowledge is changing. The society that will master this first will be the one able to move forward fastest.

The seventh and last pillar of this transformation is pluridisciplinarity and policy. This complex world is extremely chaotic and our actions are having an important effect on the environment. The environment and the ecological balance are themselves very complex systems. Biological systems are very complex systems. Neural systems are extremely complex.

In order to engage in properly informed policymaking, multidisciplinary approaches are necessary. We need the wisdom of the humanities and the ability of social sciences tied to natural sciences to be able to forge together sensible ideas and effective policies.

I will simply say that through these seven pillars, we are actively inventing the future at present. Change is happening with incredible speed because of them.

Science is transforming the very structure of the world into this incredible revolution of knowledge we are living through. We in the Library of Alexandria are proud to enjoy you all as artisans of a better future for Egypt and for the world. Working together, there is so much we will be able to do for the upcoming generation of young people.

Fostering a Strong Japanese Bioindustry

Koji Omi

Despite uncertain circumstances, BioVision is taking place as scheduled. This Conference is the fruit of the strong initiative of our distinguished host, Ismail Serageldin. I am very grateful for his leadership in organizing it.

I would like to express my thanks for the generous assistance from all over the world after the disaster that hit Japan last year on March 11, 2011. We truly appreciate the support that so many people offered us.

Over 19,000 people were killed or are missing, and almost all the fatalities were due not to the earthquake, but to the tsunami which came 20 to 30 minutes afterwards.

This natural disaster severely affected supply chains and manufacturing operations at industries in the region. But production in the automobile and other industries soon resumed and now, one year later, has recovered to almost pre-disaster levels.

In the accident at the Fukushima Daiichi nuclear power plant, the reactors were successfully shut down immediately after the earthquake, but later an unexpectedly high tsunami knocked out the emergency cooling systems.

Ever since then, people have worked tirelessly to bring the reactors under control. There have been no human casualties due to radiation, and a state of cold shutdown of the reactors was achieved by the end of the year.

Notwithstanding this disaster, I believe that, from the perspective of future energy demand and supply, cost and the environment, nuclear power will continue to be one of the major options as an energy source.

Measures should be taken to better protect nuclear power stations everywhere against tsunamis. What we learned from this accident will help us develop the best possible safety technology for nuclear energy.

A science-based economy

Japan is a country that is poor in natural resources but has a strong focus on high quality science and technology. Automobiles, electronics, and chemicals production are world-class industries in Japan, and while the pharmaceutical sector provides a major industry, there is still plenty of potential for growth.

There are a number of reasons for this. First, Japan's public health insurance system ensures accessible and affordable healthcare for everyone, thus drug prices tend to be kept low. Second, while basic research in Japan, such as in the field of induced pluripotent stem cell, continues at world-leading levels, clinical research is less advanced and takes a long time to develop. Finally, the examination and approval process for new drugs can be rather slow.

For all these reasons, Japanese drug manufacturers contend with many handicaps that their counterparts in other countries do without. As a result, the Japanese drug industry lacks a presence proportionate to the potential of the Japanese economy.

To counter this, the Japanese government has been expanding basic research, aiming to create innovative drugs and medical devices. Recently, it began to strongly promote its "Life Innovation" strategy. The main components of this new strategy are setting up a system for clinical research, which includes selecting and funding five medical institutions to serve as core facilities to conduct this research, and speeding up the new drug examination and approval process.

These measures will help make Japan's bioindustry more competitive in international markets and allow the country to offer even greater contributions to human health.

Science and Technology in Society forum

Now, I would like to say a few words about the Science and Technology in Society (STS) forum, which I founded in 2004 and where I serve as chairman.

On one hand, the rapid progress of science and technology has brought economic growth and enriched our quality of life. On the other hand, science and technology has brought about new environmental, ethical and security problems, such as climate change, chemical weapons and privacy issues in information and communication technology.

We call these the lights and shadows of science and technology. We must strengthen the lights and control the shadows of science and technology for the long term future of humanity.

For this purpose, it is important for not only professional scientists and academics, but also policymakers, business executives, media leaders, and government officials to meet and exchange views on how to deal with science and technology issues for the long term benefit of humankind. These are not issues that should be left only to science professionals; they concern all of us and we must all think of them as our own problem. This is the fundamental concept of the STS forum.

Around 1,000 participants from all over the world usually attend the STS forum. Our 8th Annual Meeting last year included 9 Nobel laureates, 23 science and technology ministers, and more than 50 university presidents among the participants.

We are now making preparations for our 9th Annual Meeting, which will take place in Kyoto, Japan, from October 7 to 9. This year's themes include energy and the environment, nuclear safety and development, global health, university research and education, sustainability, and science and technology diplomacy.

At last year's STS forum, the statement issued at the conclusion of our Annual Meeting included the following words about global health:

> "Research into genomic and regenerative medicine has been developing very rapidly. Under these conditions, research into personalised and preventive medicine should also be accelerated. Capacity for dealing with infectious diseases as well as non-communicable diseases in developing countries must be strengthened. A new international system is needed for better collaboration between industry, the public sector and the WHO."

Science and technology must be used for the benefit of humanity. We can say that most of our current challenges were brought about by the development of science and technology. But in the future, science and technology itself will be the key to achieve solutions for the long-term successful future of humankind.

BioVision Alexandria and the STS forum, working to ensure a brighter future for humanity, share a common objective, and we will maintain a cooperative relationship.

Life Sciences, Policy and the Developing World

Romain Murenzi

Today, it is widely recognized that science and technology are key to development — both in developed and developing countries. Nearly three decades ago when TWAS, the academy of sciences for the developing world, was created, that was not the case.

At that time, many experts contended that developing countries simply did not have the financial resources to build their own capabilities in science and technology. Instead the prevailing wisdom was that poor countries would be wise to buy science and technology from those rich countries that could afford such "luxuries."

TWAS begged to differ. The Academy's vision, together with its fellowship, research and awards programmes, account for its excellent reputation.

Because our membership selection criteria are rigorous, being a TWAS member is a badge of scientific excellence in the South. The strength of this membership — currently 1,036 of the world's most eminent scientists — allows TWAS to act as "the voice of science for the South" — and to undertake a range of programmes aimed at building scientific capacity in the South with the cooperation and tutelage of its best scientists.

It is a desire to strengthen the link between science and society in the developing world that is intrinsic to all of TWAS's endeavours, the programmes it seeks to fund, the sponsors it hopes to attract, and the partners it chooses to work with.

I am sure that all of us agree that investment in STI is crucial for long term economic growth and poverty alleviation. But what will STI look like at the end of this decade, or the next? How will developing countries cope with the main scientific challenges of our time? What will they do about critical issues such as climate change, increasing energy demands, food and water security, population control and conflicts resolution?

Facing the challenges

Many of the global societal challenges the world is facing now are also life science challenges. In particular, the world food shortage and issues of food security will be dramatically affected by genetic engineering and agricultural research. Climate modelling and disease forecasting systems will allow scientists to predict the likelihood of an epidemic and enable policymakers to put necessary procedures in place in time to prevent large scale spread of diseases such as malaria and rift valley fever.

Indeed, knowledge — and scientific knowledge in particular — is the single most important element that will enable developing countries to win their long term battle against disease and poverty, and to respond more effectively to natural disasters.

Science, and life sciences in particular, can make a massive difference. This is done through innovations that can reduce costs or increase productivity, newly discovered or created substances that can prevent or cure disease and surveys and data mining that can identify patterns and changes, both global and local. But these research findings, crucially, must be shared with decision makers and converted into appropriate national science policies.

In 1957, Robert Solow, an American economist, shared research results which showed that only 12.5% of US economic growth between 1909 and 1949 came from capital and labour. By far the biggest contribution (87.5%) was due to scientific and technological progress.

Professor Abdus Salam, the Pakistani Physics Nobel laureate who founded TWAS, always said that "developing nations need to help themselves and invest in their own scientists to boost development and reduce the gap between North and South."

Of course, each country has to make the best of its natural resources and invest in human capital and youth. But above all, developing countries need to commit to a massive investment in STI.

While some developing countries, such as China, India and Brazil, have moved to become powerful emerging economies, TWAS has identified 81 countries that still lack STI capacity. That translates to 81 countries with inadequate means to combat poverty and disease. Our main objective is to build up the long term STI capacities of these countries sustainably.

TWAS does this through a series of coordinated programmes and activities in 4 main areas:

- PhD training fellowships
- Human capital mobility to strengthen South-South and South-North collaboration
- Research grants to respond to the needs of young scientists
- Competitions to encourage innovation and honour excellence.

Research training

We provide PhD fellowships for the next generation of scientists. Without a critical mass of professors with doctorate-level research, there is no way a country can ensure the latest developments in scientific knowledge are passed on to teachers and students in order to build up a knowledge base in science.

TWAS administers and co-sponsors the largest South-South fellowship programme in the world. We currently have around 300 fellowships available per year (including PhD, postdoc, visiting scientists, research and advanced training). Around 50% of all of these are awarded in the life sciences.

In order to administer and fund these programmes, TWAS has established 12 programme partners in eight countries in the South (Brazil, Malaysia, China, Mexico, India, Pakistan, Kenya and Thailand). The partners cover stipend and accommodation, TWAS covers travel, visa and administration costs.

Human capital mobility

We provide opportunities for scientific exchange with colleagues in technologically advanced countries, and with emerging developed countries. Too many eager and young scientists are being deprived of opportunities, stimulation and challenges. Besides the PhD fellowships, TWAS offers:

- South to South postdoctoral fellowships;
- South to North visits from sub-Saharan Africa to Germany;
- TWAS research professors and visiting scientists exchange programmes;
- Support for scientific meetings.

For example, on our Joint Associateship Scheme, an associate is appointed for three years and visits a centre of excellence in the South twice during that period. Over 100 centres have been selected. TWAS provides travel support and a subsistence contribution (up to US$300 per month) and the host centre provides living expenses. Between 2007 and 2011 TWAS sponsored 135 of these associates, including 39 associates working in life sciences.

Research support

We provide grants and funding for students from the South to continue their studies, or to acquire the essential laboratory or technological equipment that they need. Between 1986 and 2011, TWAS awarded a total of 2,024 research grants, spending US$11 million in total.

Competition

TWAS prizes are given for significant contributions by scientists in the South. Prizes for young scientists are awarded on behalf of TWAS by organizations in the South. Competitions stimulate innovation — and prizes for the winners of competitions reward and honour those scientists in the South who have made significant achievements in their field.

Prize winners in targeted areas can also serve as role models to encourage those who are generally underrepresented in science to apply for training programmes.

Shared vision

There is a long history between TWAS and BioVision Alexandria. Indeed, the theme of this conference is New Life Sciences: Linking Science to Society, and I would like to describe TWAS's partnership with BVA as, in fact, breathing new life into the links between science and society, most particularly in the developing world, by choosing to focus on young scientists.

Eight years ago, for the first time in the history of BioVision Alexandria, the Center for Special Studies and Programs (CSSP) at Bibliotheca Alexandrina and TWAS organized TWAS/BVA.Nxt. 'Nxt' refers both to the next generation and to innovation. It was a window into the younger generation's direct and innovative relationship to new technologies.

The event ran concurrently with the BioVision Alexandria 2004 conference and the idea was to provide a forum for promising young scientists from developing countries working in life sciences to meet, share and collaborate with other young scientists from the South working in their fields. It also gave them the opportunity to meet and rub shoulders with senior experts and Nobel laureates in an informal gathering.

At each TWAS/BVA.Nxt conference since then, around 100 young scientists from around 30 developing countries have come together. They have the opportunity to showcase their research in the poster sessions and share their ideas during the main conference. The event also includes discussions with eminent researchers that enable budding scientists to exchange ideas and hopes as well as the fears, doubts and difficulties they face in their respective countries. The discussions are aimed at finding the ways and means of overcoming some of those difficulties.

This model of finding real solutions to what are often practical difficulties that researchers in developing countries have to overcome, as well as seeking out opportunities for young scientists to collaborate and network, goes a long way towards building a foundation for sustainable scientific development. This is what we at TWAS refer to as 'capacity building' in developing countries, and what we consider our most important mission.

In order to build science capacity in the developing world, it is crucial that the diverse funding bodies in the various sectors in each region are able to meet and work on a coordinated, collaborative effort. It is absolutely crucial that ministers of governments should speak with development agencies, global banking institutions, private industry, and scientific research institutions to discuss the difficulties and obstacles facing developing countries, as well as identifying success stories and possible ways forward. In this way a coherent package of funding can be developed.

Building STI capacity requires a massive team effort. It is clear that when this kind of cooperation is not in place, mistakes are made: some projects are duplicated, some necessary projects are never undertaken, and funding is wasted.

The knowledge that we share here, the research that we discuss and disseminate, eventually, ideally, will make a real difference to people's lives in developing countries.

The Remarkable Chemistry of Life: Protein Machines and Emergent Properties

Bruce Alberts

It is a pleasure to be back here in Bibliotheca Alexandrina for BioVision 2012.

I was a high school student when Jim Watson solved the structure of DNA in 1953, which truly started the revolution that we are seeing now — understanding life in molecular terms. Watson was only 25 years old. I am a big believer in young scientists. I became a professor at Princeton first when I was 28 years old. That is how it used to be in the United States. Unfortunately, in our society and many others, younger people do not have those kinds of opportunities that early any more.

In general, I am a big fan of the new young academy movement, started initially in Germany, then in the Netherlands, and now spreading through something called the Global Young Academy. I would encourage Egypt to form a young academy, since we all need to do more to empower young people.

The next major breakthrough after Watson and Crick was made by Arthur Kornberg, another Nobel Prize winner, for the discovery of DNA polymerase enzyme. At one point, it was thought to be the enzyme which alone copied the DNA double helix as Watson and Crick had predicted. But when I came to graduate school, this became my first scientific problem as a graduate student.

The problem was that this enzyme only works on DNA when it's single threaded, and yet we know that DNA is a double helix inside the cell, and that was what Watson and Crick actually showed. Also, the DNA polymerase molecule only runs in one chemical direction but the two stands of DNA run in opposite directions, so as Watson and Crick had shown, they are anti-parallel.

I was inspired, as many others were in my generation, by Watson & Crick's successful theory. I decided I'll make my own theory. I made a theory about how DNA polymerase might be able to start its DNA synthesis on a double helix, even though it only worked on a single-stranded DNA. I did many experiments trying to see if the theory was right, and of course the theory was not right. The many NO answers did not surprise anyone and did not add to the store of scientific knowledge.

Nevertheless, my professor thought after five years I was ready to get my PhD, and nobody else had ever failed their PhD at this stage at Harvard as far as I knew. I walked into my examining room with famous professors, and to my surprise and shock I failed. I wrote all about it in *Nature*, because everybody fails, and in retrospect, this failure was one of the most important ways I learned how to do science. I did not really know how to do it until I had to think deeply about what went wrong.

I eventually got my PhD and went on to my post-doctoral in Geneva, Switzerland. I later learned that I should have been reading the scientific literature. In the middle of my PhD thesis, Richard Epstein and others at Caltech had published a beautiful paper on this model organism bacteriophage T4, one of the early model organisms used by Max Delbrück and his school as the means to start the field of molecular biology. This paper that I had missed showed that there are, in fact, seven different proteins required by this virus replicate DNA based on genetic studies that these authors had done.

I then spent more than the next 20 years working out what these proteins did through the field of biochemistry. What we and others found was that DNA is replicated by a complex that works very much like a machine, call it a protein machine. It moves DNA through very rapidly, copying both strands, and because that requires two DNA polymerase molecules going in opposite directions, this one strand, the lagging strand, has to be made in short pieces as it goes.

In retrospect, protein machines make life possible. Almost every process in the cell is now recognised to be driven by a complex of ten or more proteins. These protein molecules function very much like the machines in everyday life that are driven by electric energy. They undergo ordered movements and are driven not by electric energy of course, but harness the energy of ATP or GTP hydrolysis.

Scientists are discovering things that are amazing, beautiful and elegant in nature. There are several personal lessons I learned from this.

First of all, if you are going to do science, go after some mysteries. If you solve a mystery, you actually make a contribution, because you know something that we don't understand, needs to be understood, will relate to so many other things and help other scientists learn more.

Secondly, there are many remarkable homologies between living things. Therefore, use a model organism wherever possible. That is easier and simpler to work with, and then you can make your way up to understand human cells. For example, the mechanisms we found in simple organisms like viruses and bacteria are the same as those in human cells — except there they are more complicated and involve more proteins, making them hard to study without the guidance of the work with simpler organisms. I can say that about almost any process in human cells.

Finally, nearly all cell processes will be based on elegant mechanisms that are too hard to predict by biology alone because of the complex nature of the chemistry of life. Biochemistry is the science that allows the reconstitution of many hundreds of protein machines to their purified components and figuring out how exactly they work.

As a biochemist, I am very concerned that we need many more biochemists. I hope you are going to recruit some Egyptians in the audience to help us, because biochemistry is the only way we can figure out how these protein machines work. We need to know quantitative information and rate constants and affinities. We can only claim to understand the machine when we can accurately predict the effect of altering any of these parameters, and for most protein machines and cells, we don't have that information and are far from understanding them. We often know what they are made of, but we don't understand them.

I also learned a lot — not from my failures and research — but from textbook writing. I have been writing textbooks since 1978. The last book had all of us six authors sit together for more than 365 days working on it. We never thought we would finish, and we almost quit at one point. We did all the work sitting around the corner in a house in London.

When we were done, we decided to emulate The Beatles and release it in a big trip. For some reason, we decided to go to the Chilean Air Force base in Antarctica. There I presented the 5^{th} edition of our textbook to the military general who ran the base, and he set up a special podium in the middle of Antarctica. He didn't know why he was there, I was wondering why I was giving him a book, but fortunately there was a young medical student who was the doctor who was going to be there for the next two years through the dark winter. This was his summer.

One of the many things we learned by writing is that we used to think that biochemistry in life means when A goes to B goes to C goes to D goes to E. Those are pathways. In fact, positive and negative feedback loops underlie the entire chemistry of living systems. That is the only thing that makes them stable. That is the way all cell biology looks, even when we gain complete knowledge. We can have complete knowledge of molecules, protein machines, and molecular interactions inside of a cell, but we will not be able to understand it. It is too complicated. Instead, life reflects the emergent properties that result from very complex networks of interactions.

To try to work our way to understanding, we are going to need new mathematical/computational models to decipher these systems. We do not have them yet, we have some of them, we have starts, but we are not there yet. One example of these starts is a method making use of powerful computers called agent-based modeling.

These models require a large amount of quantitative data, otherwise it is just theories. Biology is too complicated for this. So before you start, you need to know exactly the set of interacting molecules and their molecular structures. You need to know all the partners and the rate and equilibrium constants for forming each partner. Finally, you need to be able to manipulate the system. You need to understand the behaviour of this set of molecules, both in a purified system of proteins and in living cells, and manage to move from theory to experiment. Otherwise, you just have a theory that you can't test.

This means you have to start with model systems that are much simpler than the entire process. Of course, when you understand the fine protein, you can then expand to bigger systems. You need more data, more computation and more collaborators. My conclusion is that it will probably take most of the century to gain any true understanding of how cells and organisms work. We need much more biochemistry in purified systems and new quantitative methods for analyzing and understanding the enormous complexity of life's chemistry.

Now I have a little bit on innovation. We must work to simulate innovation. To do this you need to recognize how new knowledge arises. The fundamental reason for the explosive growth of science is simply that 100 units of knowledge can be combined in a 100 times more ways than can 10 units of knowledge. The more knowledge you have, the more innovation and creativity you can generate and the faster science can move.

But there is a catch. As knowledge grows, it becomes increasingly difficult to find the right combinations. Doing outstanding science is like doing art, it is a very creative process. The problem I see today arises from how our systems channel research topics due to training inertia. A famous scientist will have a lot of people fan over him or her, who will then go out and do the same kind of work they did in that lab. They will then have more students who become the grandchildren of the first scientist.

There are all these red areas of overcrowded experimental spaces where people are racing each other to find some result, while there are other unexplored experimental spaces in cell biology and other fields where nobody is using modern techniques. Our job as older scientists is to try to help young people to jump from the red spaces to the white spaces.

I think in general, we should encourage our institutions to support a set of laboratories of modest size, maybe 10 people or so, each headed by an outstanding, innovative independent investigator. These laboratories should be clustered, and embedded in a cooperative culture in which techniques and equipment are freely shared, people go back and forth and students use equipment in every lab.

Most importantly, our reward systems must change to strongly encourage risk taking and originality, and we have a lot of problems in that right now. Finally, everything must be done to encourage a random collision of people and ideas. That is how you get new ideas. That is why we tell the students to go to seminars. We want to get to two seminars a week. Go to the ones you know nothing about, that is where you are going to learn something new.

So in summary, where are biology and medicine going? We now know that the chemistry of life is incredibly complex — by far the most sophisticated chemistry known. Most of the interesting aspects of life are due to emergent properties that stem from very complicated networks of chemical interactions, whose consequences cannot be deciphered from the details of a few individual parts alone. The human mind cannot really work with that complexity, so we need innovative new methods and approaches before we can claim to understand even the simplest living cells.

I would like to just end with the theme from this morning, the values of science. Jacob Bronowski was a physicist and a great humanist as well. He wrote his wonderful book *Science and Human Values*, which looked back at history and the good and bad effects that science has had on the world, and included this passage:

> "The society of scientists is simple because it has a directing purpose: to explore the truth. Nevertheless, it has to solve the problem of every society, which is to find a compromise between the individual and the group. It must encourage the single scientist to be independent, and the body of scientists to be tolerant. From these basic conditions, which form the prime values, there follows step by step a range of values: dissent, freedom of thought and speech, justice, honor, human dignity and self respect.
>
> "Science has humanized our values. Men have asked for freedom, justice and respect precisely as the scientific spirit has spread among them."

Finally, my message to the young scientists here today is that there are many wonderfully exciting challenges for you, so be creative and intellectually ambitious.

Urban and Rural Development: Sustainability for All

Kanayo F. Nwanze

I am delighted to be here for BioVision 2012 in Bibliotheca Alexandrina in Egypt, the bread basket of the ancient world, and in this spot of ancient learning. Over the millennia, Egypt has given the world so much, and yet in many ways the nation seems younger today than it did even two years ago.

These meetings provide an invaluable opportunity to learn from each other, sharing our experiences and ideas. And, as a former research scientist, it is always a pleasure to spend time in the company of fellow scientists.

There is a direct and strong link between investment in research and the elimination of poverty and hunger. As a scientist, I like to base my conclusions on solid evidence, so let me share some numbers with you from the International Food Policy Research Institute:

In China, one person was lifted out of poverty for every USD109 spent on agricultural research. In Uganda, the impact of research was even more dramatic, with one person lifted from poverty for every USD16 spent on research.

A separate report by the agricultural research group CGIAR indicates that every USD1 spent on agricultural research produces USD9 worth of added food in developing countries.

Science and technology are the foundation of agricultural development because they can generate pro-poor technologies. For example, it was research that generated Quality Protein Maize. QPM has been widely used by farmers and is reducing malnutrition among adults and babies in developing countries. It was also research that generated high yielding cassava varieties in West Africa.

And it was research, which I'm proud to say I had a hand in, that led to the elimination of the cassava mealybug — which could cause up to 80% crop loss — through an Africa-wide biological control programme.

As a result of this IFAD-funded research programme, at least 20 million lives were saved in the cassava belt of sub-Saharan Africa, as well as about US$2.2 billion in production. The total cost of the programme was only US$20 million. In other words, for every dollar spent, one life was saved.

The theme I'm discussing today is one that is dear to my heart: Sustainability for all.

It sounds like a lofty goal, but I can tell you that sustainability is well within our reach. I know this from my 20 years of working as a research scientist at CGIAR, my 10 years leading the Africa Rice Centre, and the five years I have now spent in the world of rural development at IFAD.

When development is sustainable, the benefits last through the years and the generations. It is development that respects and responds to local conditions, whether cultural or environmental, so that the changes are able to take root and continue long after the aid workers and development agencies have up and left.

We have all seen the aftermath of what happens when development is not sustainable – we have seen the broken tractors abandoned in the fields, the withered and untended trees and the forsaken hillside terraces.

Building sustainability

There are three pillars to the sustainable development agenda: economic, environmental and social. Smallholder agriculture is central to all three elements.

In Mauritania, IFAD is working with smallholders to promote sustainable solutions to combat desertification and mitigate the impact of Prosopis juliflora, an invasive tree. It was initially introduced to protect the oases from sand encroachment, but is crowding out the local palm trees and depleting ground water.

These examples of good intentions gone bad are the results of interventions that did not properly respond to the local ecology or terrain, or where the sociology or psychology of local populations was not fully understood.

As scientists and researchers, we often tend to focus on biological and physical experiences. But in my years of working in development, I have learned that science has the greatest impact when it is combined with an understanding of the softer sciences. In order for science to truly improve the conditions of poor rural people, scientists must understand the environment where their discoveries will be used, and the needs of the people who live there.

In other words, if we want our work to be sustainable, we must apply the same rigor of thought to understanding the social dimension of local communities and the ecological dimension of local landscapes as we apply to our research in the laboratory. At IFAD, we see time and time again the transformation that occurs when development is sustainable and when local people are involved from the get-go.

Last year, I visited Zongbega, a village in a drought-prone region of Burkina Faso, where smallholders are using simple water harvesting techniques, such as planting pits and permeable rock dams, along with crop and livestock integration. As a result, they have restored land that was once degraded and have increased their productivity thanks to low-input, yet high-output, pro-poor innovations.

In Niger, a water harvesting project in the Illela department is still ongoing more than 15 years after the funding ended. The project encouraged farmers to improve traditional planting pits and half-moons. The pits are dug before the rains. They collect and store rainfall and run-off. The half-moons are earth embankments in the shape of a semi-circle. They are much larger than the pits and are also used to capture run-off water. Although the development project ended in 1996, a return to the area in January 2012 showed that farmers are continuing to make pits and half-moons.

There is also considerable anecdotal evidence that the water harvesting techniques are recharging the groundwater. In the village of Batodi in the Illela department, the water level in wells increased by 14 metres between 1994 and 2004, which has led to the creation of 10 vegetable gardens around wells. The increase is unlikely to be the result of rainfall, since 2004 and 2011 were both drought years.

The adoption of these simple water harvesting techniques probably forces rainfall and runoff to infiltrate the ground and locally recharges the groundwater. Twenty years ago, the fields around the village of Batodi were completely barren. Today, they have higher on-farm tree densities which helps keep the soil fertile and provides fodder for livestock. This is a fine example of the benefits of community-driven development.

As you can see from these examples, it is not always the most advanced technology that reaps the greatest rewards. Sometimes, the best way to grow food in an arid climate is to go back to basics, building a rock dam to stabilize soil and collect water runoff, or constructing cisterns to collect rain water.

This is particularly true in areas such as Africa's drylands, where soils are inherently poor. It is vital to first increase soil organic matter content. This determines whether inorganic fertilizers can be used efficiently, but also leads to more infiltration of rainfall and increases the water holding capacity of topsoil.

Saving rural areas

Not only does rural development contribute to food security, but the economic opportunities it creates can help stem the flood of immigrants to cities and provide career opportunities for young people, who are the life-blood of their communities. About 90% of today's young people are born in developing countries, where around half of the total population lives in rural areas.

When these young people are forced to leave their homes to search for work, their villages start to die. But when they can make a good living at home, their energy and creativity can be channelled into reviving their villages. When considering that developing countries will need to double their food production by 2050 to meet projected demand, it becomes imperative to create vibrant rural economies that offer attractive opportunities to young people.

We will need these young people to be the farmers and food processors of tomorrow, not just to feed themselves and their villages, but to grow the food needed to feed the rising populations in urban areas in developing countries. After all, farming is primarily a rural activity. Vibrant rural areas can ensure a dynamic flow of economic benefits between rural and urban areas so that nations have balanced and sustained development.

Investing in young rural people is a simple yet elegant solution to some of the world's most pressing problems. It helps eliminate poverty and hunger, it curtails migration to cities and abroad, and it lays a solid foundation for national, regional and global security. Young people without prospects have nothing to lose, and are more easily swayed by extreme rhetoric. When rural communities offer young people a range of income-generating opportunities to choose from, more will decide to stay in the villages and resist the call of often dead-end futures in the cities, abroad or in extreme religious or political movements.

A holistic approach

But in order for rural development to take root and hold, we cannot look at issues in isolation. There is no point increasing a farmer's yield if that farmer does not have the storage facilities for surplus production, or if there is no demand for what they are growing. There is no point increasing yields if the infrastructure does not exist for farmers to be able to get their produce to the market.

As scientists, when we look at how best to support smallholder farmers we must not only improve their ability to grow food, but also strengthen their ability to participate in markets, while also improving the way those markets function.

More than one third of the rural population of sub-Saharan Africa lives five hours from the nearest market town, contributing to unacceptably high transport and marketing costs. We must ensure that there is sufficient investment in rural infrastructure, with paved roads, adequate transportation and storage facilities to allow farmers to get their produce to the market instead of watching it waste on the farm.

We must also include a relevant role for the private sector. Private sector involvement, ranging from large companies to small famers and their organizations, is critical in allowing agriculture to contribute most effectively to food and nutrition security.

We must recognize that women are usually the most disadvantaged members of rural societies, even though they are often the farmers of the developing world. It is estimated that giving women equal access would reduce the number of hungry people in the world by 100 to 150 million people. And we know, from a number of studies, that when women earn money they are more likely than men to spend it on food for the family.

In addition to improving rural economies, we must change the perception of farming so that young people stop trying to escape the farm and instead look at farming as an attractive option; something that is as appealing as a career in high-tech, fashion or industry. This means affording dignity to all wage-generating work, whether tilling the fields, running the village store or heading a small business.

And, of course, as scientists we must also consider the impact of our work on the physical environment. Agricultural research successfully drove the first Green Revolution in Asia, but as we have seen in the decades that followed, too often it came at too great a cost to the environment and local species. And all too often, the spectacular gains of early years could not be sustained. It has become clear that agricultural growth must be ecologically sustainable and that a diverse range of species, genetic variation and ecosystems is necessary in order for the land to provide for future generations of farmers.

In the years since the Asian Green Revolution, we have also become more aware of climate change and its impact on agriculture and smallholder farmers. In recognition of this, and to help implement IFAD's environment policy and climate change strategy, we have developed a ground-breaking initiative: the Adaptation for Smallholder Agriculture Programme (ASAP), which will help channel finance into climate-smart, sustainable investments in poor smallholder communities.

We have many tools at our disposal and must build our strategies through all of them. Agricultural biotechnologies offer many benefits. They can boost productivity, improve the tolerance of seeds and plants to drought, temperature stress and pests, and make nutrient use more efficient. But we must recognize that biotechnology is only a tool. It is not an end in itself.

Indeed, in many developing countries, simply optimizing conventional approaches, such as the use of fertilizers and micro-irrigation, could yield dramatic results. For example, in Africa only about 6% of the total cultivated land is irrigated, compared with 37% in Asia. It is estimated that irrigation alone could increase output by up to 50% in Africa.

Small increases in fertilizer use can produce dramatic improvements in yields without risk to the environment, since farmers in sub-Saharan Africa use, on average, less than 13 Kg of fertilizer per hectare. This compares with 73 Kg in the Middle East and North Africa, and 190 Kg in East Asia and the Pacific. A fertilizer micro-dosing technique developed by ICRISAT and its partners is helping farmers grow more food without exploiting the soil by using a bottle cap to measure out small, affordable amounts of fertilizer.

Our challenge is to take what we know works, develop what we know is needed, tailor it to the local environment, and apply our knowledge, country-by-country, region-by-region, throughout the developing world.

While I advocate for more investment in research, research for the sake of research is wasteful and pointless in this situation. Research, ultimately, needs to have an application. It is our job to ensure that science and technology contribute to the improvement of rural areas. And it is our job, as responsible scientists, to ensure that our work contributes to nurturing and preserving ecosystems.

Agricultural research can ensure that the smallholder, the fisherman, the pastoralist, the forest dweller and the herder have the means to adapt to climate change. It can ensure that poor rural people, whose lives and livelihoods depend on the earth's productive capacity, have the means to produce more and to produce it better.

But in order for it to move from the lab to the field, it needs to respond to the local environment and it must be supported by enabling policies that link research to products and markets. Research into applications that benefit both the public and private sectors can foster partnerships that are essential in building future sound societies.

Exploring Asian Ethics for New Technologies

Susantha Goonatilake

Change is the norm of all living things. New elements and parts are constantly added and altered. These new realities are constructed from constituent parts to be part of an ever moving process.

This is the normal existence of a person, of a constructed being. If one were to artificially add new elements, new genes or new artefacts to this flowing system, it is but a part of the normal construction of such flows. From the point of view of a realist, there is no difference.

However, such a perspective can make one squeamish. It is scary and can raise alarm or even disgust. One might not mind a set of false teeth or even an implanted one, a prosthetic limb, a walking stick or for that matter even a motorised electronic chair. But messing up one's interior, one's subjectivity, evokes an entirely different set of emotions. It is the fear of one's own consciousness being invaded. At the end of the day, it puts one's own subjectively-felt oneness in doubt.

The Buddha himself has been very firm, however, in rejecting the views of persons who would treat the thing called the 'mind' or 'consciousness' as an unchanging constant. It was better, he argued, for a person to take the physical body as an unchanging 'self', rather than thought, mind or consciousness, because the body was at least more solid in appearance than the mental. The 'mind' is ephemeral and continually changes and so is hardly a candidate for permanency.

Interiority and consciousness is demystified into mundane components. In the ponderous and archaic language of 19th century European translations of an important Buddhist text: "Were a man to say I shall show the coming, the going, the passing away, the arising, the growth, the increase or development of consciousness apart from body, sensation, perception and volitional formations, he would be speaking about something which does not exist."

But experiencing the intrusion of the new technologies that remake us biologically and culturally is internally disturbing. It challenges our sense of self. "This idea that I may not be, I may not have, is frightening to the uninstructed" as the Buddha himself puts it. And, as the belief in an abiding self is deep rooted in humans, the contrary position is 'against the current' as the Buddhist texts say on one other occasion.

If, then, in the coming future it is inevitable that we be constructed and reconstructed, from biology and artefact, what should be our epistemological, philosophical, ethical and subjective guiding principle? If "we" would then be cyborgs and hybrids, what should the interiority of robots and constructed hybrids be, as they navigate reality, and tunnel through time subjectively?

The person is not a 'what', but a process. Being is only a snapshot in the process of becoming, lasting only the length of one thought. According to Buddhism sacred text, "just as a chariot wheel in rolling, rolls only at one point of the tyre, and in resting rests only at one point; in exactly the same way, the [internal] life of a living being lasts only for the period of one thought. As soon as that thought has ceased, the being is said to have ceased."

There is no stable substratum to be considered the self. It just symbolises a stream of physical and psychological phenomena that is perishing. This is the correct view to be internalised in the inevitable day of cyborgs. As the 5th century Sri Lankan classic of higher Buddhist theory *Visuddhimagga* puts it:

> There is no doer but the deed
> There is no experiencer but the experience.
> Constituent parts roll on.
> This is the true and correct view.

One analyses oneself, knows oneself only to realize that there is no self in the first place. This is not an intellectual knowledge, but an internally observed, felt knowledge. This elimination of the sense of self sets one free in Buddhism. This is the highest ethical goal in Buddhism. When the realization dawns that I am not a thing but a process, then the future becomes open-ended.

Buddhism is self-referential, to know oneself is to make oneself, to guide the self that is not there. In the Buddhist analysis, unsatisfactoriness and anxiety becomes essential to the 'I' because these are how the 'I' responds to its own groundlessness.

This internal experiencing of the non-self does not lead to a loss in integration, awareness or vitality of the mind. On the contrary, freeing one's awareness from false perceptions leads to perceptual clarity. Perceptions of others are enlarged because there is an empathic openness based on a non-judgmental awareness. The fully mentally healthy person, known in Buddhism as the *arahat*, is expected to have a state of continuous inner delight, attending keenly to all the circumstances of a situation and responding with skill to every situation.

This is the phenomenology of flow for human thought. These views from the Buddhist analysis of streams and the self act as the pointer of a moral compass in an inevitable future of mergings of streams from biology of a different sort, of culture and computing artefacts. This Buddhist perspective has given rise to a profound moral code of altruism, and it is not entirely far-fetched to think that it could also do so in this case of merged streams in hybrids.

But then, how do we make use of that 'external' baggage that has intruded into us? If it is not 'ours', and if in fact 'we' do not exist, how can one control this alien intrusion? How do I internally react to this massive inflow, into my biological and mental interiority, which is in store for me in the new century?

Let me recourse to a standard exercise in Buddhism in dealing with that interiority, to 'meditation' — a Buddhist observational practice.

In the beginning, one must train themselves to observe his or her own interiority to realize its constructed nature — its lack of an essential being. Secondly, in this process of observing themselves, one dispassionately must also note the coming and going away of one's thoughts. One observes them and lets them go.

This is an important meditative practice. I suggest that in everyday reality, even during the days of the cyborg, one would indulge in a parallel exercise. One could recognise the constructed nature of our internal and external cyborgs, our own Frankenstein creatures, realize their real ephemeral character and use that as our guiding principle to the external world.

But at the same time, one can use our knowledge of the constructions to locate where the constructions come from. Once can ask if they come from this lineage or that? Does their origin lie in this sub-lineage or another? Or maybe they come from an intertwined mixture?

These are, after all, some of the techniques we all use when we are involved in analytical thought, incidentally an important branch of Buddhist philosophy, which in some renderings — both classical and modern — is called a system of analysis. The analytical faculty thus is retained and can be used in our new circumstances.

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Science for the People

Philippe Desmarescaux

Today, we are faced with the challenge of ensuring that the substantial investments made in science and technology benefit mankind — the whole of mankind, efficiently. This must be done whilst taking into account new and ever-increasing realities and constraints with which we are confronted today and, even more so, tomorrow.

We are seeing diminishing and even disappearing supplies of raw materials and fossil fuels. Climate change poses a challenge and global ecological demands are looming on the horizon. There is a strong change in demographics, with the richest populations becoming wealthier and an increase in the poorest populations.

The question thus becomes how can we meet this major challenge? Is it a question of national and international political decision-making? Is it a question of encouraging partnerships between public research bodies and the business sector? Do the various stakeholders need to come to a compromise, which would require exchanging information, dialogue and debate? Is the real challenge now to raise awareness and improve communications?

I would like to highlight the importance of some of these issues by sharing with you an experience from a project which I have been a part of for the last six years.

At Eurotab, my French company, we have developed a water treatment process for turbid and contaminated water. The challenge was complex and stimulating. There are many technologies that allow us to treat contaminated water as long as the water is clear. However, when the water meant to be treated is turbid with suspended solids, things become more difficult and hazardous.

Our challenge was to propose an “all in one, standalone solution” — one able to be exploited without sophisticated equipment, used in remote places and implemented by people without any technical background.

The solution we came up with was a two-layered tablet. First, it eliminates suspended particles in the water in order to make it clear. Then, sequentially, it disinfects the water.

This 20g tablet is, in reality, a pocket-sized factory able to produce 200 litres of safe drinking water in less than one hour.

Three years ago we set up a spinoff company called Aquasure in charge of developing this process worldwide. Today, the double-layered Aquasure tablets have been tested in more than 20 countries and are in use in many villages in Madagascar, Senegal and Bangladesh.

Thanks to this easy to use technology, low-income populations of these villages have access to safe drinking water at an affordable price.

There are several conclusions to draw from this experience:

1. We must concentrate scientific and technological innovation on the major challenges facing our society, especially those affecting the poorest populations. There are still 1.5 billion people in the world today who do not have access to drinking water.
2. Even if the chosen technology is sophisticated, its implementation should be as simple as possible to enable it to benefit the greatest number of people.
3. When developing new technologies, efficiency, cost and ecological impact must all be taken into account.
4. Social marketing should be used when rolling out this technology. This must be accompanied with user-friendly after-sales services.
5. Businesses undertaking such operations should be supported by patient investors with a keen interest in humanitarian issues and by dynamic and creative managers prepared to accept lower salaries during the developmental phase.
6. Such businesses could be supported by new types of partnerships between the public and private sectors, international organisations, NGOs, etc.

To meet these challenges, future entrepreneurs will need to have a new set of skills. They must come from a strong, successful scientific and technological background. Additionally, they must be fine-tuned and sensitive to society's expectations, while be capable of building cooperation and forming the necessary connections.

The New Life Sciences: Understanding the Essentials of Life

Gilbert S. Omenn

> "Education is the most powerful weapon which you can use to change the world." — Nelson Mandela

Preamble

I am proud to return to the Bibliotheca Alexandrina for this fourth visit. This institution is a beacon and compass for science, education, and peace in the Muslim world and the broader developing world. It is an institution with a stunning legacy, magnificent architecture, splendid leader, fully digitalised resources and remarkable, diverse initiatives. This includes — among other things — the Science SuperCourse with 165,000 powerpoint lectures. It is a leading force for cooperation and collaboration between North and South.

Our host, Ismail Serageldin published a call for "Renewal of science in Muslim countries" in *Science,* the journal of the American Association for the Advancement of Science, in 2008. He wrote "Our Muslim forefathers first held up the torch of rationality, tolerance, and advancement of knowledge throughout the Dark Ages of medieval Europe."

The sciences of astronomy, mathematics, and chemistry were especially advanced. In the 10th century, Ibn al-Haytham laid down rules for the scientific method of observation, experiment and search for truth. Ibn Al-Nafis in the 13th century emphasized respect for contrarian views, to be tested with evidence. Then came the Taqlid. Ismail concluded that "Science requires freedom to enquire, challenge, think, and envision the unimagined" [Serageldin, 2008].

Introduction

There are two fundamental concepts of living things: (1) the capture, storage, and utilization of energy, and (2) the reproductions of individuals and reproduction and evolution of the species. [Simpson, Pittendrigh, and Tiffany, 1957].

Biology is now recognized to be an information science. There are many milestones on the path to our present understanding of the essentials of life (Table 1).

Table 1 Historical milestones

Biology as an Information Science
Historical Milestones

- The molecule of inheritance is DNA, not protein: 1944
- The Watson-Crick double-helix model of DNA permits transcription, replication and mutations: 1953
- 46, not 48, human chromosomes: 1956
- The triplet code for proteins demonstrated: 1960
- "Unity in diversity" applies to all living things---at all levels from molecules to cells to ecosystems: 1961
- Systems biology combines the digital code of genetics with environmental and behavioral perturbations (Leroy Hood): 2000
- Synthetic Biology (George Church)

Until the 1940's, it was widely thought that proteins were the best candidates to be the molecular code for life, not the seemingly simple nucleic acids. A classic experiment addressing the surface characteristics of pneumococcal bacteria by Avery *et al* in 1944 proved that inheritance was, indeed, carried by the DNA, deoxyribonucleic acid, rather than proteins.

A decade later, Francis Crick and James Watson, with the essential data from their x-ray crystallography colleagues, Rosalind Franklin and Maurice Wilkins, conceived the double-helix structure for DNA, which permits unzipping of the double helix and replication of the DNA in the process of cell division.

At that time, we erroneously thought there were 48 chromosomes in each human cell. A laboratory technical advance permitted better spreading of the chromosomes in the cell examined in the microscope, with recognition that we have, in fact, 46 chromosomes: 22 pairs of autosomes, same in males and females, and a pair of sex-associated chromosomes, XX in females and XY in males. So there are 24 different chromosomes in all. Then came the triplet code, explaining how the DNA sequence could be transcribed into messenger RNA and then translated into proteins that are chains of amino acids.

When I was a senior university student at Princeton University in 1961 the final 4-hour comprehensive exam had just one question: "Consider the concept of unity in diversity. Explain at all levels from molecules to cells to eco-systems". Indeed, we now appreciate how related all living things are, and how evolution has generated the remarkable diversity we observe, with many, many features conserved.

Now we aim to understand the multi-cellular, whole organism biology through analyzing and integrating information about biological networks and organ systems, and we have technologies that permit experimental manipulation of the genes and synthetic production of genes and biological functions.

Surprises and Complexity

For several decades, we operated on a central dogma of molecular biology, that there was unidirectional information flow from DNA to RNA to protein. The genetic blueprint for life is in the DNA sequence, expressed through what we now recognize to be quite elaborate regulatory mechanisms.

The information in the double helical structure of DNA in the cell nucleus is transcribed into complementary RNA molecules that are messengers to make proteins. Proteins then carry out most of the functions of the cell as enzymes, receptors, oxygen carriers, hormones, antibodies, molecular motors, intercellular signals and structural features of cells and tissues.

We have now accumulated amazing evidence that information flow in living organisms is much more complex. Information can flow from RNA to DNA, mediated by the enzyme reverse transcriptase. Genes can be turned on or off by methylation or de-methylation of cytosine in CpG sequences or by modifications of specific chromosomal proteins, the histones. Gene expression is regulated by protein transcription factors, RNA binding proteins, non-coding RNAs (micro-RNA, long non-coding RNA), transposons and LINE-1 elements.

At the start of the Human Genome Project in 1988 to sequence the genome (all the chromosomes) of humans, the number of protein-coding genes was estimated to be 50,000 to 100,000 or even more. By the time the primary results were published in 2001, the estimate was reduced to

35,000. Still, more redundancies were recognized and the number kept slipping lower. Now it is 20,300, corresponding to just 1.2% of the genome. Mammals compensate, in large part, by generating multiple alternatively spliced transcripts and protein splice variants –which is a major focus of my research laboratory.

While DNA is essentially the same in nearly all cells of the body, proteins are dynamic. They increase or decrease in concentration in response to external and internal stressors, and they undergo numerous covalent modifications (adding sugar, phosphate, acetyl, ubiquitinyl, and other side-chain groups) and specific proteolysis. The result is dozens or hundreds of related structural variants with highly varied functions from one original gene-coded protein.

Far from being the random result of packing two metres of DNA sequence into a sphere 10 microns across, chromosomal structures in the nucleus vary across cell types and exert a still-mysterious influence on gene expression. The nucleus is an uncharted landscape with increasingly interesting "topography".

Long range looping interactions bring gene sequences into physical contact with far-off regulatory elements. Inactive chromatin is shunted to the nuclear periphery (except in retinal photoreceptor cells). Physical proximity mediates chromosomal translocations and fusions in cancers. Modifications of DNA and especially of chromosomal histone proteins affect gene expression, too. This phenomenon can be called "spatial epigenetics".

New microscopes make these chromosomal interactions visible, but represent only a snapshot. Chemical cross-links (chromosome conformation capture) convert the images into sequences. Similar methods map transcription factor binding sites with gene promoter sequences. This is a huge signal-to-noise challenge to interpret.

Advances from genetics, genomics, and the Human Genome Project

Mendel described the laws of inheritance in 1865 and the roles and structures of chromosomes were noted around 1900. Watson & Crick described the DNA double helix, Nirenberg and Khorana & Holley determined the genetic code, and Sanger and Maxam & Gilbert developed DNA sequencing methods. By 1982, the GenBank database was established.

Major advances in the technology platforms for DNA and protein sequencing and synthesis, led by Leroy Hood, were essential to make the Human Genome Project feasible, overcoming extreme scepticism by many scientists of the time. The Project included sequencing of other species. The first full sequence was that of the bacterium *Hemophilus influenzae* in 1995, followed by the yeast *Saccharomyces cerevisiae* in 1996.

Then came a torrent of other sequences for *E. coli*, the roundworm *Caenorhabditis elegans*, the fruitfly Drosophila, human, mouse, chicken, rat, dog, chimp, honeybee, sea urchin, rhesus monkey, and now dozens and hundreds of other species. In the past decade many large follow-on projects have been launched, including the HapMap, genome-wide association studies (GWAS) for many diseases, ENCODE, 1000 Genomes and human ancestry and population migration studies.

The entire issues of *Nature* and *Science* the weekend of 15–16 February 2001 were filled with sequence data from the public sector and private sector consortia of the Human Genome Project, respectively, with numerous associated studies. The two teams were led by Francis Collins of the U.S. National Institutes of Health and J. Craig Venter of Celera Corporation. The advances in scientific knowledge have been tremendous, including discovery of many functional elements noted in the surprises and complexity section above: evolutionary innovations in proteins, non-coding RNAs, promoters and enhancers, transposons, and epigenetics (Lander E, Nature 2011 — same issue as Green *et al*, next].

There is an equally ambitious agenda currently outlined for the period to 2020 by Green *et al* in *Nature* 2011 (Table 2).

Table 2 Goals for Genomics to the year 2020. [Green *et al*, 2011]

Imperatives for Genomic Medicine-2020
(Green & Guyer, Nature 2011)

- Acquire foundational knowledge of genome function, gain insights into disease biology, and create powerful genomic tools
- Make genomics-based diagnostics routine
- Define the genetic components of disease
- Comprehensively characterize cancer genomes
- Introduce practical systems for clinical genome informatics
- Determine the role of the human microbiome in health and disease

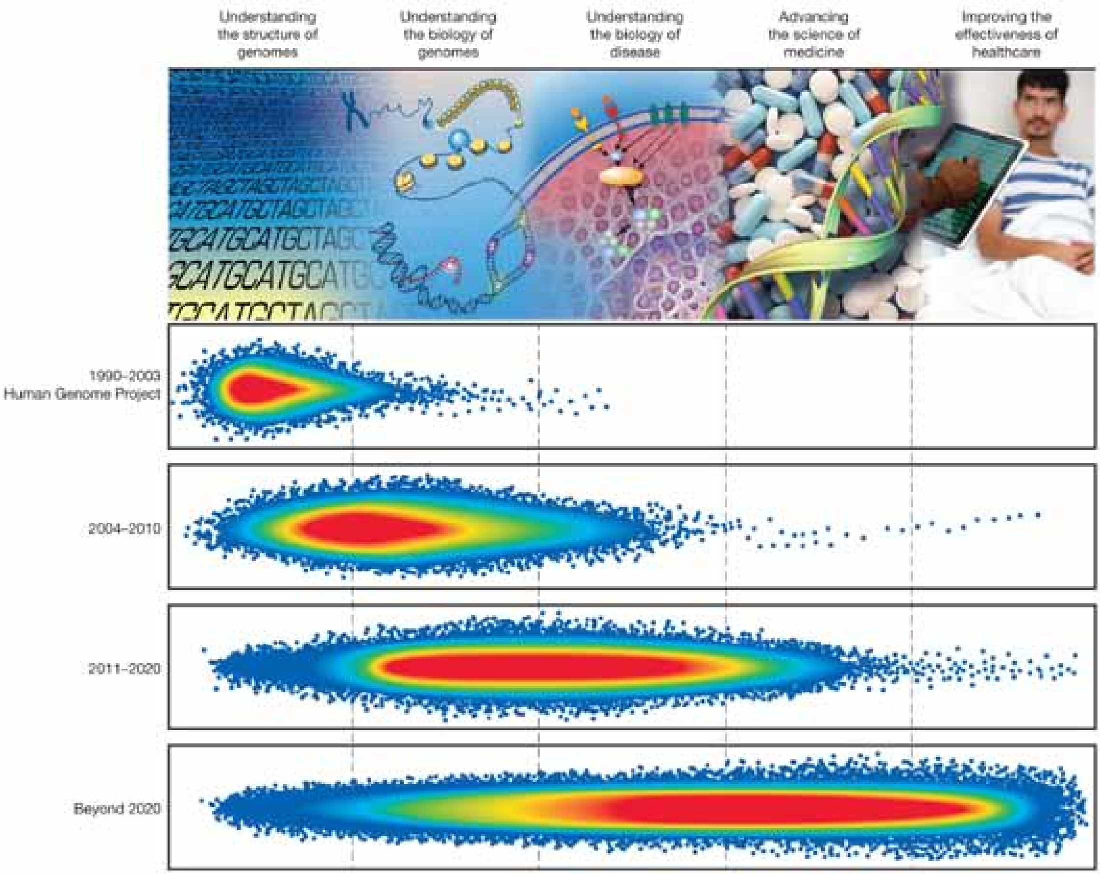

Figure 1 Goals for Genomics to the year 2020. [Green *et al*, 2011]

The "microbiome" refers to the microorganisms living on and in other organisms throughout the ecosystem and in our own bodies. We now know that 90% of the cells of humans are microbial cells, occupying the surfaces of our skin, respiratory tract, urinary tract, and gastrointestinal tract. These microorganisms affect what happens to what we eat and everything else that comes in contact with these surfaces.

The critical role of proteins and the need to integrate all the omics

A new field, called "proteomics", has emerged. Just as genomics refers to all the genes, proteomics refers to all the proteins. As noted earlier, proteins carry out most of the major functions of our bodies. Proteins are the primary targets of most of our effective pharmaceutical products to treat or prevent various diseases. They are also our best candidates to be diagnostic biomarkers for diagnosis, prognosis, choice of alternative therapies and monitoring the responses to therapies of cancers and many other diseases. fig. 2 shows the multi-level approach to link genomes with phenotypes of health and disease, capturing environmental, behavioural and genetic influences on health.

The Human Proteome Project (HPP)

I am chairing a major new initiative, called the global Human Proteome Project [Legrain *et al*, 2011]. Scientists everywhere can participate and can

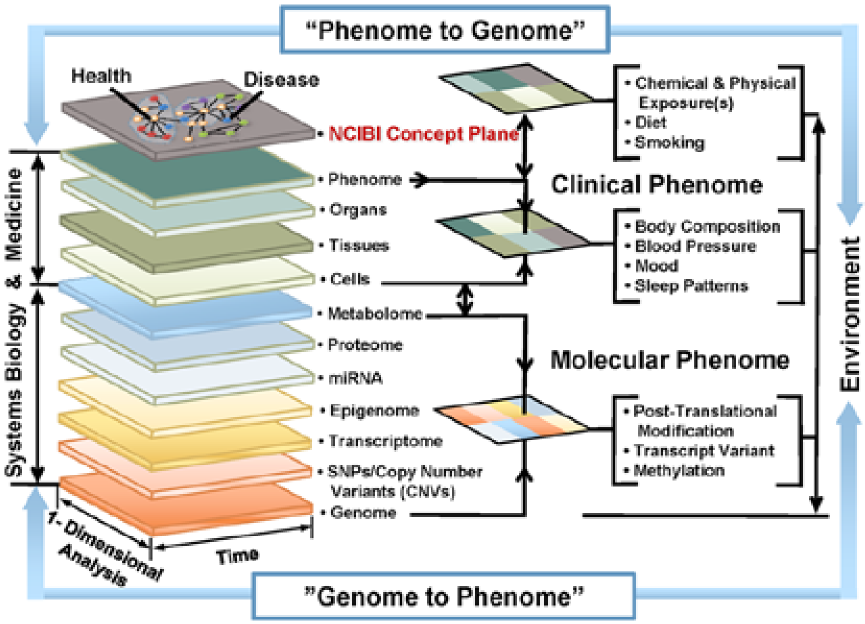

Figure 2 Scheme linking genome and phenotypes [Omenn, 2012]

surely benefit from the new knowledge and new reagents emerging from this project. fig. 3 shows the chromosome-centric C-HPP and the biology and disease-driven B/D-HPP.

We aim to identify the 7,000 protein products of protein-coding genes for which we currently have no experimental evidence, and characterize all 20,000 proteins and their variants. We also aim to understand the co-expression and co-regulation of disease-associated genes and proteins like those associated with Her2/neu-amplified breast cancers on chromosome 17.

A big part of the HPP and all omics is bioinformatics, a major opportunity for young scientists around the world; databases are publicly available, so the cost of such research can be within reach of appropriately trained scientists everywhere.

A golden age for public health sciences

Sequencing and analyzing so many aspects of the human genome generates an avalanche of genetic information. This must be linked with statistical and epidemiologic methods, nutrition and metabolism, lifestyle behaviours, microbial/chemical/physical exposures, diseases/tests/medications, and public health policy, health services, and bioethics.

Every discipline of the field of public health is needed. Most of all, we must bring together good data about behavioural and environmental exposures that interact with genetic predispositions, as shown in fig. 2. Such interactions are the subject of "eco-genetics".

There are large epidemiologic cohort studies around the world suitable for such combined analyses. In the United States, these include the Framingham Heart Study, the Centers for Disease Control and Prevention National Health and Nutrition Examination Survey, the Department of Defense Millennium Cohort Study, The Women's Health Initiative, the Behavioral Risk Factor Survey, the Health & Retirement Study, the National Children's Study and various disease-related cancer, diabetes, kidney, and heart disease cohorts. Many large studies include biobanks; some of the best are outside the US in the UK, Iceland, Estonia, and Japan.

When we focus on diseases of special public health significance, our attention turns to major infectious diseases, depression, heart disease, and increasingly now obesity, diabetes, and such related diseases as non-alcoholic fatty liver disease (NAFLD). GWAS have identified numerous genomic

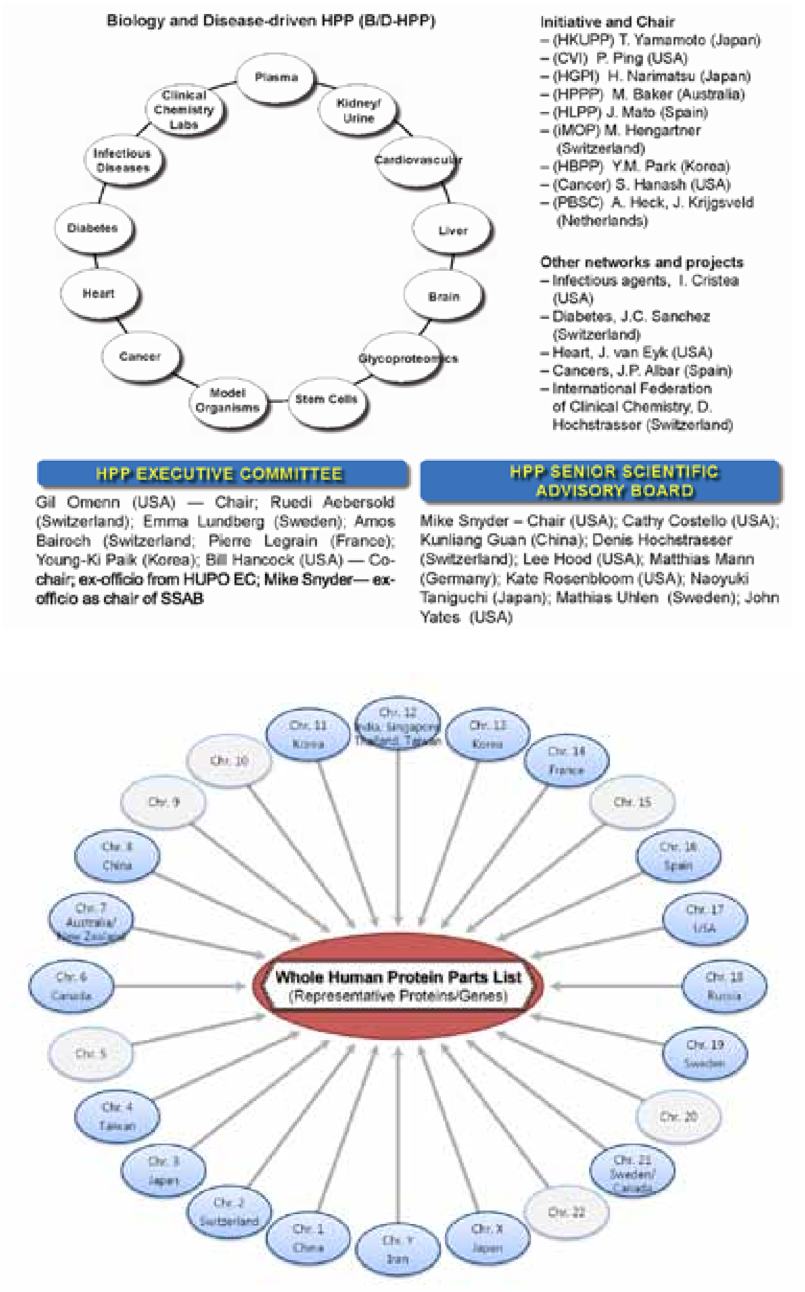

Figure 3 Components of the international Human Proteome Project (HPP) including the biology and disease-driven B/D-HPP and the chromosome-centric C-HPP.

variants statistically associated with particular diseases. Occasionally, these variants fall in protein-coding gene sequences.

For example, my colleague Elizabeth Speliotes at the University of Michigan has discovered several variants associated with increased risk for NAFLD that have distinct effects on metabolic traits and pathways [Speliotes, 2011]. While we remain concerned about hunger and malnutrition in many countries, obesity has become a global epidemic, affecting more than one billion people worldwide.

From Epidemiology-based medicine to personalised medicine

Genetic and non-genetic information can together help us understand the biology underlying disease predisposition and disease features, sub-classify individuals into disease risk categories and develop new directed therapeutics and preventive interventions. This strategy is becoming prominent in diagnosis and treatments for cancers.

For example, Arul Chinnaiyan and his colleagues have discovered totally unanticipated fusion genes that account for a majority of prostate cancers in the US [Tomlins *et al*]. The promoter region of an ordinary membrane-bound serine protease TMPRSS2 is fused with one or another gene of a family of ETV transcription factors. The TMPRSS2 is driven by male androgen hormone, which then drives the ETV gene and causes proliferation of the cancer. Fusion genes and proteins can be detected in individuals; a combination of TMPRSS2-ERG and PCA3 is being evaluated as a diagnostic test in clinical studies.

Other fusions involve genes called SPINK1 (10–15%), B-Raf (1–2%), and K-Ras (1–2%). There are specific drugs to inhibit each of these "targets"; the patient requires the right drug for the activated target. With such drugs in hand, we can search for the patients who will benefit from each drug, rather than deducing new targets for drug development over the typical 10–15 year period.

It is very important to pose "patient-centric questions". For example, the most important question for prostate cancer patients is "which cancers will become invasive and metastatic, and which cancers will be relatively harmless?" What are the molecular markers and mediators for aggressive behaviour of the tumour? Telling apart these two extremes is more important than making more diagnoses, since only 10–15% become invasive and metastatic.

A combination of metabolomics and bioinformatics methods led to the discovery of the small molecule called sarcosine (methylglycine) as a mediator of metastasis. Its levels are negligible in normal prostate, very low in localised cancers, but highly elevated in metastatic prostate cancers [Sreekumar *et al*, 2009]. This finding also is being evaluated in clinical studies.

Developing omics-based predictive tests requires a rigorous framework to discover biomarker candidates, confirm and validate the findings with locked-down assay conditions and classifier parameters and then evaluate the proposed test in clinical studies tied to the intended clinical use [IOM Omics Report 2012].

Omics assays have an inherent risk of over-fitting the data due to the vast number of analytical variables (hundreds or thousands of expressed genes or proteins) far exceeding the number of patient specimens. Failure to respect this problem has led to innumerable candidate biomarkers not being replicable in follow-up studies.

Conclusion

In 1999 Francis Collins, director of the Human Genome Project and now director of the entire U.S. National Institutes of Health wrote that "mapping the human genetic terrain may rank with the great expeditions of Lewis and Clark, Sir Edmund Hilary, and the Apollo Program".

Realizing the full benefits of such knowledge will require understanding of the dynamic proteomic compartments and gene regulation, and incorporation of behavioural, environmental, and healthcare variables, applied to diseases throughout the world.

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Sustaining the Global Water Resource

Margaret Cately Carlson

I am not a hydrologist or an agronomist or an algologist or any kind of specialist

But I work with good scientists in different fields and have come to have a lot of appreciation for the importance of policy and securing financing for various water issues.

The 20th century was one where we spent a lot of time talking about rights and very little time talking about responsibilities. Yet through our choices, we can exercise some responsibility in the whole issue of water.

First of all, I'll make you an expert in water very quickly. When people say to you "isn't it dreadful that there is less and less water in the world?" That is not true; we have the same amount of water globally as the dinosaurs or Julius Caesar did. It is a close system; therefore, we are working with the same amount of water that has always been on the planet. The problem is, and if you live in Egypt or the MENA region you would know, that water is a question of time, place, and people's use.

When we had a billion people, the water situation in most places was not that critical and we shared water resources. But today, with humans at 7 billion and heading towards 9 billion, the situation is critical.

We have about 70 rivers closing, which means we have abstracted all we can from the river. When I fly out of Cairo, I see the Nile River disappear in the Delta and the desert. It is strange to realize that the Nile no longer reaches the Mediterranean except in a trickle. There are 70 rivers around the world that do not reach the sea or do not reach their previous outfalls because of human use of the water there.

This is a very serious issue because it means that the ecology, environment and livelihood of delta systems have significantly changed. There are water quality and quantity problems everywhere in the world. Egypt is in a unique water situation because of population growth. The per person availability of water continues to go down even though we have the magnificent Nile flowing almost all the way through Egypt. Add to the equation a series of unique, if turbulent, relationships up and down the river.

As prosperity grows, we use more water, but as I said earlier, water is unequal in time and space. To help you better visualize, imagine a triangle which we will use to represent the nexus of demand for water. On one corner, there is agriculture, in another corner you have energy and on the last corner you have the use we make of water in terms of industries, human use, etc. This is the nexus triangle. We will talk about the demand for water and how responsible decisions can make that water more plentiful.

Oceans make up 97% of all the water on Earth, so there is just about 3% or 2.5% left for freshwater. The majority of that is trapped up in trapped up in glacial, groundwater, permafrost, and in the atmosphere. Therefore, we only have 2% of the 2% to actually work with in terms of the water that we all use. Water is scarce, in terms of the usable water that we have compared to the very large mass.

Agriculture is responsible for 68% of global water consumption. This number can vary depending on the country. Usually, more industrialized countries use less water than developing countries. This is an example of an area where we can make responsible decisions to start making a difference.

There are many ethical and intergenerational issues involved in water management. For example, how does our water use affect others? If we secure more water what will happen afterwards? For example, Egypt is very concerned about Ethiopian growth and Ethiopian future plans because it is worried about the effect it could have at home.

How does our use patterns affect next generations? If we are pulling water excessively out of an aquifer that was put down during a totally different geological age, that aquifer is not going to come back. Some aquifers are restored by rainfall or by different underground patterns, but we know enough about how aquifer get where they are. If we are pulling water out, as the case in Libya, from the aquifer that is highly unlikely to be restored, then there is an intergenerational implication.

Are we polluting? If you pollute water then it is not available for you or anyone else to use. If we trade development for pollution then that is not a good deal. Our agricultural patterns are such that we constantly pollute water. When we talk about pollution, people usually have smokestacks and industrial pollution in mind, but in fact agriculture is a bigger polluter of water than industry or cities.

The responsibility we have for water is hardly talked about, but the rights are very much talked about. Drinking water makes up only about 7% of water consumption, and that's what we talk about as having the right to water. But we have to look at all the other uses to exercise the right to clean water.

Another ethical issue is who in our society is taking the responsibility of making sure that water is available for all possible uses in different sectors of society. Who is accountable for this? Who reports this and how do you know what is going on about water? Who is reporting to you, as a citizen, in a way that you can actually understand about the availability of water and its condition? Is this being done in a transparent manner?

Lots of countries make water information available, but without a double PhD in statistics and something else you would never understand what was going on. So the water reporting has to be transparent and clear, and there needs to be education about water and the increasing stringency in water.

There are many reasons for us to be concerned about water. It takes a litre of water to produce every calorie of food. A litre of water to produce every calorie, coupled with one billion people and 2,500 calories a day equals a certain number of litres of water used in agriculture. Now increase the number of people to 5 billion, then 7 billion and up to 9 billion and multiply by 2,500 calories and look at the amount of litres. This here is the incredible linkage between water and food. More people, or more demand from each of us because of increasing prosperity, means a great deal more demand for water.

As prosperity demands increase so does our demand for protein; a huge amount of water demand is related to the demand for meat and chicken. It takes a metric tonne of water to produce a kilogramme of wheat, but it takes 5 tonnes to produce a kilogramme of chicken and about nine of them to produce a kilogramme of beef. This is one of the places where responsibility comes in. It starts to come in in terms of how much water you are actually using.

I listen to my speeches far too hard and decided I really could not go on telling the world about this and still keep on eating meat. So finally, about three years ago, I decided that my personal contribution to trying to rebalance the use of the world's water would be about that.

It is not just about agriculture; we have water usage for energy. We are tremendous energy users and with prosperity energy use goes up. Energy is an enormous water user, but it takes a lot of energy to produce water too. In California, about 28% of the state budget goes into the energy bill for pushing water around and putting it through pipes, collecting it back and cleaning it up. So we have got tremendous water use in energy and tremendous energy use in water.

If we want to make a difference here, we have to start understanding how our systems in our own cities and countries are actually using energy in our water and using water in our energy. We can also make a responsibility decision by trying to use these more responsibly.

This brings up the ethics angle, or the responsible use of water reuse. Three days ago a story in the New York Times read:

> Without mining an ancient aquifer, draining a natural spring or piping in the pricey harvest from a greenhouse-gas-and-brine-generating desalination plant, there is a solution to provide a valuable source of extremely pure water, reclaim it from sewage.

Egypt is getting better and better at this, but if you want a cure that can make a difference, start in this country with how you could more responsibly reuse water. This quote talks about sewage but there is an awful lot of water that is not sewage. There is grey water, industrial water, and are all sorts and kinds of water that can be recleaned, recycled and reused.

So where do we go from here, and how does biochemistry or a biotechnology actually help? We talked about reducing the demand for water and energy and that we can be responsible and not just claim the right to water. But we also have to agitate and act and speak up for better rational water use, better agricultural use of water and more rationalized municipal use. We can add our voices to the need to invest and develop into water, energy and agriculture and we can develop practical and sustainable tools.

We also need to advocate for policies that promote the efficient use of resources and sustainable practice. We can change the world; cities can be their own catchment area. There is very exciting stuff that is being done in some cities where you start making the city an entity that takes in water but then uses it, recycles it, reuses it, harvests the wastewater, reuses the grey water and then the water goes out to agriculture.

So if we start thinking about how technology and how science and how our own personal decisions and habits can be used, we will find that we are adding to the supply of water instead of simply claiming our right. We need really to start thinking about the multiple use of water.

Reducing conventional water supplying network, more water for environmental flows and ecosystem services and better livelihood opportunities have to be what are after. We have got lots of helpers to allow biotechnology to be more helpful, one of them is membranes where we have astonishingly moved forward in the last 20 years where they can now help us not just with desalination, but also with the cleaning of the water so that we can reuse it. They still use energy so are not a free lunch, but through intelligent design we can make good use of membranes and good science and technology to clean up water so we can reuse it.

The Gold Coast in Australia has change their building codes and now you can imagine a large apartment building where grey water – which is water from dishwaters, washing machines, bathwater and hand washing – is recycled through pipes, goes through a small water cleaner and then goes back into the water systems because as it is as clean as it would be if it came from a new water source. There is a little bit of new water that's added in every time. You are not recycling toilet stuff here, you aren't recycling sewage. But you are recycling the available water and cutting down enormously on the need for new water.

It is possible to make a change, but the important element here is not the technology. It is the municipal changes, it is public opinion – which is you, and it is political leadership.

Water is a complex issue. We like to claim water. But what I hope I'm getting you convinced with is that we have responsibilities that go throughout the system in terms of our consumption patterns, what we advocate, what we talk about, what we decide to study and what we do in our lives in terms of using water responsibly.

1

THE ROBUST EVOLUTION OF HEALTHCARE

1

Tissue Engineering: Recapitulating the Cascade of Development

Mona Marei

Ancient Egyptians may have been the first to apply tissue engineering principles to wound care around 1500 BCE. In the papyrus of Ebers, there is a description of how skin wounds were treated with lint, grease and honey. Lint served as a fibrous scaffold to guide wound regeneration, grease provided a barrier to environmental pathogens and the honey played the role of an antibiotic.

Millennia later, in 1993, Langer and Vaccanti introduced tissue engineering as an interdisciplinary field which applies the principles of engineering and the life sciences to the development of biological substitutes that restore, maintain or improve tissue or whole organ function.

The concepts behind the current principles of tissue engineering and regenerative medicine can be traced back to the 1960s when Malcolm Steinberg proposed that heterogeneous populations of dissociated mammalian cells could sort themselves and assemble into distinct populations with tissue-like characteristics using a porous scaffold that influenced the organization of neo-tissues.

The key components for tissue engineering are: The cell, scaffold and growth factors. The cell synthesizes the matrices of new tissue, while the scaffold provides the appropriate environment for cells to be able to effectively accomplish their missions. Growth factors facilitate and promote cells to regenerate new tissues. While regenerative medicine through cellular therapy alone without the use of scaffold is possible, it has seen very limited success.

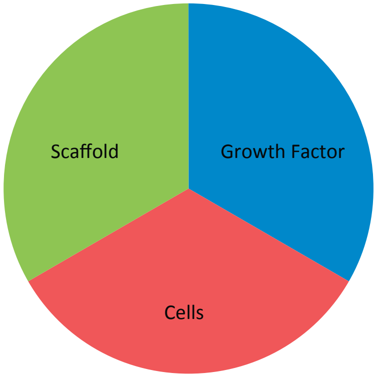

Figure 1 The key components of tissue engineering.

A paradigm shift

Tissue loss due to trauma, injury or diseases represents a significant cause of chronic morbidity that extends to affect an individual's wider health, social and economic status. The fields of tissue engineering and regenerative medicine have been introduced in the last century with the expectations that these technologies will have a major impact on patient healthcare.

Over the past several decades, the field has made significant progress toward finding optimal scaffolds, cell sources and cultivation techniques to create constructs that have the potential to cure or treat a variety of diseases and injuries. Most of this research has been geared toward eventual clinical translation and patient use.

This was mostly achieved through the introduction of new products. Over the years, a number of implant products made their way to the market and have substantially improved clinical care, such as dermagraft, INTEGRA Dermal Regeneration Template and INFUSE bone graft.

However, the long-term therapeutic effectiveness and profitability of these interventions has been marred by high product development and manufacturing cost and slow market acceptance.

The tissue engineering industry's path has been far from smooth. Expectation and hype in the 1990s were high and the technology was considered the greatest scientific accomplishment of the 20^{th} century. Yet in 2003, tissue engineering entered a dark period due to the poor economy, failed product launches and disappointing clinical trials.

By 2008, the industry had rebounded and was back on track to meet the expectations set in the 1990s. Tissue engineering companies increased over 10-fold compared to 2003. FDA products entered clinical trials, received approval and in some cases became profitable, paving the way towards success once more.

According to the 3D cell growth paradigm, *in vitro* generation of bio-artificial tissue involves the development and appropriate selection of the technical tools used *in vitro*, such as cell type, growth factor, differentiation factors and the properties of the scaffold. Certain detail, such as how the cells optimally will survival and multiply in 3D, how they will differentiate to cells of specific tissues, and what are the best combinations of tools that will result in best findings were all the focus of rigorous investigations. Additionally, it is not easy to determine which of the numerous factors involved, such as age and number of cells, must be modified and how.

The conclusion was to develop a rational methodology to design *in vitro* processes based on the fundamental understanding of what makes vital tissue and organ different from a 3D cell construct.

The challenge of building a completely biological organ, such as skin, muscle or even teeth, from bottom up was ostensibly insurmountable. However, in the early days of tissue engineering, there was little to offer from development biologists. Over the past two decades, biologists have identified critical genes switches, growth factors, signal transduction and pathway cascades that mediate formation of the primitive axes in the early embryo as well as organ formation during later stages of embryogenesis.

The current paradigm of tissue engineering

The progress required to recapitulate developmental events of morphogenesis to engineer tissue and organs was of vital relevance to the outcome of tissue engineering. To repeat every developmental stage is almost impossible in the tissue culture petri dishes. The alternative would be to mimic and integrate developmental events with bioactive materials and mechanical cues.

This shift of concept was clearly demonstrated recently in bone formation via tissue engineering. Earlier studies were concentrating only on intra-membranous ossification via differentiation of mesenchymal stem cells into osteoblasts. Recently, endochondral ossification has gained more attention as it imitates the optimal condition for bone formation. The development of cartilage becomes a self-designed scaffold that is osteo-inductive and angiogenic, leading to recruitment and differentiation of osteoblasts and ultimately bone formation.

As we begin to understand the complexity of cell condensation in synovial joint development, we start to realize the value of factors such as cell age, density and migration. Early studies on adult stem cells focused on isolation and expansion of mesenchymal stem cells (MSCs) *in vitro*. However, latter effort expanded toward identifying and localizing these cells *in situ*. Considerable results support the notion that MSCs are observed in a prevascular location for almost every blood vessel, as well as in intimate contact with the basement membrane and surrounding endothelial cells. These and other observations allowed scientists to speculate that all MSCs are pericytes and to contemplate about their role in the local tissue microenvironment beyond their mesenchymal differentiation capabilities.

The potential therapeutic benefit of MSCs has been investigated in many clinical trials from 1995 to 2011. MSCs injected into the blood stream localize to sites of tissue injury, such as in acute myocardial infarcts, strokes, spinal cord injuries or acute kidney failure. MSCs activities in all of these previous disorders were based on immune-modulation and tropic effects(18).

Numerous studies have shown that MSCs migrate to and accumulate at the sites of tissue damage and inflammation, but this subset always appears to be a small fraction of the delivered cells (1–2% are present after 1 week and may decline further). Additionally, results confirmed that although MSCs propagate in culture, there is little evidence this happens *in vivo*. Their anti-inflammatory effect at the site of tissue damage produces many soluble proteins capable of altering the course of the local inflammatory response.

In clinical settings, the optimal route for administration of stem cells depends on the involved tissue or organ, offering one of two approaches: direct local (intralesional) implantation, or systemic intravascular administration. Local implantation is invasive, costly, causes local microenvironment disruption and results in significant morbidity. On the other hand, only a small number of cells reach the affected areas in systemic intravascular administration. Successful regenerative therapy critically depends first on identifying the range of molecules that mediate organ-specific stem cell homing and secondly on manipulating their activity.

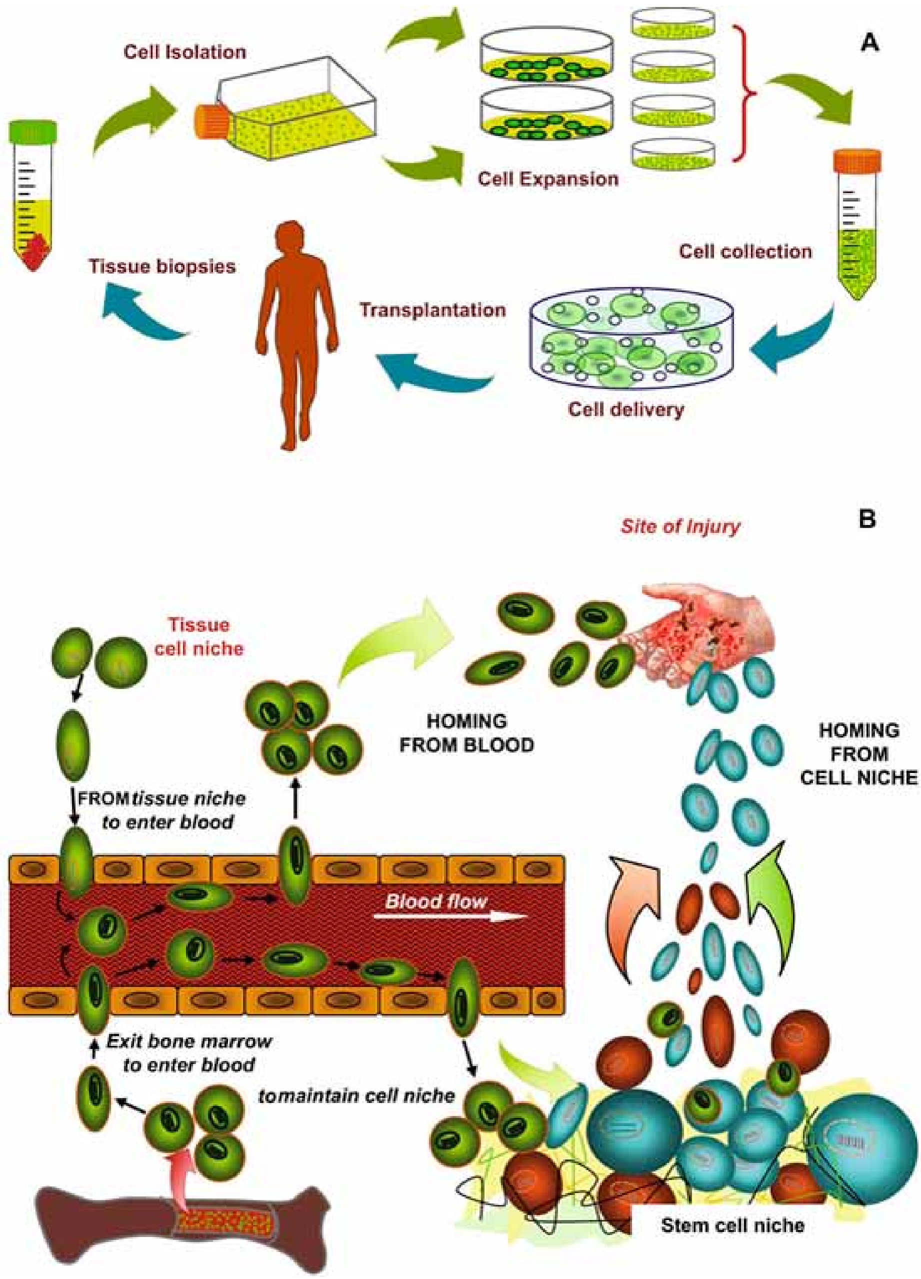

Figure 2 Tissue engineering via cell therapy

It is now well documented that stem cell niches are present in many adult organs and tissues, including the brain, bone marrow, skeletal muscles, skin and the liver. The bone marrow is the main reservoir of stem cells in the body. Under steady state conditions, it maintains the niche of stem cells, ensuring a dynamic balance in which a small number of stem cells constantly leave the bone marrow, enter tissues and travel back to the bone marrow or peripheral tissues — which act as specific niches. The stem cells may remain quiescent for long periods before they are activated during disease or tissue injury. Once they are active, they exit the niche and differentiate to regenerate lost tissue.

Endogenous cell homing is the focus of current efforts of tissue engineering. The idea is to actively recruit host stem cells into a predefined anatomic location for *in situ* tissue engineering. There, a scaffold allows host cells to migrate into the affected tissue to regenerate it — a role previously played during embryiogenesis.

Advances in biomaterial design and engineering are converging to enable a new generation of instructive materials that bear complex information in their physical and chemical structures. Release technology not only enhances *in vivo* stability of information cues, but also allows homing factors to prolong the maintenance of biological function. These are all the challenges to be addressed in the current paradigm in order to recapitulate the cascade of development.

First paradigm of cell transplantation therapy.

Second paradigm of the body self-healing via endogenous cell homing to recapitulate response to injury.

Conclusion

Promising, cell-based approaches have for decades encountered crucial barriers in therapeutic translation, such as immune rejection, pathogen transmission or potential tumourigenesis.

There are several clinical trials being performed worldwide to examine the systemic administration of MSCs and transplantation of cell/scaffold construct to treat a variety of diseases and tissue defects. Despite the general excitement about these trials and the promising results thus far, there still remains a major lack of understanding of how MSCs target specific tissue.

The current clinical dosing requires a high number of cells: 150–300 million MSCs administrated twice per week over the course of two weeks.

Furthermore, the balance between the beneficial effects from locally engrafted MSCs versus systemic effects from secreted paracrine factors that diffuse into target tissues is unclear. There is mounting evidence that host MSCs appear to mobilise in response to inflammation or injury and target specific tissues via active mechanisms. However, homing of expanded MSCs is inefficient compared to what naturally happens inside the human body, which is apparently due to a lack of chemokine receptors. These accumulating findings were the driving power for shifting tissue engineering approaches from cell transplantation/scaffold construction to biomimetic-based tissue engineering that utilizes the current fundamentals of developmental biology. There is currently much research going into developing biomaterials to produce scaffolds that send out navigation cues that are better at attracting stem cells to their location.

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2

Equity in the Delivery of Vaccines and Vaccination in Developing Countries

Stephen Jarrett

Vaccination has arguably been one of the most successful public health interventions, with an estimated 2.5 million child deaths prevented annually. Smallpox was the first disease to be eradicated, with the 33rd World Health Assembly in 1980 endorsing the conclusions of the Global Commission for Certification of Smallpox Eradication that smallpox had been eradicated worldwide.

Now, poliomyelitis is close to eradication with 650 reported cases in 2011, and currently only three countries remain endemic, namely, Afghanistan, Nigeria and Pakistan (WHO, 2012a). India was declared non-endemic in early 2012 after recording a year without a case since 13 January 2011. Measles deaths have been significantly reduced, by 78% since the turn of the century, with notable progress in sub-Saharan Africa, although the threat of resurgence does exist if vaccination falters due to the high transmissibility of the disease. Altogether, deaths from diphtheria, tetanus, pertussis, polio and measles have fallen to 600,000 a year, down by 60% in just the last decade.

At the same time, newer vaccines, such as hepatitis B (HepB) and *Haemophilus influenzae* type B (Hib) vaccines have been widely introduced. The substitution of the diphtheria, tetanus and pertussis vaccine (DTP) with a combination (pentavalent) DTP-HepB/Hib, taken up by 65 developing countries with funding from the GAVI Alliance, has created the type of sustainable market required to attract new manufacturers, create competition and put pressure on lowering prices. The number of WHO-qualified manufacturers of the pentavalent vaccine has risen from one in 2004 to five in 2012, with the lowest price available at US$1.75 per dose-halving the original price given to developing countries. Pnuemococcal and rotavirus vaccines, also with support from the GAVI Alliance, are now being introduced into developing countries. The pneumococcal vaccine had already been introduced in 16 countries by December 2011 and 36 million doses were distributed during that year. Twenty countries have been approved by the GAVI Alliance for funding rotavirus vaccine but only a small number of doses were distributed in 2011 (GAVI Alliance, 2012).

Vaccination strategies have evolved in recent years to expand routinely-provided vaccination services. Many countries also added focused immunization days or weeks allowing for greater outreach to communities. These allow for other primary healthcare interventions such as vitamin A supplementation, deworming and impregnated mosquito nets distribution to be delivered, thus increasing the health impact of these sessions. Vaccination delivery systems have been strengthened in some countries to accommodate the increased throughput of vaccines, but in many countries new vaccines have been introduced in a staggered fashion in accordance with the capacity of the delivery system.

Increasingly complex vaccination plans

An unprecedented increase in new vaccine development has occurred over the past three decades. There are new vaccines that protect against an increased range of vaccine-preventable diseases, vaccines that reduce the number of required injections, and vaccines with improved safety and purity (Rappuoli, 2011). Already a decade ago, as many as 400 different vaccine development projects were estimated to be taking place (Gréco, 2001).

In just a quarter of a century, the WHO-recommended vaccination schedule has changed dramatically, from just four basic infant vaccines, namely, Bacille Calmette-Guerin (BCG), DTP, polio, and measles. Currently, 10 vaccines across all age groups are recommended, as published in WHO position papers. These are BCG, HepB, DTP, polio, Hib, pneumococcal, rotavirus, measles, rubella and human papilloma virus (HPV) (WHO, 2012b). Additional recommendations relate to regionally-relevant vaccines or to individuals in some high-risk populations, such as mumps, influenza, yellow fever, Japanese encephalitis, tetanus-diptheria booster, typhoid, meningococcal, cholera, rabies and hepatitis.

To address this increasing array of vaccines, specific initiatives relate to giving HepB to babies within 24 hours of birth, immunizing adolescent girls with HPV, providing school-age boosters of tetanus toxoid, and developing new strategies to reached formerly unreached populations.

Vaccine supply

The supply of vaccines remains a logistical challenge. As biological products, there are stringent quality assurance requirements in manufacturing. Shipment requires continuous cold storage from the manufacturer to the user. UNICEF is the largest supplier of vaccines to developing countries, procuring vaccines for between 60 and 100 low and lower-middle income countries annually and reaching one third of the global birth cohort with one or more vaccines. In the last four years, purchases for lower-middle income countries have increased sharply, reaching 45% in value and 57% in volume (from 8% value and 5% volume in 2007). This is mainly due to a number of large population countries having graduated from low income to lower-middle income status (UNICEF, 2012).

In 2011, UNICEF purchased 2.5 billion doses of vaccine, with around 64% of the volume of vaccine purchased being polio vaccine for the continuing eradication effort; the remainder was for both traditional and newer vaccines. In the same year, 62% of UNICEF purchases of vaccines of close to US$1 billion were funded by the GAVI Alliance, with the remaining amount split between country funding and UNICEF's own funding. The cost of vaccine procurement was dominated by 3 vaccines; polio, DTP-HepB/Hib (pentavalent) and pneumococcal. Value-wise, however, this represents less than 5% of the total vaccine market, already valued at US$22.1 billion in 2009, showing the persistent gulf between developed and developing vaccine markets (Pharmaceutical Technology, 2010).

Significant challenges exist in country-level delivery systems. Cold chain systems, which are essential to protect vaccine quality during storage, distribution and use, are deficient in many countries, having been mostly built in the 1970s and 1980s and relying on old technologies. A review of 24 countries found only two having effective vaccine management systems, while three were ineffective and the rest mediocre. The main in-country problems relate to vaccine arrival, storage capacity, distribution and transportation and stock management (Kone, 2009).

These deficiencies are particularly serious considering that new vaccines are more expensive than traditional vaccines by a multiplier of 10 or more, heightening the risk to quality and wastage. Few countries, however, record specific wastage rates. For example, this runs the risk that wastage costs of multi-dose vials of the pneumococcal vaccine could exceed the storage savings they offer, making the single-dose vaccine, which requires significantly more storage space, more cost effective.

Continuing inequity

An estimated 19.3 million infants still remain unvaccinated with a third dose of DTP every year due to geographic, social and economic factors. Of these, 68% live in just 10 countries (India, Nigeria, Democratic Republic of the Congo, Indonesia, Uganda, Pakistan, Afghanistan, Iraq, South Africa and Ethiopia). Around 2 million deaths a year still occur from diseases for which vaccines currently exist, specifically acute respiratory infections, diarrhea, measles, pertussis and tetanus. More deaths would be averted with a malaria vaccine.

The Universal Child Immunization initiative of the 1980s led to 75% of infants in 1990 receiving a third dose of DTP, as compared to 20% in 1980. Over the following 20 years, the coverage inched up to 85%. This level hides geographical differences, with Africa and Southeast Asia at 71% and 75% respectively, and other regions 90% and above. Also hidden are differences within countries especially by wealth quintile. Nigeria ranges from less than 10% of the poorest quintile vaccinated to 60% of the wealthiest quintile. India ranges from under 40% to over 80%, the Democratic Republic of Congo from under 30% to over 70% and Yemen from under 20% to 70%. Poverty is closely associated with low vaccination rates in countries with the largest unimmunized population.

The reasons children remain unvaccinated or under-vaccinated are complex. Family characteristics, such as poverty, together with parental attitudes and knowledge, have been cited in about half the studies assessing the under-vaccinated and nearly 80% of the unvaccinated. The failure of immunization systems and the lack of public information comprise the remainder. More specifically, in a systematic review of India, there are significant inequities in childhood vaccination based on various factors related to individual (gender, birth order), family (area of residence, wealth, parental education), demography (religion, caste), and society (access to healthcare, community literacy level) characteristics (Matthew, 2012).

Similarly in Nigeria, at the individual level, ethnicity, mother's occupation and mother's household wealth were characteristics of the mothers associated with full immunization of children. At the community level, the proportion of mothers that had hospital delivery was a determinant of full immunization status (Antai, 2009). Looking at Tanzania between 1990 and 2005, there was a marked disparity as the poorest experienced a significant decline in complete immunization while the least poor had a significant increase. Additionally, children from households whose head had low education were less likely to complete immunization (Semali, 2010).

The unreached can be found in diverse settings; peri-urban populations who do not fully utilize accessible services, rural and urban populations with access to services but who drop-out, remote rural populations with poor access, and marginalized groups and sects. The vaccine community demands rigorous evidence on vaccine efficacy and safety and technical and operational feasibility when introducing a new vaccine, but has been negligent in demanding equally rigorous research to understand the psychological, social and political factors that affect public knowledge and trust in vaccines (Larson, 2011).

Equity-focused vaccination

Based on the findings across countries, an equity-focused immunization strategy needs to address:

- Societal issues: social norms, behaviors and practices that impede access to services or create discrimination or deprivations;
- Services and systems: barriers to access and systems constraints that prevent vaccines from reaching those who are most in need;
- Governance issues: accountability, policy, legislative and budgetary factors that effectively disadvantage or exclude children, families and groups.

A strong partnership between the health system and the community is considered central to improving equity. Awareness-raising, joint planning, performance assessment and resource pooling, with a shared sense of purpose and accountability, can lead to ensured service availability and decreased drop-out rates. Immunization strategies need to be specifically targeted towards certain socioeconomic determinants in order to reduce socioeconomic inequalities in immunization coverage (Lauridsen, 2011).

The unfinished agenda in immunization is still daunting. Traditional vaccines such as measles, pertussis and tetanus still need to reach the unvaccinated, while polio vaccine has to continue to be widely used to meet the eradication goal. The use of newer vaccines, such as HepB, Hib, typhoid, pneumococcal, rotavirus and HPV has to be accelerated to reduce mortality from these diseases. Continued research into malaria, tuberculosis and HIV vaccines is vital in order to enhance protection against these major diseases. From a systems perspective, there are significant opportunities in the use of modern communication tools, such as SMS and the Internet and other technologies, to improve delivery systems. Some countries, such as Turkey, have fully automated systems using such technologies.

Many of the newer vaccines, though, particularly pneumococcal and rotavirus vaccines (and the same will almost certainly be true of a malaria vaccine), do not completely protect against disease, unlike traditional vaccines such as measles and tetanus. They need to be combined with other primary healthcare interventions in order to prevent, protect and treat specific diseases. The cost-effectiveness of these vaccines, therefore, may not be directly associated with decreased disease burden and deaths averted, as they are just one intervention of several. Having a combination of interventions available, including vaccination, points to more complex management.

Without serious investment in national delivery systems, additional vaccines cannot be introduced and equity in delivery is unlikely to be achieved. This implies not only infrastructure improvement but also enhancing the skills and motivation of the health workforce, which is continuously being asked to deliver more service often without additional benefits.

Conclusion

Despite the significant advances in vaccine development and introduction, equity in the delivery of vaccines and vaccination has to be a primordial objective of all countries. Governments have an obligation to provide vaccination which is an essential component of the right to health. Individuals have a responsibility to be vaccinated, or ensure their children are vaccinated, to stop the spread of infectious diseases. The factors causing inequity have to be understood and tackled. Society, through political and civic leaders and their respective organizations, has to respond in two ways; ensure that governments meet their obligations to provide vaccination, and ensure that individuals in the society understand their responsibility to be vaccinated or to ensure that their children are fully immunized.

Science has to act on multiple fronts simultaneously. It needs to advance the development of new vaccines to tackle remaining disease burdens, but also address their improved stability and quality maintenance during delivery and use. This will help vaccines reach those currently unreached, achieving equity among all populations targeted for vaccination. Although science is the key to the development of new and novel vaccines, this is insufficient as public trust and confidence in immunization has to be continuously built, through rigorous research and effective communication with policymakers and the public (Maxon, 2011).

At the same time, while many countries are increasing their budgets for vaccines, they are still dependent to a large extent on external funding of newer vaccines, leading to doubts about long term sustainability. Strengthening supply chains, adjusting financing schemes and increasing national ownership will be key to the sustained use of HepB and Hib vaccines and the eventual addition of other important vaccines where they are most needed (Zuber, 2011).

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3

New Life Science: Genomics and the Essentials of Life

Huanming Yang

In 2000, scientists around the world celebrated the first "working draft" of the human genome sequence. The International Human Genome Project (HGP) allowed us our first glimpse into life at a "whole genome" scale and at base level.

It was once viewed as an impossible mission, but we did it together: more than 3,000 researchers in six nations accomplished this unparalleled goal in 13 years. Ten years later, using advanced next-generation-sequencer (NGS), we can now decipher about 100 human genomes in a single day. By the end of 2011, the Beijing Genomics Institute (BGI) had released approximately 650,000 Gb of sequence data.

Sequencers and computers constitute the essence of BGI's research platform. By translating A, T, C and G into 1's and 0's, bioinformatics unite two of the most important contemporary technologies. The software our bioinformaticians developed for analyzing NGS data is acknowledged as among the best by peers [Bao et al., 2011]. To continue the HGP spirit: owned by all, done by all and shared by all, a collaboration of genomics cultures was created. BGI was born for and out of the HGP, and is most known for its work on the rice genome project. Since then, it has grown steadily with the NGS revolution.

Sequencing made three major technical breakthroughs in the last few decades. First, the invention of automated fluorescent DNA sequencers in the late 1980s made the human genome project possible. In the late 1990s, the advert of capillary sequencers rapidly accelerated the project's progress and allowed researchers to reach the HGP goal [Meldrum, 2000]. Massively parallel sequencing technology paved the way for the third breakthrough of genomics and lifted the curtain on the "Century of Biology" [Silver, 2007b].

Seizing on this opportunity, BGI transformed itself into one of the largest genomics centres, becoming a strong advocator for sequencing for health, food, energy and environmental issues for all. In collaboration with global partners, BGI-China has made significant progress in *de novo* assembly and other fields, and has sequenced and analyzed numerous genomes of humans, other animals, plants and micro-organisms.

First, BGI independently sequences the reference genome of diverse organisms. In animals, we have already published the genome sequence of the crab-eating macaque and the Chinese rhesus macaque, along with the naked mole rat and several others in 2011. A plan to sequence animals in the three poles of the world was launched earlier in 2009. The emperor penguin, Adélie penguin, polar bear, tibetan antelope, domestic sheep, and domestic pigeon are included in this project. From 2009 to 2011, several important plant species had been sequenced according to the 1000 Plants Genome Project, such as cucumber, potato, and turnip. So far, 540 animal and plant species sequences had been contributed to the reference sequences. We are also researching the third field — microbes. Efforts have also been taken to unlock the mystery of gene-environment-interaction. For instance, the Metagenomics Project studies the micro-organisms living inside and on humans. So far, 5,359 microbe and metagenome samples have been sequenced.

Secondly, the strategic sequencing of the whole genome not only generates fundamental knowledge about human genomes, but also contributes to our understanding of human evolution and migration. For example, researchers sequencing the Mongolian genome using the DNA of Genghis Khan descendants found that approximately 0.5% of the males carry the Y chromosome of Genghis Khan. The *de novo* assembly of Asian and African genomes indicated the differences in genome structural variation. Analysis of 50 human exomes reveals the adaptation development in them to deal with high altitudes.

Thirdly, we are sequencing for defined phenotypes — "from genomics to genetics". We have successfully sequenced and analyzed the genomes of chicken, silkworm, maize, soybean and many other species. Further research helps us understand the effects of cultivation and the adaptation mechanisms developed in these species. Undoubtedly, studying those evolutionally and agriculturally important species is just the beginning as we dive into the beautiful world of genomics.

The fourth focus is making use of sequencing for clinics and breeding. Millet has a long history of cultivation in China. We used the sequence information to substantially cut down the breeding period. Based on the genome sequences of 100 strains, seven mapped loci controlling important traits were discovered. A hectare of this newly developed hybrid millet can produce twice as much crop while using only a third of the water.

Strategically sequencing exomes not only generates fundamental knowledge about human genomes, but also contribute to our understanding of human monogenic diseases. For instance, re-sequencing of 200 human exomes identifies an excess of low-frequency non-synonymous coding variants. Single-cell exome sequencing helped scientists understand the single-nucleotide mutation characteristics of a kidney tumour, what can be further applied in tumours study.

Finally, we also decoded social insects like ants and Chinese hamster ovary (CHO) cells lines for use by the bioindustry [Bonasio et al., 2010; Xu et al., 2011]. We traced the genomes of social insects and pathogens for biosafety and biosecurity reasons. Our immediate response to the *Escherichia coli* outbreak in Germany is a case in point here. In the face of such a possible pandemic, the principles of open-source analysis and timely sharing of data become essentially important, and BGI has long endorsed them.

Most of the above projects are collaborations with our domestic and foreign colleagues. On a larger scale, we co-initiated the Netherlands Genome Project, the International 1000 Genomes Project, the International Cancer Genome Project, the 1000 Mendelian Disorders Project, the Microbial Genome Project, the Social Insects Research and the Genome 10K Project. Those international scientific endeavours reinforce HGP's spirit of "owned by all, done by all, shared by all" [Muzny, 2006], and ensure the scientific results being timely and accessible to scientists all over the world, and that their fruits benefit all.

Besides technological breakthrough in genomics, four other technologies are about to change our world completely. These are gene manipulation (GM), cloning, stem cell research and synthetic biology. By employing those four technologies we can bridge life science from sequence, molecules, cells, tissues and organs to individual and population levels. Much has been said and debated about gene manipulation and cloning, so here we will emphasize two emerging technological revolutions in stem cell research and synthetic biology.

Foremost, the discovery of induced pluripotent stem cells (iPS cells) in 2006 shocked the life science community, and brought new hope for stem cell research and its applications [Takahashi, 2006]. The coming years witnessed amazing progresses. For instance, iPS cells produced viable mice through tetraploid complementation [Zhao *et al,* 2009], and human kidneys were created from stem cells [Anonymous, 2011]. Such exciting successes created the hype that people could soon "grow their own organs" from stem cells.

Secondly, through synthetic biology, humanity can start realizing its highest ambition in life science: "writing" the program of life. Synthetic biology beautifully elevates genomics to a higher level: from "reading" to "writing" life.

"The genetic code is 3.6 billion years old. It's time for a rewrite," stated Tom Knight [Silver, 2007a]. A series of historical papers were published during the past few years that approved the concept of artificially synthesizing genomes [Lartigue et al., 2007; Gibson et al., 2008]. *Synthia* became the first bacteria created entirely by synthetic biology methods in 2010 [Gibson et al., 2010], and competitive research teams have been dedicatedly working on bacteria like *E. coil* and *Saccharomyces cerevisiae.*

With the fundamental knowledge generated by genomics and these four key technologies on hand, we are going to liberate life science and shape this 21st century into "the Century of Biology". At this dawn, however, we also need to prepare for new enormous ethical and safety issues arising with life science evolution.

Inheriting the HGP legacy, BGI has grown into one of the largest sequencing centres in the world [Carr, 2010], and integrated HGP's sprit into our research culture. We have set out on our goal to promote widespread vast international collaborations for the benefits of mankind, future generations and coexisting with the environment. We genuinely welcome friends from all around the world to visit, cooperate and join us in this new life science endeavour.

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4

The Right to Proper Healthcare

Alastair Kent

Health for all

Good health is something we all aspire to enjoy. While many in our populations can experience this, at least for a substantial proportion of their life, sadly there are many for whom this is not possible due to chronic disease. This is not a matter of "choice" by those affected. It is a situation they find themselves in as a result of circumstances which are, more often than not, beyond their control. Often, these are genetic in origin, but opportunities, access to healthcare, education, adequate nutrition and many other factors all influence the health and well-being of individuals and families.

Whatever the cause, chronic disease reduces both the quality and quantity of life for millions of people worldwide. While the strife for health is universal, the reality is that many are denied this. But there can be no such thing as a "right" to health. Current scientific understanding of the basis of many life-limiting diseases is such that there is little that we can do to alter their trajectory in those affected.

A much more relevant question is the extent to which we can create a healthcare system that is able to respond to the needs of patients and families with serious and chronic ill health appropriately and fairly, given available resources and current clinical possibilities. No patient wants to feel that their disease is too rare, too difficult or too expensive for their healthcare system to do what it can to meet their needs.

The importance of research

While the hope for a cure is ubiquitous amongst those with life-limiting conditions, the reality is that for many this is not yet a possibility. To change this situation, it is essential that there is sustained support for high quality biomedical research and for the translation of the outcomes of such research into safe, effective interventions that are available to all who stand to benefit equitably and sustainably.

In recent years we have seen unprecedented advances in our understanding of the faults in our basic biology that give rise to many different life-limiting diseases. But knowing what causes a disease is not the same as being able to cure it – or even to intervene to alter its natural history in those affected. The cause of many diseases still remains a mystery. Without a sustained effort to support research this situation will continue indefinitely, leaving patients and their families in a situation where they have little understanding of what to expect, and little hope of a change in their situation for themselves, their families and for future generations.

Yet patients and families, when asked, are generally very supportive of biomedical research and development, even when it is a long way removed from the possibility of interventions appearing that will materially improve their own situation directly. In part this is because research gives hope that things will not always be as they are now, and that future generations can expect to be in a better place than we are now. Participation in research can also help patients feel that they are taking steps to manage their disease, rather than being managed by it — gaining and retaining a degree of control over their own lives.

However, in the absence of a cure for — or even effective therapies that will treat and manage the symptoms of — many chronic conditions, we need to manage these in a way that delivers the maximum possible health gain, taking best advantage of all available resources. This active approach to manage the demands on national healthcare systems is happening in the context of rising demand outstripping supply due to demographic pressures, increased opportunities to intervene, a climate of rising expectations from patients and economic pressures which at best are slowing the growth of healthcare systems and in many cases actually reducing the resources available nationally and globally.

New opportunities

While the problems facing patients are immense, there has been much progress. An increasing number of formerly incurable diseases are becoming treatable or even curable. This creates hope, but novel possibilities come with a price attached, and in the case of new drugs this can sometimes be a high one. No healthcare system can afford to do everything, and even if it could, just because something can be done does not mean that it should be done. Healthcare systems need to create robust frameworks for making resource allocation decisions that allow them to choose sensibly between competing demands on the same restricted resources, and for justifying decisions to invest in one set of possibilities over any other options available.

Health Technology Assessment (HTA) offers such a framework. Increasingly, healthcare systems around the world are turning to HTA to assist with the allocation of resources between competing priorities. They are using methods which claim to allow healthcare policymakers and planners to compare the benefits and costs associated with different intervention (often in widely differing areas of healthcare) and choose between them in an apparently rational way.

The rhetoric supporting the HTA approach to healthcare decision making is unarguable. Healthcare systems need a way of looking at specific interventions and ascertaining the answers to questions such as:

- Does this work?
- How well?
- For which patients?
- Under what circumstances?
- How much does it cost?
- How many people might benefit?

Generating this sort of knowledge is essential for informed decision making in regards to any particular intervention. HTA is reassuring for policymakers because it appears to give a scientific framework for arriving at conclusions about the relative merits of novel possibilities generated by scientific advances, and also a way of making comparisons between interventions in very different disease areas using methods that are fair, objective and replicable. It can seem to de-personalise the difficult decisions that restricted resources make necessary. It removes the subjective element that can often lead to patients feeling they have been unfairly denied something that might have seemed to be beneficial. Surely we should be happy at the development of this field of knowledge?

A patient and family perspective on HTA

While HTA has undoubtedly created a set of helpful tools and frameworks for guiding decision makers, even its keenest advocates would hesitate to claim that it provided a comprehensive answer to the question of how to spend the national healthcare budget to best advantage. The provision of healthcare is not an exact science. Decisions inevitably include a subjective element, and sometimes subjective factors can outweigh all others in determining whether or not a patient is potentially going to benefit from a particular opportunity or be denied access.

Stage two of HTA is the process of appraisal, where somebody has to take the outcomes of the assessment process and make a decision as to whether or not they are actually going to authorise the provision of the intervention under consideration to the patients who stand to benefit. It may be a brilliant intervention, but for a whole range of non-scientific reasons patients may not be able to benefit from it. It may be deemed too expensive, the necessary infrastructure to deliver it to patients may be lacking, there may be insufficient skilled personnel available to manage its use or some other factor may tilt the balance towards a negative decision with regard to patient access.

It is also important to realise that systems for HTA in use around the world generally focus on issues that are important to the healthcare system they are established to advise. Things that are important to healthcare systems may overlap with things that are important to patients and families but the two lists are not necessarily identical. Too often, the possible benefits of an intervention fall outside the immediate environment of the healthcare system. For example, a reduction in the expression of a specific symptom may not radically alter a patient's healthcare needs overall, but it may reduce the stress on carers, enabling them to cope better and possibly reduce the risk of later, more costly interventions being necessary.

Carer and family benefit does not usually weigh in the balance of most HTA systems, at least insofar as they are currently used in health economies around the world. How can we create a framework for determining access to healthcare that carries the confidence of patients, their families and the wider public that is robust, transparent and seen to be appropriate, equitable and sustainable?

Patient expectations

Given our starting point — that having a serious chronic disease is not a lifestyle choice made by patients, but rather a consequence of events leading to this situation — is it possible to categorise patient expectations, and use these as a guide or framework for planning services and support and allocating resources?

It is important to start from the perspective of the patient and their family and carers. The emergence of symptoms will be the indication of a potential problem. In the early stages, the nature of the problem and the issues it raises for the patient, the family and the healthcare system may well be unclear. This means that the patient and his or her family will almost certainly be experiencing some stress, anxiety and probably a degree of distress arising from the uncertainty of their situation. In these circumstances it is possible to identify a cascade of expectations which need to be addressed systematically and (probably) sequentially.

This starts with the need to have a diagnosis. Patients need to know what has happened to them. Without a name to put to their condition it is almost impossible to appreciate the implications and to take coherent action to manage change and exercise options where these exist. Given a diagnosis, the next question a patient will often ask is the availability of a cure. Is there something that can be done that will make the problem go away and make me better? If a cure is not possible, the third step in the journey will be the search for treatments that help to manage the symptoms, improve the quality of life for those affected and reduce the burden on other family members providing care and support for the affected individual.

Moving from the here and now, attention will then turn to the issue of prevention. This is often high up the family agenda when the disease in question is genetic in origin, and access to genetic testing and the opportunity to exercise appropriate reproductive choices will be of critical importance. Where diseases are not genetic in origin, awareness of preventative measures to avoid recurrence in future — where these exist — empowers the family and reduces the future impact on the healthcare system that arises when these opportunities are missed.

In all cases, access to appropriate, comprehensive and comprehensible information in a timely manner is essential. Patient friendly information allows those affected and those around them to understand their situation and to plan for a future based on a realistic appreciation as to what that future might look like. If, for example, a condition is degenerative and extra support will be needed at some predictable point in the future this can be factored into the family's planning for their future, and also taken account of by any appropriate statutory service providers in a timely manner.

The demands imposed by a chronic, debilitating illness usually leave families looking for help from outside their immediate circle. Access to patient support groups, practical help and other welfare benefits can help the individual and the family to cope better. Knowing you are not alone can be of immense psychological and social benefit, as well as an invaluable source of practical day-to-day help.

Finally, there is the need to feel that the statutory healthcare system is there for you in the same way that it is there for any other citizen. This is particularly the case in those systems driven by the underpinning notions of equity and solidarity. This is not to imply that everyone is treated the same, or entitled to the same level of resources. Such measures are facile and inappropriate. Rather, it is to be able to appreciate that, as a patient with a serious and life limiting condition, your needs are recognised and taken seriously. This does not necessarily imply that anything that can be done will be. Rather, it is to know that no patient feels put aside because they are deemed too difficult, too expensive or too rare to figure on the radar of the health service to which they look for help and support.

A responsive healthcare system for patients with chronic diseases

Given the above patient and family centred agenda for shaping healthcare that is responsive to their needs requires systematic planning and a commitment to action from professionals and planners alike. The development of a partnership framework between all key stakeholders that recognises that each has specific skills and knowledge that they can bring to the table to shape the resulting patterns of service delivery is crucial to achieve success.

The traditional hierarchical approach, where doctors knew best and patients were expected to be unquestioningly acceptable is no longer tenable — if indeed it ever was. For chronic conditions there is no "magic bullet" that will effect a cure, so the provision of services must be to manage the patient's condition in light of their and their family's situation.

This requires flexibility, not the imposition of a standard framework that is imposed whether it fits or not. It must focus on what is important to the patient and his or her family. It must be implemented as far as possible in a way that fits healthcare around the life of the patient and his or her family, rather than requiring them to adapt to the demands of the healthcare system. Some interventions will necessarily carry with them limited opportunities for flexibility in their implementation. Where this is the case, careful explanation and ready access to information is likely to maximise compliance and secure the best possible outcomes.

It is also important to be realistic, and to match the aspirations of patients and their families with the evidence of efficacy available from research so realistic expectations about potential benefits and possible risks associated with a particular course of action can be identified. This will help make an informed decision as to whether or not this is an option the patient wishes to exercise.

To achieve this in practice, it is essential to engage with patients and with patient organisations. Those living with a particular disease and the organisations that support them have important insights in respect to its impact and the aspects that cause particular difficulties which, if possible, need to addressed as a high priority. This will make it possible to create a plan of action that can be agreed on as realistic, with all parties knowing who is doing what and when they will be doing it. This helps to ensure compliance, and provides a framework for follow-up so that progress can be monitored and amended in light of changing circumstances.

Any such plan needs to be realistic in the context of the level of resource likely to be available, and avoid over-promising if resources of specific services are unlikely to be available in the relevant health or social care services. Over-promising and then failing to deliver destroys trust between the stakeholders, and leaves patients in a worse situation than they need to be. The ability to be able to measure progress is central to success, setting appropriate metrics that everyone involved can see the value of. For example, an increase in lung function of a few percent might seem insignificant unless it is also accompanied by evidence of the positive impact it has on the patient's quality of life. This adds value to numerical data and enables a more balanced picture of the value of a given course of action to be developed.

The right to proper healthcare

The adoption of a partnership-based approach to the provision of care and support to patients and families living with life limiting serious and chronic disease means that the aspiration to provide proper healthcare for all need not be an unattainable goal. It is adaptable to suit the circumstances of almost any healthcare system, and avoids the creation of unrealistic expectations that patient "wants" not patient needs will be the driver. It creates a robust framework that can identify needs and set priorities that can be acceptable to all parties.

It also allows for plans to be modified and developed in light of changes in the patient or family circumstances, or due to novel possibilities arising from new scientific knowledge or better clinical expertise developed elsewhere.

At the same time, it recognises the reality of available resources, and should be effective in securing the most efficient use of scarce resources or expertise. As such, it can provide a tool for equity-based planning and delivery of services and support for those with long term complex healthcare needs.

This is the stated goal of healthcare systems around the world. It is an outcome that patients and families wish for. It demonstrates a sustainable commitment to the provision of needs-based healthcare in the long term because it will carry the endorsement of citizens necessary for the allocation of public resources.

5

Personalised Medicine or Preventive Public Health?

Werner Christie

Introduction

Global collaborative life sciences projects now taking place will sequence a broad diversity of genomes and produce massive amounts of new genomic data. They will reveal information about innumerable metabolic connections and relationships. This science has the potential to produce broad and deep new insights into our own organic constitution and generate paradigm shifts in the understanding of ourselves as biological beings.

Many projects underway are dependent on huge sequencing and computing capacity able to handle and make sense of large amounts of raw data by statistical methods and mathematical modelling. But information in itself does not necessarily represent new insights into the biological constitution and functioning of life. Other large international collaborative projects are underway, with a large number of research centres and scientists working to interpret the results from genomic sequencing and investigate their functional significance.

The first results from the Human Microbiome Project were published early in the summer of 2012. The findings show that we carry about 1.5 kg of microorganisms in and on our body. Their numbers are estimated to be about 10 times the total number of cells in our body. They can be linked to various aspects of health and disease, and may play a role in our biology and health on par with that of our own genes and cells.

In September, the ENCODE collaboration released the first results mapping the sequences of the so called "junk genes", the dominating non-coding sections of our DNA. The surprising results indicate that more than 80% of the DNA may have a biological function, even though it is not yet clear what. However, it seems clear that an abundant amount of this DNA, influenced by various environmental factors, is involved in orchestrating the level and timing of expression of protein coding genes.

In November 2012, the first results from the 1000 Genomes project were released, mapping variations between individual human genomes, and searching for genetic foundations for common diseases. Interestingly, it found that individuals carry many defunct genes and even disease-related genes without even having the disease or metabolic disorder. The relationship between genome variation and major diseases remains obscure.

From information to knowledge

The main question raised — and one that remains unanswered — from these huge and immensely interesting new explorations into our inner universe is: How can one understand and make sense of all the new information?

As always, the insights gained will depend on the questions asked, and the questions we ask will depend on the mental models we have of the issue at hand. There is no such thing as a neutral observation (Kofler 2012). Our observational approach will have implications for what we observe.

Our mental models and methodology in life sciences research is still mainly based on the traditional and very successful paradigms of the late Renaissance. Descartes have been our main philosophical guidance in this respect. His reductionist view, that the whole can be understood as the sum of its parts, and that it is possible to study and understand reality as a sum of numerous linear cause and effect relationships, have dominated our scientific mindset and methodology since the late 18th century. He has also been a famous advocate for our long tradition of separating mind and nature, or body and soul — a tradition with much older roots in Greek philosophy.

These concepts may now have to be fundamentally reconsidered. It seems evident from our recent insights into biology, ecology and even social and political structures (Homer & Hirsch, 2006) that they are complex systems where the whole is more than the sum of the parts. To understand the functioning of the entire system we need new scientific approaches and huge computing capacity to fully comprehend the complexity and its dynamics.

Such efforts are already underway. The European Union (EU) is funding projects under the label of "Future and Emerging Technologies" (FET) that address some of the innovative opportunities the new science generates. Among the flagship projects under FET are the Human Brain Project, which maps brain connectivity and networks, and the IT Future of Medicine, which constructs personal tailored biological data.

Both of these projects, and other ambitious ones such as the more focused "Virtual Liver Network", aim to chart the metabolisms representing our complex inner universe and even simulate it to predict the outcome of medical interventions.

The Norwegian Cancer Genomics Consortium intends to develop diagnostics and personalised cancer treatments based on genetic analyses of tumours. Such ambitions are based on the insight that cancers stem from mutations in the normal genetic and cell environment of the individual. The focus therefore is on how cancer genomics differ from the normal inborn genome, and keeps mutating and evolving through various stadiums of cancer.

To accomplish such ambitions, we need more than genomics and the massive amounts of information accompanied. We need to understand the dynamic metabolic interplay between all the involved factors at various levels. The genes need to be understood in light of their expression patterns and timing. The regulatory principles steering these processes needs to be understood in light of the influence played by various environmental factors, such as the microbiome, our diet and nutritional habits and our physical and even social influences and behaviour.

The obvious ultimate objective is to understand and make predictions about how all these complex interplays impact our phenotype – our diseases, health and well-being. To be able to make these comprehensive evaluations of information about the biological interplay between every level of our metabolism, there is a dire need for new tools as well as new analytical concepts.

The rapid development of information technology and complex mathematical modelling may indicate that this is not entirely unrealistic, at least for limited elements of the total systems. One such system that tries to bridge all the different aspects of knowledge involved in our total metabolism is Coremine, a data mining system developed by PubGene, to support the efforts of researchers in this field.

Personalised Medicine

The ultimate vision for many of these efforts is to develop a future paradigm of clinical medicine based on the new systems biology. This vision is often summed up with the catchwords personalised, predictive, pre-emptive and participatory medicine — often called "P4" or personalised medicine for short (European Science Foundation, 2012).

This may seem as a very promising and revolutionary concept, and will become a major target for many projects and researchers in the coming years. However, even against the background of these immensely ambitious and sophisticated projects, this emerging new paradigm for clinical medicine must still be realistic and logic. Among reasonable issues to raise related to these future prospects are:

- Epistemology: How well does the new science provide foundations for the P4 paradigm?
- Epidemiology: Which public health challenges will find this new approach relevant?
- Existentiality: What impact will this paradigm have on the way we experience ourselves as persons and patients, what impact will it have on our understanding of our life and the world?
- Health systems: How will it change and challenge health systems, their work model and their sustainability?
- Health politics: Will it be reasonable or even realistic to recommend this approach to public health policymakers?

It will not be possible to address these huge issues in an appropriate and sufficiently comprehensive manner within the limited scope of this article. It may still be worthwhile to consider some of the aspects that deserve further investigation under each of these broader topics.

Epistemology

The emerging picture of how our inner biological constitution is organised seems to defy the oversimplified concepts we have had about the relationships between genotype and phenotype. Genes and genetic variations seem to have less penetration into phenotype and diseases than expected. Regulation of genes and epigenetic mechanisms, some of which are also inheritable, seem to play a much more important role than we have been aware of until now.

The regulatory mechanisms for gene expression seem to be under substantial environmental influence, so that even social relationships early in life may have important impacts over several generations. This indicates that for P4 to be relevant it has to focus on much more than genes and metabolism. It must take into consideration the complexity of the relationship between cells, organs, and the human organism, as well as the behaviour of individuals and their environment.

Furthermore, the way the environment affects our genes and their regulatory mechanisms must be considered. The environment may influence the regulation of metabolism in the short term, but it may also impact the regulation and structure of the genome over several generations. Thus, our concept of systems biology must be expanded to also include its evolutionary repercussions. (Loewe 2009).

Therefore, our fitness, the evolutionary term for what in other contexts will be called "health" and "well-being", depends in a very tangible way on the relationship between ourselves as organisms and our environment. Health

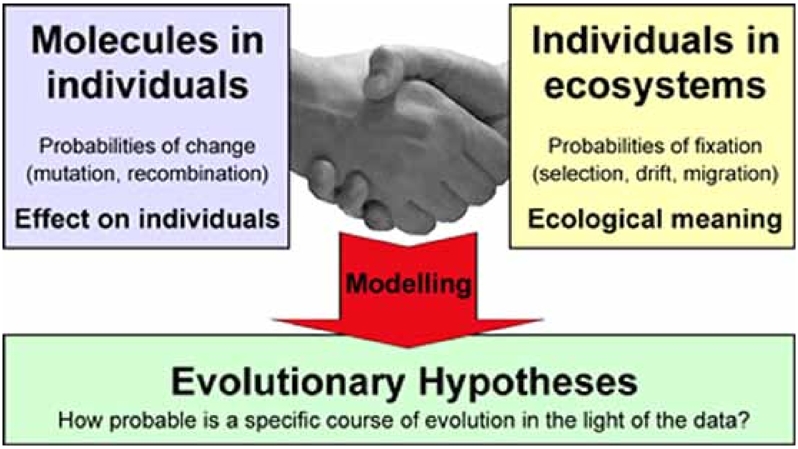

Figure 1 Evolutionary Systems Biology

strategies need to take this into account. Up until now, trends in innovative medicine have been very focused on biotechnology, a methodology strongly influenced by the Cartesian reductionist mindset. The concept is inspired by physics and engineering and their formidable success with linear cause and effect reasoning.

We have sought to understand individual genetic and metabolic mechanisms to be able to address diseases. However, the complex sources of modern public health challenges seem to make this approach inadequate and inapropriate, even though it was proven successful in many clinical aspects of medicine.

New developments in the science of evolutionary biology indicate that we also need to understand the way we impact and change our environment through our technology and culture. Since they first emerged, human beings have actively transformed their own environment more than any other species. We have acquired fire and cooked and cultivated our own plants and animals for food.

Our recent, rapid increase in technological capabilities have changed our capacities and environments, and therefore also our own fitness, substantially. Through this effort, we have gained better nutrition, better health and longer lives, while reducing physical effort. But this also created new challenges to health and well-being. We have in fundamental ways changed and evolved our own ecological niche (Wilson 2012).

The pertaining question for our discussion thus becomes: Does P4 reflect an adequate and relevant understanding of the relationship between our metabolic system and major public health issues, or is it too limited in scope to address more than partial and specific disease mechanisms?

The fact remains that health is a relationship between two basic principles: Entropy (disorder or disease), and negative entropy, (order or health) (Schrödinger 1967). In the medical context, entropy, the processes that creates disorder and disease is often called pathogenesis . The negative enthropy will be all factors that create and maintain order and homeostatic continuity in the organism, and can be termed salutogenesis.

$$\text{Health} = \frac{\text{Negative Entropy, or: Salutogenesis}}{\text{Entropy, or: Pathogenesis}}$$

Figure 2

Based on fig. 2, preventive public health should lead us to search as aggressively for the mechanisms of salutogenesis as for the mechanisms of pathogenesis. They may even be easier to effectively impact than the disease mechanisms. It is a well established fact that the reduction of disease in society over that last few generations owes more to the general evolution of society and living conditions than to medical progress and the impact of the healthcare system.

The further development and improvenment of our ecological niche may be a better approach for maintaining health and preventing disease than artificially manipulating our methabolism. However, we still need to adress the pathogenetic processes of those already living with a disease. Along those lines, P4 may have a lot to contribute to our healthcare systems.

Epidemiology

Based on WHO figures that illustrate disability adjusted life years lost due to 19 leading global risk factors (fig. 3), we can determine appropriate public health strategies. It is obvious that the issues necessary to address are to a great extent related to ecological challenges as well as to our own behaviour.

Given that we are now very much in control and construct our ecological niches through our technology-dominated lifestyles, this can also be an effective approach to improve global health in the world and to reduce the burden of disease. As ENCODE coordinator Ewan Birney suggests, the new information gained paves the way to "understanding how much of complex traits are due to environmental effects, or free will — things we CAN change…"

When taking into consideration the global burden of disease, one may wonder how the disease panorama is related to malfunctioning of the metabolism of the individual, and how much this relates to suboptimal adaption of our environment to our generic biological constitution. After all, it is intriguing that there are so many healthy individuals living in adverse conditions who have particularly high resistance and resilience against the common diseases that obviously challenge us all the time.

Usually, only a minor fraction of those infected by various agents develop related disease. Of all the cell divisions going on and mutations apparently taking place in our bodies during our lifetime, very few damage metabolism and lead to pathology. There must be huge redundancy in our bodies resisting the forces of entropy and keeping us healthy. To fight the conditions illustrated in fig. 3, three strategies seem pertinent:

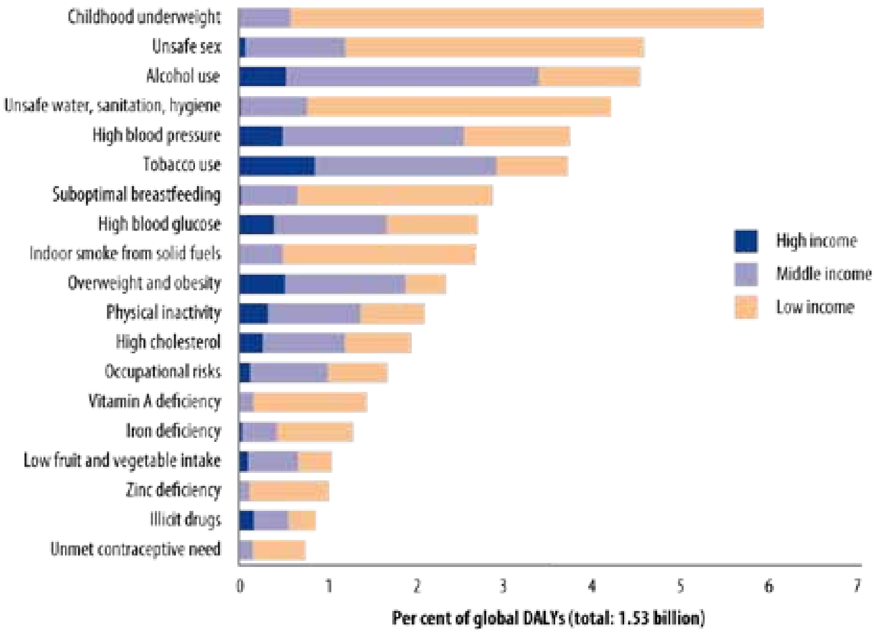

Figure 3 WHO burden of disease statistics (http://www.who.int/topics/global_burden_of_disease/en/).

To understand and enhance the internal resistance and resilience of our metabolism.

To adapt our behaviour to avoid adverse effects on our biological system.

To adapt our environment to reduce external challenges to our metabolism.

Existential issues

Our understanding of our personal health and disease status is a fundamental element of our sense of identity, independence and dignity. Therefore, we need to know how new paradigms for understanding disease and health will affect our world view, self confidence and our general well-being.

Extensive genomic and metabolic mapping of individuals may be relevant and necessary to gain specific understanding of current diseases and develop treatments for them. However, used as a predictive and pre-emptive tool, such mapping raises a number of issues.

The only fairly stable element in the map of our internal metabolic universe will be our DNA and genes. Most other indicators and factors vary according to time and situation. The predictive value of each specific test for various end conditions may be uncertain or fairly low, even under the best testing conditions.

This indicates that what we will be able to offer clients through pre-emptive and predictive efforts will be a fairly nebulous guidance for vital life choices. Too much focus on individual risk factors and disease may make daily life less invigorating and decrease the experience of independence and the feeling of dignity.

We know that beyond health, well-being is not necessarily the absence of disease. Our well-being is as much related to our ability to cope with risk factors, adversity and ill health. This can be enhanced through our education and knowledge, through support from professionals, friends or family and from adapting our environment to our smaller or bigger disabilities.

Increasing our capacity to cope, motivation and psychological and physiological resilience will usually enhance our feeling of independence, self-respect and dignity. In order to increase well-being, it may therefore be better for the clinical community to focus on intrinsic and generic resilience factors rather than individual risk factors. Health literacy will play a crucial role in this respect, together with motivation and cognitive approaches of positive psychology.

Challenges to the Health systems

A personalised medicine approach may be both necessary and productive for treating already manifest diseases. However, for preventive and public health challenges, other strategies should have a higher priority. The emerging understanding of our biological systems seem to indicate that a large proportion of the public health challenges illustrated in Figure 3 above are generic and not genetic in nature. They are affecting large numbers of people because broad segments of the population face similar challenges from their environment.

The proclamation that "All men (and women) are created equal" from the international declaration of human rights is based on the fact that all humans have basically similar genomic and metabolic constitution. It is therefore also reasonable to assume that they also share their main disease risks, resilience factors and relevant coping strategies. These are the low hanging fruits that public health should primarily focus on, and find new innovative strategies to cope with.

By using the ever increasing information garnered from genomic science to build a broader understanding of evolutionary systems biology, it should be possible to identify the major generic disease development processes. Using this information to further develop and enhance the ecological niches we have created for ourselves, to adapt our behaviour and to facilitate our intrinsic resilience will most probably be a much more cost effective preventive strategy than P4.

Challenges for Health Policy

Upcoming generations are posing a growing challenge to health systems all around the world. The world population is expected to grow by some 2 billion, mostly in developing countries. Developed countries will be faced by continuously aging populations, with more medical needs, new demands and higher expectations. This will pose challenges of medical effectiveness, cost efficiency and economic sustainability.

It will be necessary to impose strict priorities and demand effective use of all available resources. Only time will tell whether the paradigm of personalised medicine will be successfully implemented in its current form and where it would be most appropriate. Whether it will be possible to get sufficient funding to do so in an equitable way that is available, accessible and affordable for all is another question.

In either case, commercial interests will probably push for the implementation of such strategies on a broad scale. Huge profits stand to be gained from the necessary testing and development of new, personally adapted drugs to stratified and small segments of the prevailing disease pattern. The market will most probably respond with demand for these services if offered. However, preventive measures are commonly ridden by fundamental market failures, since preventive measures spoil a potential market, and do not address specific consumers already in need.

For health systems to be able to take advantage of the low hanging fruits of preventive public health based on facilitating intrinsic resistance factors, public policy needs to compensate for the market failures. Policies needs to inspire, initiate and fund basic research in evolutionary systems biology, as well as applied science for developing innovative public health technologies and strategies. Everything from nutritional advice and vaccines to health literacy and healthy behaviour campaigns can be relevant in this respect.

Conclusion

The new collaborative large science projects that are mapping and investigating our metabolism will be hugely interesting and very valuable for the future of healthcare. Personalised medicine will obviously become a new paradigm for health systems, but should not be the only one. More emphasis on new knowledge and new innovative opportunities within generic public health approaches should also be explored and developed.

This will be crucial if we are to cope with increasing demands from a growing population, new innovative opportunities and higher expectations. Beyond biotechnology, we need a new paradigm of bioculture, which stands at the interface of biology, medicine, humanities, and culture, and which taking the emerging knowledge embedded in evolutionary systems biology into account.

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6

Genomes, Metagenomes, and Microbiomes: A New Biology for a New Millennium

Bas E. Dutilh and Ramy K. Aziz

Introduction

Biology of the invisible

By definition, microbiology is the biology of microscopic organisms (microorganisms or microbes). After centuries of biological research, it has only recently become common knowledge that the vast majority of life forms cannot be seen by the human eye, and a great proportion of them cannot be cultured in the laboratory with commonly used culturing techniques.

The number of microbes on the planet is estimated to be between 1029 and 1030 (Whitman et al., 1998), and the number of viruses is estimated to be ten times higher (Wommack and Colwell, 2000). These tremendous numbers of microbial cells and virus particles reflect an immense diversity of lifestyles that can adapt to nearly every environment on the surface of the Earth and in the depths of its oceans.

A new biology for a new millennium

It is intriguing that the vast majority of living forms were not even detectable until the invention of the light microscope. It was only in the 17th century when the Dutch tradesman, Antonie van Leeuwenhoek (1632–1722) was able to observe the first microbes, which he called 'living animalcules', using a prototypic microscope that he manufactured. Yet, it was not until 150 years later that Louis Pasteur (1822–1895) and Robert

Koch (1843–1910) established the science of microbiology and the germ theory of disease causation by detecting, culturing, and isolating living microbes.

It took the scientific community almost another 150 years to figure out how to deal with organisms that could never be cultured by standard techniques. Only after DNA was discovered, and its composition unfolded, did we devise the technologies that have ultimately made it possible to detect uncultured microbes and viruses by sequencing their genetic material, most notably their ribosomal RNA genes.

At the turn of the 21st century, the use of DNA sequencing was first applied randomly to microbes in their natural habitats for the purpose of not only detecting their types and phylogenetic descent, but also to sample parts of their functional genome sequences and reveal their biology and lifestyles. This random community genomic sequencing technology, commonly known as metagenomics, has revolutionized biology and ecology at the dawn of the new millennium and ushered a novel approach and perspective to studying life sciences. As with the invention of the microscope more than 300 years ago, genomic and metagenomic technologies have offered scientists 'new eyes' and a new level of access into the invisible world of bacteria, viruses, and other microbiological entities.

Environmental and host-associated microbiomes

The Earth microbiome

As soon as the technology of metagenomics was developed (Breitbart et al., 2002; Rondon et al., 2000), it quickly gained ground in the field of environmental microbiology. This was due to a real need to deeply probe uncultured bacterial communities, and an even more pressing need to study the diversity of viral assemblages, which is very hard to understand otherwise (Edwards et al., 2005).

With the accrual of dozens of studies on microbial and viral metagenomics, pieces of a jigsaw puzzle depicting the global microbiome started coming together. The promise of forming a comprehensive picture of the Earth microbiome slowly became feasible (Gilbert et al., 2010). There is no limit for scientific questions that can be asked based on the availability of those global metagenomes, the simplest of which is the question about the most abundant genes and pathways in nature (Aziz et al., 2010).

The human microbiome

Like other environments in nature, the human body itself is an entire ecosystem that hosts different communities of microbes and viruses. The total number of bacterial cells associated with our body is estimated to be ten times greater than the number of human cells, and the number of viral particles is expected to be a hundred times greater (Mokili et al., 2012).

These microorganisms greatly impact our life. While it has been known since Louis Pasteur and Robert Koch that microbes can transmit diseases, modern techniques including metagenomics have shown that bacteria are beneficial to humans in many ways. For example, they degrade food products and synthesize vitamins (Gill et al., 2006), among other critical functions.

These considerations have prompted the funding of research projects aimed at mapping the normal human microbiota in healthy individuals. Perhaps the two largest such projects are the Human Microbiome Project (Peterson et al., 2009), funded by the US National Institutes of Health, and Metagenomics of the Human Intestinal Tract, funded by the European Union. Those projects have paved the way to tens of published studies, most notable of which are those that catalogued entire microbiomes of different organs of healthy humans (Human Microbiome Project Consortium, 2012; Qin et al., 2010).

Human microbiome in health, disease, and therapy

At the same time, the role of human-associated microbes in a wide variety of diseases is becoming increasingly clear. Beside the usual examples of microbial involvement in respiratory infections, acute intestinal infections, or allergies, they have also been implicated in diseases not previously thought to have a microbial etiology. Examples include autism (Shaw, 2010), obesity (Turnbaugh et al., 2006), type II diabetes (Qin et al., 2012), cardiovascular diseases (Ordovas and Mooser, 2006), and several forms of cancer (Dalton-Griffin and Kellam, 2009; Tjalsma et al., 2012).

For many such cases, evidence is still circumstantial: scientists observe a correlation between the presence of a bacterium and the occurrence of the disease, but proving causality is rarely straightforward. Not only does the human microbiome modulate human health and disease conditions, but it also affects the outcome of drug therapy (Rizkallah et al., 2010; Saad et al., 2012).

Current state of the field

We can ask several types of questions about the human or Earth microbiome. The first are questions about the identity and role of the microbes in their niche, and have been formulated as "Who is there?" and "What are they doing?" The second set of questions focus on the influence of the environment on the microbial population, and vice versa, the influence of the microbes on their environment, including the effect they have on the health or disease status of their human host. Thirdly, our aim may be to manipulate these microbiota, so we may ask how we can help the beneficial species, while deleting the detrimental ones.

Determining the composition of a microbiome

"Who is there?" is often addressed by sequencing taxonomic marker genes that are amplified from an environmental sample. This environmental amplicon sequencing yields an overview of the microbial species in the sample, also known as the microbiome (not to be confused with the metagenome, see below).

The most prominent example of such a taxonomic marker is the gene encoding the small subunit of ribosomal RNA (16S rRNA). This gene contains a good taxonomic signal, which means it is possible to infer which bacterial species the gene was derived from based on its sequence. One of the reasons that 16S rRNA is such a good taxonomic marker is that it has the same cellular function in every organism, and its sequence is therefore conserved. However, its strength is also its weakness: this gene gives us little information about the functional differences between the microbes in the sample. In other words, it does not answer the question "What are they doing?"

Nevertheless, several rules of thumb about the functions generally associated with identified species have fuelled interesting hypotheses about the involvement of specific microbial lineages in diseases, such as colorectal cancer (Tjalsma et al.., 2012). As determined in several environmental sequencing projects, the microbial populations on the developing tumour differ from those of the adjacent, unaffected mucosa (Marchesi et al., 2011). Whereas the unaffected tissue harbours potentially pathogenic Enterobacteria, the colorectal tumour was mainly enriched in Fusobacterium (Castellarin et al., 2012; Kostic et al., 2012).

In an ongoing study, we hypothesised that these spatial differences mirror a difference in temporal association of the microbes with developing tumours. Before the tumour onset, the bacteria in that region may have been similar to that found in the currently unaffected areas (Tjalsma et al., 2012).

Tumour development changes the microenvironment, which can favour the outgrowth of different species. If there exist bacterial drivers that contribute to the initial steps of colorectal cancer, we might expect them to be more prevalent in the yet unaffected areas rather than on the full-grown tumour, which contains passenger bacteria that have a competitive advantage in the altered microenvironment. Of course, these passenger bacteria may or may not play a role in the further progression of the disease (Tjalsma et al., 2012). It should be noted that these ideas are based on comparisons of species profiles, and their functional roles remain to be investigated.

Determining the functional potential of a microbiome

The question about the functional roles of a microbiome's components — "What are they doing?" — might be more appropriately answered via sequencing other genes rather than the functionally uniform marker gene 16S rRNA. As illustrated above, taxonomic profiles may provide useful hints about the role of the microbial organisms in a sample, but closely related strains may have very distinct phenotypes due to the differential presence of mobile elements, including bacteriophages.

The mobile fraction of the genome may be enriched for genes involved in interaction with the environment, including virulence genes. The most prominent example is perhaps the CTX phage that infects Vibrio cholerae, turning this bacterium into a dangerous pathogen by providing it with the phage-encoded cholera toxin gene (Waldor and Mekalanos, 1996). To address the functional potential of a microbial community, the metagenomics approach, defined above, was developed.

Metagenomics randomly samples sequences from the collective genomes of all the members of the community, thus sampling a large diversity of genetic functions in a single experiment and providing a functional profile of the sampled site. This is analogous to the taxonomic profile that is obtained by using environmental amplicon sequencing of taxonomic marker genes. It should be noted that metagenomics also allows for the reconstruction of a taxonomic species profile, albeit at a lower resolution than 16S rRNA-based methods.

Computational challenges

Complex processes

Some of the state-of-the-art technologies in the research of microbial communities are concerned with answering the questions posed above. The most commonly used approaches include mapping the metagenomic sequencing reads to a suitable database, followed by statistical analysis of the resulting taxonomic or functional profiles. Depending on the stringency used in the database mapping step, this is often a very computer intensive process due to the many millions of sequencing reads obtained and the large size of the reference database.

Stringent mapping is relatively fast, while similarity searches that identify sequence homology at greater evolutionary distances (with more mutations in the sequence) require slower, more sensitive search algorithms. Several promising statistical approaches have been outlined that determine significant biomarkers among the identified species or functions (Baran and Halperin, 2012; Gianoulis et al., 2009; Segata et al., 2011).

Further interpretation of the differences and similarities between environments is often still an elaborate process. One special case is represented by metagenomes with a high fraction of unknown sequences – reads that do not resemble any previously encountered DNA sequence even when a sensitive similarity search algorithm is used. Viral metagenomes are a prime example, as they belong to a particularly fast-evolving superkingdom (Bonhoeffer and Sniegowski, 2002; Mokili et al., 2012). In those cases, it might be instructive to compare the sequences not to an external reference database, but to the sequencing reads obtained in similar environmental sequencing projects. Cross-assembly of sequencing data is a suitable tool for this (Dutilh et al., 2012).

Sequence assembly is a process in which the sequencing reads, which are often short due to the technologies used, are joined together into longer contiguous sequences (contigs) that reflect the biological sequences in the original sample. By assembling reads from different samples together (cross-assembly), some contigs will be composed of reads from the different samples combined, thus representing metagenomic entities that are shared between the samples. The number of cross-contigs is a measure of the similarity of the samples (Dutilh et al., 2012).

One of the major remaining challenges is to understand the functional interactions between the different organisms in a microbial ecosystem, and between the microbes and their biotic (e.g. the human host) or abiotic (e.g. the geological habitat) environment. Computational models will be invaluable in addressing this challenge. Advances have been made in the systems modelling single biological cells, intended to describe how a phenotypes arise from the interactions between individual molecules (Karr et al., 2012).

In combination with large scale co-occurrence and co-culture assays that predict cooperative and competitive relationships between species (Faust and Raes, 2012), these system-level models are paving the way toward ecosystems biology (Raes and Bork, 2008; Thiele et al., 2012; Zengler and Palsson, 2012). Although several research groups are ahead of the crowd in this field, this area is still very much under development.

Computational tools for decoding genomes, metagenomes, and microbiomes

Several tools have been developed, and are continuously being developed and updated, for the interpretation of genomes, metagenomes, and microbiomes. Among those tools are the subsystems annotation tools and servers (Overbeek et al., 2005; Ye et al., 2005), which take an automated, integrative, human expert-based approach to the interpretation of complete or partial genomes, as well as genome fragments or metagenomes (Meyer et al., 2008).

We find these tools to be both accurate and efficient, and we have personally been involved in developing several of them — or used them to develop other tools. Below we list a selection of tools and servers relevant to the topic of this article (Table 1). It is to be emphasized that the list is not comprehensive (because of space and reference limitations), but focuses on tools with which we have experience.

Table 1 Computational tools for the interpretation of genomes, metagenomes, and microbiomes

Tool	URL	Use	Reference
FACIL	http://www.cmbi.ru.nl/FACIL	Predicts the genetic code of an unannotated DNA sequence	(Dutilh et al., 2011)
Signature	http://www.cmbi.ru.nl/signature	Identifies taxonomic signature genes in a set of protein sequences	(Dutilh et al., 2008)
The SEED Database	http://theseed.org	Database for all complete or near-complete microbial genomes and human-curated genomic subsystems	(Overbeek et al., 2004)
The SEED Servers	http://www.theseed.org/servers	Allow remote programmatic access to the SEED via the web and includes several methods and web services	(Aziz et al., 2012)
RAST	http://rast.nmpdr.org	Provides nline rapid genome annotation using subsystems technology	(Aziz et al., 2008)
MG-RAST	http://metagenomics.nmpdr.org	Allows the annotation and access to metagenomes using RAST technology	(Meyer et al., 2008)
Real-time Metagenomics (RTMG)	http://edwards.sdsu.edu/rtmg	Allows real-time annotation — but not storage — of metagenomic sequences in a few minutes using k-mer technology	(Edwards et al., 2012)
myMGDB	http://edwards.sdsu.edu/cgi-bin/mymgdb/show.cgi	A database for sequenced, annotated metagenomes/microbiomes that allows comparison and BLAST similarity searches against stored metagenomes	N/A
crAss	http://edwards.sdsu.edu/crass	Tool for comparing metagenomic samples by using cross-assembly	(Dutilh et al., 2012)
PhAnToMe	http://www.phantome.org	A database and portal for the storage and annotation of bacteriophage genomes, based on the SEED system	Aziz et al. In preparation
Phage Eco-Locator	http://www.phantome.org/eco-locator	Allows the visualization and analysis of phage genomes in metagenomic data sets	(Aziz et al., 2011)
PhiSpy	http://sourceforge.net/projects/phispy	Allows the prediction of prophage sequences within complete or near-complete microbial genomes	(Akhter et al., 2012)

Applications and future perspectives

Manipulating the microbiota associated with our body is one of the applied goals in the human microbiome field. This may not only help us fight diseases, but also improve health. An in-depth understanding of the interactions between microbes and their human host, as provided by the computational models introduced above, will help us design solutions that apply microbial organisms to specific problems.

However, examples of specific solutions that target the human microbiome have already been described more than a century ago (Vaughan, 1965), and were applied long before that. Metchnikoff believed that the consumption of lactic acid bacteria would inhibit the growth of proteolytic bacteria, leading to increased longevity. This illustrates that applications may run ahead of the fundamental understanding of all the processes involved. Moreover, as described above, statistical analyses are very powerful at finding strong relationships such as biomarker associations between diseases or phenotypes and bacterial species or functions (Baran et al., 2012; Gianoulis et al., 2009; Segata et al., 2011).

Conversely, the elucidation of the molecular process underlying these correlations is time-consuming and expensive. Thus, personalised microbiomic treatments, including the application of probiotic agents and the elimination of potential bacterial drivers associated with diseases, is a promising area for the enhancement of human health. Moreover, novel fields, such as pharmacomicrobiomics, are being developed to take microbes in consideration when designing personalised therapy (Aziz, 2012; Rizkallah et al., 2010).

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7

Nanomedicine for Cancer Treatment and Theragnostic

Patrick Couvreur

Scientists are on the search for new chemotherapeutic agents with less severe side effects and better therapeutic outcomes. However, even if new chemotherapeutic compounds are discovered to treat cancer diseases, their clinical use and efficacy will be hampered by several limitations:

1. Drug resistance at the tumour level due to physiological barriers (non cellular-based mechanisms);
2. Drug resistance at the cellular level;
3. Non-specific distribution, biotransformation and rapid clearance of anticancer drugs within the body.

Thus it is important to develop nano-devices that are able to overcome the resistance of cancer cells or tissues to chemotherapeutic treatments. The potential of this approach will be discussed through different examples.

Camouflage

P-glycoprotein 1 (PgP) is a membrane glycoprotein which is known to cause multidrug resistance — including developing resistance to anticancer drugs. The camouflage of the anticancer drug doxorubicin inside polyalkylcyanoacrylate nanoparticles has allowed it to overcome the effects of PgP, thus reversing the multidrug resistance. This is a first illustration of the use of nano-devices to fight resistant cancers (fig. 1).

The higher cytotoxicity of doxorubicin when loaded onto poly (isohexylcyanoacrylate) nanoparticles has been shown *in vivo* on a transgenic mouse model of hepatocellular carcinoma which mimics several steps of human hepatocarcinogenesis.

Based on this data, a phase III multicentric clinical trial is currently being performed on patients with resistant hepatocarcinoma or liver metastasis.

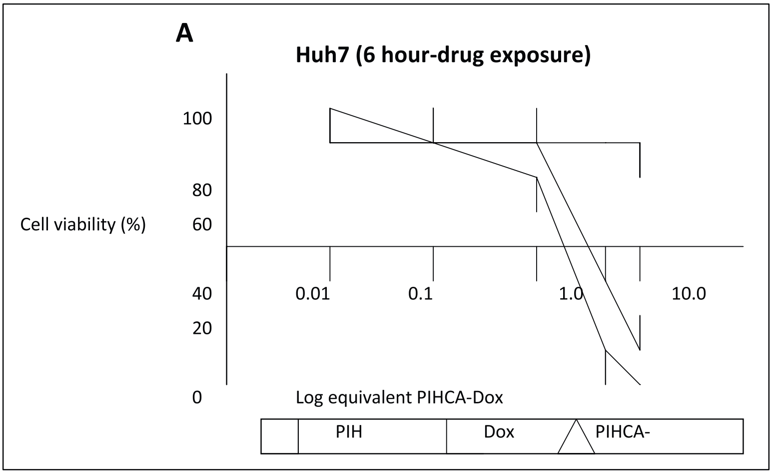

Figure 1. Cytotoxicity on human hepatocarcinoma cells of doxorubicin loaded onto PIHCA nanoparticles versus free doxorubicin (from Barraud, et al., J. Hepatology, 42, 736-743; 2005)

Squalenoylation

Another example of the potential of nano-devices is squalenoylation, a technology that takes advantage of a certain ability of the naturally occuring lipid squalene, which acts as a precursor for the biosynthesis of cholestrol in mammals.

Squalene is able to dynamically fold its conformation to link to anticancer and antiviral nucleoside analogues in order to achieve the spontaneous formation of nanoassemblies (100–300 nm) in water without the aid of surfactants. When applied to the anticancer compound gemcitabine, the squalenoylation allowed the efficient treatment of several cancers, including leukaemia (fig. 2).

Interestingly, this original approach was able to overcome different mechanisms of resistance to gemcitabine, such as its deamination by blood deaminases, its insufficient phosphorylation by the deoxycytidinekinases (dCK) and the downregulation of nucleoside transporters.

In a nutshell, the squalenoylated gemcitabine nanoparticles were found to be: resistant to deaminases; able to diffuse intracellularly independent of the presence of nucleoside transporters; and able to improve the phosphorylation of gemcitabin by dCK.

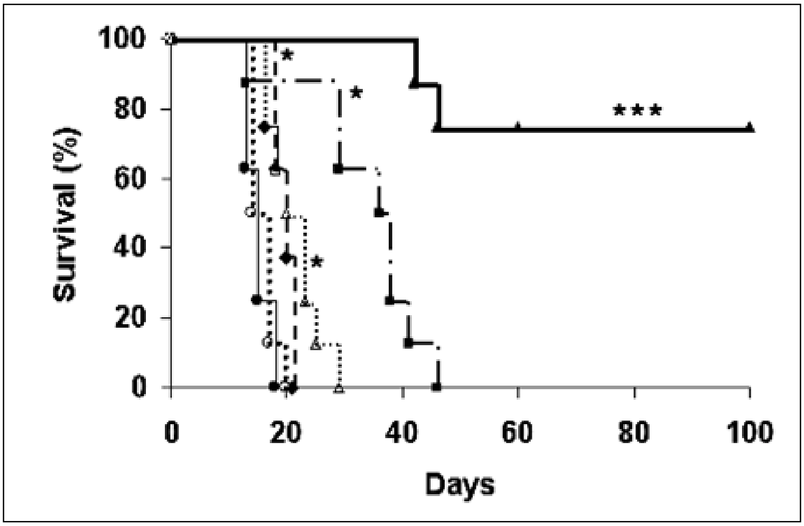

Figure 2. Survival analysis of L1210 leukaemia bearing mice (from Harivardhan Reddy et al., J. Pharmacol. Exp. Ther., 325, 484-490; 2008)

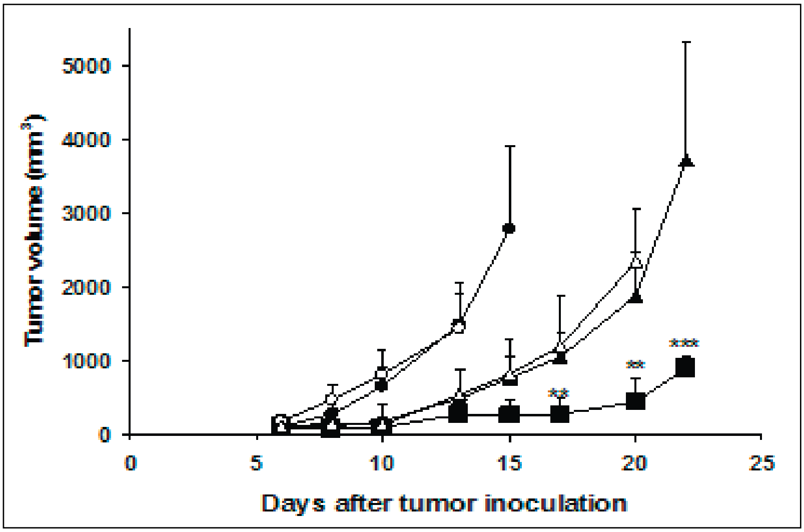

Figure 3. Top: In vivo anticancer activity of USPIO/SQgem composite nanoparticles (with extracorporeal 1.1 T magnetic field) (5 mg/Kg equivalent of gemcitabine) compared with USPIO/SQgem composite nanoparticles (no extracorporeal magnetic field applied) (5 mg/Kg equivalent of gemcitabine), with SQgem nanoparticles (5 mg/Kg equivalent of gemcitabine) and with gemcitabine free (5 mg/Kg) in L1210 subcutaneous tumor bearing mice. Below: Tumor imaging in the absence or in the presence of the magnetic field (From Arias et al., ACS Nano, 22, 1513-1521; 2011)

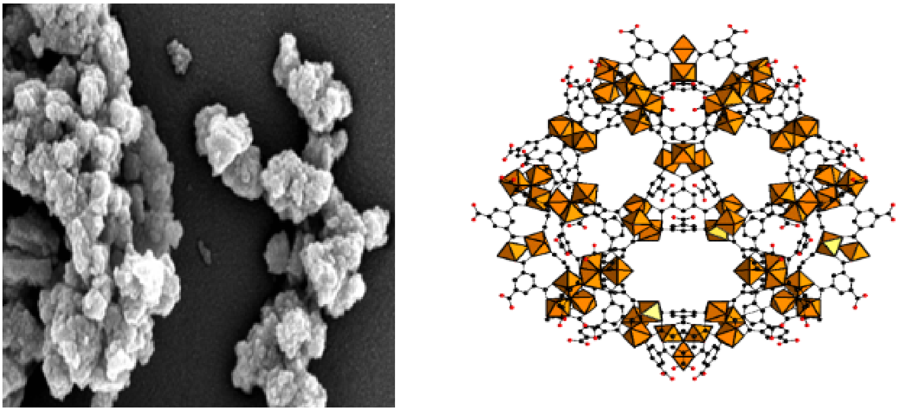

Figure 4. Transmission electron microscopy appearance and structure representation of MIL-100 metal oxide framework based nanoparticles (nanoMOFs) (for more details, see Horcajada ***et al.***, Nature Materials 9, 172-178: 2010)

This breakthrough concept has been further expanded to other anticancer drugs, including paclitaxel, cisplatin and small interfering RNA (siRNA).

The entrapment of ultra-small iron oxide nanoparticles in these squalene-based nanoassemblies has further allowed the designing of multifunctional nanoparticles combining therapeutic and imaging properties (aptly called "nanotheragnostics"), (fig. 3). This paves the way to personalised medicines.

A final example can be seen in the use of organic/inorganic nanohybrids, constructed with metal organic frameworks (nanoMOFs), (fig. 4). These have shown remarkable ability to encapsulate unprecedented high quantities of the anticancer compound busulfan.

These new approaches show the potential that nanomedicines can offer in the field of anticancer therapeutics. They may not be a magic bullet, but the can offer solutions to address some of the most serious limitations of anticancer drugs today.

Acknowledgements

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2

THE GLOBAL CHALLENGES OF A CHANGING CLIMATE

8

The Psychology of Denial: Forms of Self-Inflicted Blindness in the Anthropocene Era

Alberto Zucconi

Introduction

> Earth provides enough to satisfy every man's need, but not every man's greed. — Mahatma Gandhi

There is ample and mounting scientific evidence that our present relationship with ourselves, others, and the planet we live in is the main variable influencing all life forms and the planet itself, a dramatic epochal change referred to by many scientists as the Anthropocene (Crutzen and Stoermer, 2000). The human population's exponential increase in numbers and consumption behaviours has produced such dramatic and exorbitant costs to the environment.

Our present way of life has negatively impacted many of the ecosystems of our planet and a mounting number of scientist warn that we are fast approaching a tipping point where mitigation or reversal of trends will be impossible if we do not act promptly and effectively (IPCC, 2007, 2012).

Notwithstanding the seriousness of the threat, many obstacles remain in the way of effective community, national and international climate governance. The lack of awareness of the magnitude of the problems and the changes needed in the behaviours of all the stakeholders to manage the serious challenges facing humanity is in part due to barriers of a sociological and psychological nature and impede effective coordinated actions by the various stakeholders. The underlying mechanisms at work in the promotion or resistance to change vary from culture to culture. How reality is socially construed and how individuals and organizations construe their experiences and narratives is also relevant when trying to understand the changes needed to promote climate governance.

Anthropocene times

Human population has drastically increased in the last century, with billions more people adopting consumption behaviours that have negatively impacted and polluted the earth at levels that our great-grand parents were never capable of.

The anthropogenic impact has largely surpassed the planet's metabolic capacities. It now takes the Earth one year and six months to regenerate what we use in a year. At present, humanity, with its destruction of natural resources, pollution of air, land and water, is altering the climate 5,000 times faster than the pace of the most rapid natural warming episode in our planet's past (Caldeira, 2012).

In his message to the Planet Under Pressure conference, Ban Ki-moon, the UN Secretary General, said:

> "Climate change, the financial crisis and food, water and energy insecurity threaten human well-being and civilization as we know it. The scientific community can help us make sense of these complex and interconnected challenges, including by strengthening our understanding of 'planetary boundaries' and critical thresholds…. But policy makers often fail to turn to scientists for advice, or discount it too easily owing to electoral or other political considerations."

More greenhouse gases continue to flows into the atmosphere, a consequence of the near doubling of the human population and the near tripling of global consumption. This could likely result in a catastrophic climate disruption caused by greenhouse heating (Ehrlich and Ehrlich, 2009). If not resolved, the inequities of resource access, distribution, consumption, and levels of pollution are formidable obstacles to international agreements for a more effective, equal and sustainable governance of our planet.

Barriers to change

The ineffective or dysfunctional ways in which we may see things, the way in which we construe the experience of reality, is at the root of the many barriers to effective climate governance. The pervasive mechanistic reductionist approach of the past has led to a boomerang effect. The world has been largely bent on creating policies, services and products focused on fixing a specific part of the system, ignoring the obvious impact that the single action will have on the whole.

A well-known example of a mechanistic reductionist approach is the use of pesticides and chemical fertilizers. After World War II, they were seen as a scientific breakthrough to feed humanity and build a better and more prosperous world. The unlimited use of these chemicals fit the prevailing expectation of scientific progress for the betterment of society. Unfortunately, this view did not take into account the complex interrelationships of the world in which we live. The massive use of pesticides and chemical fertilizers initially expanded the production of food. However, success encouraged one-crop cultivation that soon impoverished the soil, necessitating an ever greater use of chemicals. This created a downward spiral of increasing chemical usage and decreasing soil vitality. Moreover, after boosting crop production and killing unwanted pests and weeds, it became apparent that pesticides had a long period of continued action on the environment, affecting the food chain and water quality (Zucconi, 2008).

Systems theory, on the other hand, is based on the awareness of the essential interrelatedness of all phenomena — physical, biological, psychological, social and cultural. It is a total ecology model wherein the common denominator is the relationship. Systems theory sees all the structures of our universe as comprised of extensive subsystems that are in constant interaction and impact each other. The ecological, systemic view has relevant implications for the understanding of the health and wellbeing of individuals and society.

Reality

What is perceived as real varies from society to society and is produced, transmitted and conserved through social processes. Our perception of reality is largely modelled after beliefs and assumptions of the society and culture in which we belong. What we consider true and right and the behaviours we adopt are all influenced profoundly by the social and cultural environment in which we grow and live. This process happens through the internalization of a "reality" that occurs during the socialization process (Berger & Luckmann, 1966).

The social construction of reality is not easily criticized or modified when aspects of it are dysfunctional. A consequence is the persistence of dysfunctional attitudes and behaviours — both in individuals and society (Zucconi, 2008). Our relationship with ourselves and the world is an important determinant of our mental, physical, and social health. People and societies that are alienated from parts of themselves relate to others and the planet in alienated and distorted ways.

At present, global profit is calculated based on Gross National Product (GNP), a scale that completely ignores the eventual destruction of human and natural capital. A more realistic and sustainable approach is to look at at least three variables that account for the so called Triple Bottom Line (TBL) that measure economic, ecological and social results. The Quadruple Bottom Line (QBL) also takes into consideration cultural aspects, including governance.

Recently an Inclusive Wealth Index (IWI) has been formulated. It is a broader way of measuring natural capital, such as forests, produced capital, such as roads and factories; and human capital, including levels of education, knowledge, and creativity. The preliminary findings indicate that it is possible to trace the changes of the components of wealth by country and link these to economic growth, underlying the impact of declines or increases in natural capital as an economic productive base (UNU-IHDP, 2012).

Denial

When change generates a new threat, one way individuals, communities and cultures can cope with it is experiencing fear which in turn generates actions — fight or flight. However, another less functional way of coping can be activated: anxiety. When anxiety (fear without awareness of the source of the threat) is the response to a new threat, it results in cognitive dissonance.

Instead of self-regulation and actions to deal effectively with the threat, denial, a sort of self-inflicted blindness, takes over. Denial is a well-known defence mechanism, seen in situations in which people feel unable to face reality.

The defence mechanisms of a person or a society can be functional or dysfunctional. They are dysfunctional when the defence becomes chronic, severely limiting the ability to cope.

For example, in the case of drug users, the following are indicators that a person is in denial:

- Refusing to learn the facts about the effects of addiction
- Distorting information related to his addiction
- Minimizing the significance of his compulsive behaviours
- Lying to family and to oneself about the addiction
- Selective awareness of his addiction, limited only to the non-alarming aspects
- Wishful thinking, the addiction could continue without negative consequences
- Avoiding conversations related to his addiction

Denial functions to protect the self-image from awareness of things that the individual feels unable to cope with, making it the biggest barrier to recovery.

Similar mechanisms are rampant in the denial about climate change experienced by individual, institutions and societies. Awareness of man-made climate change not only generates fears and feelings of impotence, but it also shatters one of our strongest held mythologies: our identity.

We are all deeply invested in the narrative that we are surrounded by unlimited resources, and that the planet and all animal and plant life forms are at our disposal. Industrialization and the consumerist lifestyles to which we have become addicted are socially seen as a clear sign of success and are synonymous with our civilization and a measure of our progress. Thus, confronting the new realities of climate change throws us in a science fiction nightmare.

Interpreting denial

Sociologist Kari Marie Norgaard (2009) addressed the issue of climate change denial, offering insights into the social construction of denial occurring in Norway, a country with a national identity rich with positive narratives about nature. Some Norwegians, when offered more information about pollution and man-made climate change, including the fact that Norway is one of the European countries with the highest per capita ecological footprint, go into denial to avoid the unpleasant truth. They do not want to acknowledge that they are doing something that they culturally consider wrong and with this dissonance. Thus they manage to preserve their national identity and their positive mythologies of a nature-loving nation.

Sheila Jasanoff underlines that different *civic epistemologies* shape different responses to the anthropogenic climate change. The construction of public knowledge varies from culture to culture and from community to community. These different epistemologies and various hermeneutics need to be kept in mind in the promotion of change because what may work in a community may not automatically be effective in another (Jasanoff, 2011).

Communicating these issues effectively to society can be quite a challenging task, complicated by several variables such as the lack of a systemic and interdisciplinary understanding of how the barriers to change are created and how to effectively deal with their abatement or mitigation. Most road maps proposed for the governance of the anthropogenic impact and climate mitigation are mainly focused on financial, technological variables, giving little attention to the psychological, social, political, cultural, organizational, and institutional variables (Ekstrom, Moser and Torn. 2011).

Conclusion

Many countries are currently facing an economic crisis, forced to shoulder the burden of an accumulated national debt having in the past constantly spent more than they produced. Similarly, an ever growing number of countries are faced with an exponentially growing population with mounting consumerist lifestyles burning more resources than our planet can regenerate each year. The risk of bankruptcy is becoming very real not only in financial terms but also in basic Earth resources. Our current lifestyle is a blueprint for a man-made epochal catastrophe.

Though the anthropogenic burden has a global impact, it is neither created nor distributed equally around the world as a result of variability in resource availability and access, and of different consumption and pollution patterns among nations. This is why many developing countries are reluctant to curb their pollution by limiting the rate of their economic growth in spite of the negative impact on their natural and human capital.

As Albert Einstein eloquently put it: *We cannot solve the problems of today at the level of thinking at which they were first created.*

The mechanistic way of perceiving and managing reality generates problems at every level. Psychology shows how some neurotic people, institutions and cultures go into denial when they feel that their self-image is threatened by facing facts, and in so doing create barriers to awareness. In this way they disassociate themselves from their ability to cope effectively with the threats they face.

Carl Rogers' seventy-year-long research experience in the promotion of change in individuals, groups and organizations, shows that in healthy organisms self-awareness generates effective self-regulation. A neurotic personality structure is, however, unable to symbolize its experiences in an attempt to protect its rigid self-image.

We need to foster a new psychological literacy and psychological resilience, a sort of psychological compass; a more grounded way of being in order to navigate the rippling currents of change and cope effectively in the Anthropocene times.

The capacity to be in emphatic and respectful contact with ourselves, others and the world may be our most precious and needed natural resource.

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9

Global Change and Ecosystem Management

Jeffrey A. McNeely

It is sometimes said that change is the only constant, but in today's world the rates of many changes seem to be unprecedented and constantly accelerating. While climate change gets most of the attention, legitimate claims of global status can be advanced for a multitude of other changes, from demographics to forest degradation. Many of the global environmental changes can have significant negative impacts on people, including increasing fragmentation of habitats, declining biodiversity, and over-harvesting of renewable natural resources.

These changes are examples of 'wicked problems' that cannot easily be defined so that all interested parties even agree on the problem to be solved, making objective solutions near impossible (Conklin, 2006). Resource managers today are forced to address these problems as best they can with the incomplete information at hand. They must be prepared to adapt to further changes that may appear in the course of seeking to manage ecosystems sustainably — an ideal end point that can never be definitively reached because ecosystems are constantly evolving.

Global environmental change is reaching planetary boundaries, also called 'tipping points' — critical transitions that will lead to new ecosystems from which no return is likely (Scheffer, 2009; Barnosky, 2012). Biodiversity loss, climate change and global nitrogen cycles may have already exceeded planetary boundaries (Rockström, et al., 2009).

Global changes affecting ecosystems

It is now well recognized that Earth is being affected by a combination of unprecedented ecological, socioeconomic, and institutional changes. While this article focuses on the ecological changes, these are intimately related to socioeconomic changes (such as economic growth, global trade, energy demand, human rights, consumption patterns, demographics, and land use) and institutional changes (laws, regulations, technological innovation, governance, and so forth). The various kinds of global changes are not independent variables; instead, they interact in dynamic and complex ways that are not always well understood. Such variable factors are often both drivers and consequences of change, with feedback loops that may accelerate or decelerate change.

Increasing habitat loss and fragmentation

It is widely agreed among ecosystem managers that human-induced changes to the landscape are the greatest threat to native ecosystems, even more damaging than climate change (MEA, 2005). For example, as prices for food increase, farmers expand the land they cultivate, and rising incomes encourage more consumption of meat (which requires more land to grow fodder). Demand for timber and biofuels is depleting forests, further fragmenting natural habitats. A global 'and grab', with countries expecting to need more food and energy purchasing access to land in other parts of the world to grow crops, seems likely to lead to more habitat conversion and therefore pose greater challenges to ecosystem management (Hall, 2011).

Current rates of human-induced habitat change globally are not easy to determine, at least partly because governments have not agreed on a common metric for measuring such change and their capacity for monitoring such measures is widely variable. However, satellite observations suggest that the current rate of forest loss is about 13 million hectares per year (FAO, 2010). The cumulative cost to human well-being from the loss of forest goods and services could amount to more than US$6.4 trillion by 2050 (7% of global GDP), if current trends of forest loss continue (TEEB, 2010).

Other kinds of ecosystems are also affected. The Millennium Ecosystem Assessment (MEA) found that more land was converted to crops from 1950 to 1980 than during the 150 years from 1700 to 1850 (MEA, 2005). During the last several decades of the 20th century, 20% of coral reefs and 35% of mangrove forests were lost or severely degraded.

Declining biodiversity and ecosystem services

Biodiversity is "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (CBD, 1992).

Much of the international concern about biodiversity and its relationship to ecosystem management focuses on biodiversity loss, especially at the gene and species levels (May, 2011). Species are often taken as a useful surrogate for biodiversity, though estimates of species numbers vary widely among experts. The most recent authoritative estimate is that about 8.7 million species (plus or minus about 1.3 million species) share the ecosystems of planet Earth (Mora, et al., 2011).

Species are particularly useful indicators because at least the larger ones are relatively easy to see, count, and monitor, thereby helping to assess the status of ecosystems. The 2010 IUCN Red List assessed about 56,000 species of animals and plants, including 18,351 within threatened categories.

The concept of ecosystem services was given a significant boost by the Millennium Ecosystem Assessment when it assessed 26 "ecosystem services", defined simply as the benefits people receive from nature. These were divided into four broad categories: provisioning services, such as food and water; regulating services, such as flood and disease control; supporting services, such as nutrient cycling; and cultural services, such as spiritual, recreational, and cultural benefits.

Some 60% of the world's ecosystem services are degraded to the point where they have lost some of their ability to meet human needs for food, water, clean air, fuel and many other services. Human exploitation of ecosystems has resulted in increased production from a small number of services, such as crops and livestock, produced at the cost of other services provided by nature.

Although evidence remains incomplete, the ongoing degradation of 15 of the 24 ecosystem services examined is increasing the likelihood of serious negative impacts on human well-being, including the emergence of new diseases, sudden changes in water quality, creation of 'dead zones' along the coasts, the collapse of fisheries, and shifts in regional climate (MEA, 2005).

Over-harvesting of renewable resources

Humans have always harvested species of plants and animals, but increasing global demand for resources due to population growth, increased per capita consumption, and many other factors has led to over-harvesting of many species, contributing to the profound ecosystem changes described in the MEA.

A review of harvesting of wild game has found that many species are now becoming at least locally extinct in the humid tropics as a result of over-hunting, thereby losing an important source of food and income for forest-dwelling people (Milner-Gulland and Bennett, 2002) as well as disrupting ecosystems through, for example, the loss of seed dispersers and pollinators.

Over-harvesting of fisheries is far more obvious and has become a growing ecosystem management issue, driven by growing demand, improving fisheries technology, and economic incentives (Pauley et al., 2002). Over-harvesting affects pelagic, coastal and inland waters (Allen et al., 2005), disproportionately affects the most valuable species such as tunas and billfishes (Collette et al., 2011), reduces the resilience of kelp beds to climate-driven catastrophic phase shifts that can lead to widespread sea urchin barrens (*Ling* et al., 2009), and even influences zooplankton dynamics and ecosystem structure (Mollmann et al., 2008).

Over-harvesting is often driven by economic factors, making the issue a difficult one for ecosystem managers. But providing strong evidence of the impacts it has on ecosystems and human well-being can help to ensure that economic values reflect the costs of negative impacts on biodiversity and ecosystem services.

Ecosystem management responses to global environmental changes

Ecosystem management responses to global change can take place at multiple levels ranging from local to global. Most of the global responses are at the policy level, but the actual management responses will typically take place at national or lower levels where the action is appropriate to the scale at which the impact of the change is perceived.

People throughout the world are seeking to provide forms of stewardship that will enable adaptation to rapidly changing conditions (also called resilience). General strategies include reducing the magnitude of known stresses, thereby reducing exposure and sensitivity to these changes; developing policies that will shape change rather than responding to effects that have already taken place; and avoiding or escaping from socio-ecological traps that are unsustainable (Chapin et al., 2009). But the growing challenges to ecosystem management have also generated some new approaches or modifications of traditional approaches.

Reconnecting fragmented habitats and recovering lost ecosystems

To address the problem of habitat fragmentation, many governments are making efforts to re-establish connections among ecosystems, for example linking protected areas with other land uses that support conservation and establishing conservation corridors to support ecosystem services. Examples at the international level include the Yellowstone to Yukon Corridor in North America, the Mesoamerican Biodiversity Corridor, the Andean Corridor in South America, and the Great Limpopo Transfrontier Park (from Mozambique to South Africa).

Conservation corridors may include community-managed forests, which often have lower and less variable annual deforestation rates than formally protected forests (Porter-Bolland et al., 2011), an indication that these approaches can be useful in at least some situations.

One of the world's most ambitious such efforts is in Southeast Asia, involving Myanmar, Lao PDR, Thailand, Cambodia, Vietnam and two provinces from the People's Republic of China, Yunnan and Guangxi. These countries form the "Greater Mekong Subregion". Their Biodiversity Conservation Corridors Initiative was launched in 2006 and now has nine pilot Biodiversity Conservation Landscapes that cover mixed landscapes including over 17 million hectares of forest and a total area of over 50 million hectares (Moinuddin et al., 2011). They each have their own governance structure and action priorities, and many lessons are already being learned and applied more widely.

Conservation corridors build cooperation between local people and protected areas, provide sufficient habitat to conserve the key species, and are sufficiently large to enable ecosystems to adapt to climate change (especially those that have a north-south axis and altitudinal variation that enable species to move to new habitats as their existing ones are affected by changes in temperature or rainfall regimes). Managing connectivity has now become a well-documented approach to ecosystem management (Warboys et al., 2009).

Reversing declines in biodiversity

Reversing declines at the three main levels of biodiversity — genes, species, and ecosystems — often requires different approaches, though ecosystem management needs to address all levels of biodiversity.

Genetic diversity is constantly changing in most species, and the greater the genetic diversity, the more likely the species will be able to adapt to changing conditions. Ecosystems, too, are constantly changing as species are added or subtracted, or species populations change. Ecosystem science is still at an early stage, with active research on how nature's complexity can persist, and how ecosystem changes affect their functioning (Ings et al., 2009). Some can undergo catastrophic shifts, which convert them into a very different ecosystem, such as coral reefs becoming rocky systems, forests becoming grasslands, or lakes becoming mudflats. Maintaining resilience in ecosystems at risk of catastrophic shifts seems the best ecosystem management strategy.

Much of conservation biology is directed at the species level, but this also includes genetics and ecological relationships. When species have been reduced to a very low level, their genetic diversity has typically also been substantially impoverished and their role in ecosystem functioning may have been greatly diminished. However, recent experience in the management of small populations has shown that restoration and reintroduction is possible in many cases (Seddon et al., 2007).

While the growing threats to species are disheartening, a comprehensive review has found that conservation actions are having a positive impact on the status of at least some species, providing a foundation to support investment in conservation action (Hoffmann et al., 2010).

The most effective policy to conserve native biodiversity through ecosystem management is to establish and maintain protected areas. In many countries, this incorporates the traditional association between people and the rest of nature, and can be managed to provide benefits to local people.

Given the high value of biodiversity and ecosystem services, it is not surprising that protected areas have become very popular, with over 100,000 sites in virtually all countries, approaching 13 percent of the total land cover (WDPA, 2012). However, the protected area agencies in most countries still give more attention to income-earning tourism than to ecosystem management problems. But the provision of ecosystem services and forest protection is gaining more attention as these gain economic support. At the country level, the government protected area management agencies are supported by thousands of civil society organizations that are contributing to protected areas in everything from research to public outreach.

Protected areas can contribute to conserving biodiversity, but they are not a sufficient response in all cases. Some species may require farmland and many ecosystems today include a significant human component that also needs to be conserved. But for many threatened components of biodiversity, protected areas remain a popular ecosystem management tool.

Ensuring that any harvesting of renewable resources is sustainable

In principle, any species could be harvested sustainably; and indeed the continued survival of any species is arguably an indication that its harvest has been sustainable until the present. But ensuring that any harvest is sustainable is far from simple, as indicated by the continuing decline of many species due to over-hunting.

Solutions may well come through a variety of approaches to ecosystem management. For example, through establishing a mosaic of hunted and no-take areas, ecosystem managers could balance conservation with continued subsistence use. Such ecosystem management will also require collaboration of local people, resource extraction companies, government agencies, and scientists.

In the case of fisheries, marine protected areas and fishery closures have been shown to provide multiple benefits, including to the harvest of fish outside the protected area or closure zone. In South Africa, the Langebaan Lagoon Marine Protected Area effectively protects a migratory species (white stumpnose *Rhabdosargus globiceps*) during its spawning season and the time of peak recreational fishing activity, indicating that the degree of protection depends on the time fish reside inside the no-take zone rather than on the size of the protected area (Kerwath et al. 2009). For ecosystem management, both location and management approach are key factors for successful marine protected areas.

Aquaculture may follow the process of converting wild harvest into domestication of plants and animals. It already provides over half of the fish and other aquatic resources consumed by people (Naylor et al., 2009). This seems a sustainable solution, but has come at the cost of converting important aquatic ecosystems that have long been managed to provide multiple ecosystem services into over-simplified ecosystems that provide only a provisioning service (food). When the full costs of converting mangroves into shrimp ponds, for example, are calculated, maintaining the mangroves makes far more economic sense (MEA, 2005).

Consumption pressure on renewable resources is unlikely to recede, calling for increased efforts to promote sustainability through ecosystem management. But ecosystem managers will need to be aware that sustainability is an elusive target that often can be observed only in retrospect.

Policies to support ecosystem management responses

The ecosystem management responses discussed above are the practical application of more general policies that have been put into place to address environmental problems. These policies have been established at global, national and local levels, by governments, the private sector, farmers and others. The following examines some of the most relevant global policy responses to the challenges of ecosystem management.

Ecosystem services

The concept of ecosystem services has now been broadly embraced, including by governments such as China that see it as a tool for stimulating development in rural ecosystems of the country (Scherr and Bennett, 2011). It also has important policy implications for governments when determining how to invest their scarce resources. It provides a framework for deciding the relative priority for the services that support consumptive uses, such as food, fuel, and construction materials, as opposed to those that support non-consumptive uses, such as watershed protection, disaster prevention, cultural values, pollination, health, and so forth.

It also clarifies the tradeoffs that are often implicit in decision-making, especially about the distribution of benefits from ecosystems. Finally, decision-makers need to be reminded that environmental conditions are changing rapidly in much of the world. This makes it all the more important to maintain healthy ecosystems that will be able to provide their functions (such as carbon sequestration, evolution, nutrient recycling, and watershed protection) as part of adapting to changing conditions. This is likely to require conserving the maximum possible biological diversity and effectively managing ecosystems.

Economic incentives for ecosystem management

Treating ecosystem functions from the anthropocentric view of ecosystem services has given them an explicitly economic dimension. If effective ecosystem management is yielding economic benefits, the argument goes, then those delivering the benefits should be compensated, especially if they incur costs in delivering them.

The funds now being devoted to payments for ecosystem services (PES) are substantial. In 2007, annual payments under all payment schemes and markets for ecosystem services reached about US$77 billion globally, and some expect such payments to reach US$300 billion by 2020 (Carroll and Jenkins, 2008).

Practical experience in applying PES to ecosystem management is beginning to generate some general design principles. For example, China's "Grain to Green" programme found that providing payments based on the costs of landholders of foregoing alternative uses of land was substantially more successful than a flat payment scheme that provided the same amount to each family. While transaction costs may be higher, the planning that ensures cost-effective targeting of payments for the land that provides the most effective conservation return can greatly improve the efficiency of the PES investment (Chen et al., 2010).

Payment for ecosystem services seems here to stay, and many see considerable potential for both supporting ecosystem management and helping alleviate rural poverty.

Community-based ecosystem management

Local communities, and especially indigenous peoples, are often politically and economically marginalised, yet they are frequently the stewards of the most biologically rich areas. Traditional indigenous territories cover up to 22% of the world's land surface and some estimates suggest they may support as much as 80% of the planet's terrestrial species diversity (Sobrevila, 2008).

Over the past several decades, many governments have begun to return ownership, or at least tenure, to forest-dwelling people, pastoralists, and others who had previously occupied land that was considered to be owned by the state (or, in previous times, by local rulers). Such transfer of responsibility can have important policy implications for ecosystem management. A recent review of peer-reviewed case studies from 16 countries in Latin America, Africa, and Asia found that providing greater autonomy over ecosystem management to local people slowed the rate of deforestation. It found that protected areas managed by government agencies lost an average of 1.47% of forest cover per year, while community-managed forests lost just 0.24% of forests per year. Of course, the sites had a range of variation, but the range was greater in protected areas than in community-managed forests (Porter-Bolland et al., 2011).

The wide variability among countries in the way they relate to rural people, especially ethnic minorities, makes generalizations difficult. Several recent studies have indicated that in at least some cases, indigenous leaders are more effective ecosystem managers than the government agencies that reluctantly ceded responsibility. In Ecuador, for example, indigenous peoples from the country's Amazon region won title to over a million hectares that had previously been considered government-owned.

In pre-colonial times, concepts of land ownership were dynamic, with claims by extended kinship groups and regular changes in boundaries. In modern times, however, cooperatives have become governing bodies over fairly substantial areas. Resident peoples may be better ecosystem managers because they have an intimate knowledge of the ecosystems they are managing, while government agencies tend to consider land and resources in the abstract (Erazo, 2011).

Community-based ecosystem management also has a human rights dimension. Policies and laws have established that environmental degradation may interfere with many rights, including rights to life, health, privacy, and property, as well as components of the right to an adequate standard of living, such as sufficient water and food.

On the other hand, ecosystem management practices can also reduce human well-being and at times may have undermined local livelihoods through human rights violations, forced resettlements and impacts on local livelihoods, especially of indigenous peoples and local communities (Chatty and Colchester, 2002).

International conventions, programs and agreements

Ecosystems provide both global and local goods that often span geopolitical boundaries. In dealing with global changes through ecosystem management, governments have realized that global responses, or at least cooperation, will be necessary. Many ecosystems cross international borders: water often flows between countries and managing international rivers requires cooperation among the riparian states; some ecosystem management issues involve global trade; and some ecosystems (such as deep pelagic systems or Antarctica) are beyond national borders and can be managed only through international agreements.

In 2010, the tenth Conference of Parties of the Convention on Biological Diversity (CBD) approved a strategic plan for the coming decade (2011-2020), which specifically addressed ecosystem management in its articles. Perhaps more interesting, prior to the CBD meeting, other multilateral environmental agreements agreed to adopt the CBD Strategic Plan as the common basis for their own work in the coming years, taking a significant step towards coherence in obligations, data collection and reporting.

Other important recent policy outcomes relevant to ecosystem management responses include the 2010 UN General Assembly resolution that supported the establishment of an Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES). It is expected to further strengthen the credibility, legitimacy and saliency of the information exchange processes between the scientific community and policymakers in areas relating to biodiversity and ecosystem services.

Conclusions

This review has addressed several of the global changes that are affecting ecosystems and ecosystem services, almost as if they were independent. But these changes are better understood as a package of variable changes, with the relative impacts differing from site to site and depending on numerous external factors, ranging from geographical location to human demography. A global change that harms some components of an ecosystem can benefit others, further complicating the challenge of making broad generalizations. That said, the review has reached the following conclusions:

All ecosystem management responses need to be based on good information, including solid science, political reality, and local knowledge.

Few ecosystem management challenges have yet generated the appropriate institutional responses, at least partly because they tend to have complex drivers that are the responsibility of many different actors, their symptoms are not always apparent to the public and policy-makers, and many of the major issues are influenced more by social, economic, and political factors than scientific ones. This calls for renewed efforts to strengthen the science component of ecosystem management and seek more effective means of reaching policy-makers.

Many management responses will involve tradeoffs, as the different interest groups negotiate for favourable outcomes. This argues for including the key interest groups in negotiating the tradeoffs, and addressing some of their major concerns, particularly the economic and social dimensions of ecosystem management.

Establishment of protected areas remains a major ecosystem management tool that is relevant to all five of the global ecosystem changes examined here, but relatively few such areas are actually managed as ecosystems. This argues for much greater attention to the implementation of protected area management at the ecosystem level, which is becoming more popular through the adoption of conservation corridors, where discrete protected areas are linked by ecosystems that are managed for resource production in ways that promote the movement of species between the protected areas, provide a useful way to expand the overall habitat size and therefore the diversity of species that can be conserved.

The concept of ecosystem services has had a significant impact and has considerable potential to provide the funding that will be necessary to ensure sustainability in the future.

With budgets becoming increasingly tight in many countries, creative ways to enforce ecosystem management regulations will be required, for example using citizen scientists and non-governmental organizations to help monitor ecosystems.

Planet Earth is experiencing multiple wicked problems that are undermining the ecosystems upon which humanity depends. Increased investments in ecosystem management will be required to ensure a healthy and prosperous future for all of humanity and the rest of the living world.

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10

The Psychology of Global Climate Change

Walter Truett Anderson

Introduction

Science is becoming ever more capable of detecting troublesome ways that the planet is changing. Some of these, like the extinction of more species of plants and wildlife, seem remote — even trivial. Others, such as droughts in some regions and spreading fires in others, cause enormous damage and loss of life. Amid these tangible disturbances we are faced with growing evidence that the greatest threat of all is within us, in the mind's remarkable ability to reject information it finds unpleasant.

This is called denial, and it plays a major role in the lives of many people. In psychotherapy, it sabotages a patient's efforts to see the cause of his own emotional suffering. It blocks an addict's way out of a substance addiction or a behavioral one such as compulsive gambling. It blinds families and the general public from recognizing the prevalence of sexual child abuse.

As we enter the Anthropocene age, we begin to understand that human thought — with all its wisdom and its weakness — is an inseparable part of how the world works. Denial becomes a reality of governance, as people draw the boundaries between deniers and believers. It is a part of life in the Anthropocene and we need to deal with it by both understanding it, and showing people how to move beyond it.

Anthropocene when?

In order to make ourselves at home in the Anthropocene, we need to form a sense of its place in the history of human evolution — in particular, when it began. A tentative answer to the "when" question was offered several years ago in an article co-authored by Paul Crutzen and Eugene F.

Stoermer. Crutzen is a Nobel laureate, honored for his part in the discovery that chlorofluorocarbons (CFC's), the basis of an enormously profitable global refrigeration industry, were the main cause of life-threatening depletion of the ozone layer surrounding Earth. Stoermer, a biologist and environmentalist, is generally credited as the word's inventor.

In the article, which appeared in the newsletter of the International Geosphere-Biosphere Programme (IGBP), they described humanity's growing impact on the life of the planet and offered "Anthropocene" as their candidate for the name of the new geological epoch.

They also granted that the beginning date they proposed for the new epoch (around 1800) was only an approximation:

> To assign a more specific date to the onset of the "Anthropocene" seems somewhat arbitrary, but we are aware that alternative proposals can be made (some may even want to include the entire Holocene). However, we choose this date because, during the past two centuries, the global effects of human activities have become clearly noticeable. This is the period when data retrieved from global ice cores show the beginning of a growth in the atmospheric concentration of several "greenhouse gases," in particular carbon dioxide and methane. Such a starting date also coincides with James Watt's invention of the steam engine in 1784 (Crutzen, P. and Stoermer, E. F. 2000).

I should point out here that the Anthropocene is a social construction of reality. That's all right; so is the Equator. Human beings create such fictions because they help us get around in the world and in practically everything we do (Zerubavel, 1991). The fact that we need boundaries does not relieve us from our complementary need for flexibility. Crutzen and Stoermer were quite right in identifying the past two centuries as a time of escalating human impacts — the evidence for that is enormous. Yet the very act of opening a conversation about human impacts in the present has opened up new conversations about human impacts in the past — one which gives us a new perspective on the popular notion that our prehistoric ancestors lived in benign harmony with their surroundings.

Crutzen and Stoermer mentioned in their article that they expected disputes about the timing of the transition into an Anthropocene condition, and they were right. William Ruddiman of the University of Virginia published a journal article titled "The Anthropocene Greenhouse Era

Began Thousands of Years Ago" (Ruddiman, 2003). He followed it with a book elaborating his own theory of how climate change was happening — although not on a scale comparable to what is occurring now — thousands of years ago.

Ruddiman is a palaeoclimatologist — a specialist in the study of the climates of past ages. He contends that agriculture, which began with scarcely-noticeable changes in the practices of grain-gathering people in Mesopotamia some 8,000–10,000 years ago, has had massive impacts on the planet. It allowed human populations to increase and disperse, led eventually to the worldwide migration of favoured food crops, and caused spreading deforestation as people cleared land for cultivation. It had its most dramatic effects after the development of irrigation, especially in Asia where rice agriculture, accompanied by deforestation and increasing use of domesticated animals, poured so much methane into the world's atmosphere that, by 5,000 – 4,000 BC, it was diminishing glaciations in Canada.

Ruddiman's theory is not the only amendment to the Crutzen-Stoermer account of when the Anthropocene era began. Other researchers push the limits further back beyond the early Holocene (when agriculture began) and into the Pleistocene, the last Ice Age. They identify hunting as the human activity that changed the world. In several books, such as *Twilight of the Mammoths* by Paul Martin of the University of Arizona, they describe links between the arrival of human beings on several continents and the disappearance of species they hunted:

> In what palaeontologists have begun to call "near time," the last 50,000 years, datable by radiocarbon, the world lost half of its 200 genera of large mammals (those weighing more than 45 kilograms or 100 pounds). Beyond the living bears, bison, deer, moose, and other large mammals familiar to us now, an additional 30 genera and 40 species lived in North America, and even more in South America. Most of the Western Hemisphere's most charismatic large mammals no longer exist (Martin, 2005).

The "overkill" theory attributes more to the human impact than merely the disappearance of the animals they hunted. It also cites the secondary impacts caused by the loss of "apex" species, such as those that were predators and prey to other species. Many scientists believe those explanations to be overstated, and argue that other causes like disease or natural climate change (caused by Earth's distance from the Sun or irregularities in its orbit) must also be taken into account.

The strongest case of an "overkill" extinction is the early history of New Zealand, which for millions of years went its own evolutionary way, developing into a mini-world unlike anything known elsewhere on Earth. It was dominated by birds, such as the giant emu-like moa, huge eagles and flightless geese. It remained in that state until about a thousand years ago, when the first settlers arrived — Polynesians in long boats. Skilful hunters, they feasted on the birds and made tools and artwork from their feathers and bones. Within 50 years or so, the moa kingdom had collapsed (R. Leakey and R. Levin, 1995).

Another category of human impacts, another huge piece of world history that shows the Anthropocene transition as a large and complex series of events rather than an abrupt shift brought on by the Industrial Revolution, is the one that its leading historian called the Columbian Exchange. (Crosby, A. 1973). It began slowly with the first voyage of Columbus to the New World, which carried seeds but none that survived the crossing. The second voyage had better preparations and better success, and brought several kinds of garden vegetables and melons, grapevines, sugar canes, and fruit stones to establish orchards (Plucknett, D. I., Smith, N. J. H., Williams. J. T. and Anishetty, N. M. 1987).

In the years that followed, with advances in the technologies of navigation and mapmaking, ships of many nations travelled back and forth across the oceans with many results: new farms and plantations carved out of the jungles of colonial countries, new samples for the seed collections of imperial powers, tomatoes and wheat to transform the cuisine of Italy, and potatoes to transform the culture of Ireland. This globalization continues today, but now the travellers are more likely to be frozen embryos or semen to produce herds of the world's best breeds of domestic animals on farms around the world.

Denial, information, and behavior-guiding conversations

The Anthropocene is becoming known to scientists and the general public as the age in which the human footprint becomes increasingly heavy on the planet, when our numbers and ways of living threaten ecosystems everywhere. We cannot avoid being exposed to such information. We have become so accustomed to it that we pay little attention to how different it makes us from people who lived only a few decades ago. We are told that the world's climate is changing, that it may bring enormous damage, and that we — and the way we live — are the cause of it.

Denial has generally been described as a futile reaction to a personal problem such as substance abuse. In regard to climate change, it seems to be more complex: social scientists trying to gain a better understanding of people's feelings about climate change often find that they have strikingly different ways of describing their opinions when the issue is put to them in different contexts.

For example, a research project in Switzerland discovered a surprising difference in the responses of focus group subjects to different sets of questions about climate change. The first set of questions focused on their opinions about the gravity of the risks it presents, and the second set concerned what they might do about it. (Stott-Kleeman, S., O'Riordan, T., Jaeger, C., 2001)

1. Concerning climate change risks:
   Swiss citizens generally perceive climate change risks and other environmental problems as serious issues. Accordingly, they often perceive a world characterized by high levels of energy use as unattractive, if not nightmarish. The evidence suggests that participants tended to regard low-energy futures as highly desirable for the planet and the human race to avoid disasters. A high-energy scenario is associated with images of catastrophes, monsters, wars, destroyed nature and general chaos. There was a remarkable consistency in the replies from all the participants.
2. Concerning active commitment to dealing with climate change:
   Here, the respondents who had spoken boldly become cautious and plaintive. They apologize about their inability to act in any meaningful way, berate themselves, speak of the need for somebody else to take the lead. The answers all followed a similar pattern, "As long as the US does not do anything. . . . You can't force things. . . . I am a bit disappointed that countries carrying so much responsibility lag so far behind. . . . If only those countries with their enormous populations concerned could make this clear. . . ."

In Norway, an independent social psychologist, using a different research methodology (one-to-one interviews) found similar ambiguities among people in regard to their feelings about climate change. (Norgaard, 2011)

During her research project, sociologist Kari Norgaard lived in a middle-sized town to which she gives the fictitious name of Bygdaby, a Norwegian word meaning "halfway between a rural hamlet and a city." It was a place where people normally enjoyed skiing and skating in the winter, but for some years it has been warmer, bringing various disturbing changes. One year "a woman walking through the lake fell through the ice and drowned when it cracked." The tourists from other parts of Norway ceased coming to fish in the winter. The skiing was similarly affected: "Because of lack of snow, the opportunity to ski was greatly reduced, and the resort owner had to invest a considerable amount of money and effort to produce a single run made completely of artificial snow."

She found, however, that the people of Bygdaby had very little to say about the change:

> What perplexed me was that despite the fact that people were clearly aware of global warming as a phenomenon, everyday life in Bygdaby went on as though it did not exist. Mothers listened to news of unusual flooding as they drove their children to school. Families watched evening news coverage of the failing climate talks in The Hague, then just turned into American sit-coms. Global warming did not appear to be a common topic of either political or private conversation unless I brought up the topic. Apart from small talk about the unusual weather, few people ever seemed to spend much time thinking about global warming. (p. xvi)

In her book, *Living in Denial*, she challenges the "information deficit" model of explaining why a public fails to respond to a critical situation and offers instead a "social organ of denial" model in which the public actively resists available information. She also points out that "respondents who are better informed about climate change express less rather than more responsibility for the problem" (p. 68).

Finally, she points out one more reason — beyond their understandable fondness for everyday life in their country as they have known it in the past, and their pride in their reputation as a world leader in environmental responsibility — for their ambivalence concerning global climate change.

Norway has tripled its production of oil and gas in the past ten years and is the third-largest oil exporter in the world.

She notes the important role of casual conversations with friends, neighbours and fellow workers in forming opinions about climate change, and believes that they exert a great influence by **not** talking about it. Climate change appears to be something people know about, even express concern about when asked, but do not discuss in public. I was struck by the difference from the US, where everybody has opinions about climate change. Strongly outspoken denial — especially concerning the idea that it might be caused by human activities — is a major element in the philosophy of the Republican Party.

Conclusion: The challenge of now

It is tempting to dismiss denial as nothing more than moral laziness, a refusal to "look at the facts" or a simple lack of good information or irrational thinking. To many, especially those trained in some field of natural science, it is simply a tolerance for irrational thinking, which — as the subtitle of a recently-published book warns, "hinders scientific progress, harms the planet, and threatens our lives" (Specter, M., 2009). I sympathize with that author's impatience: every person in denial about impending global climate change may seem like the patient diagnosed with a possibly-fatal disease who insists on going about his or her life.

But we need to understand that our challenge now is not merely to put a halt to runaway climate change, but to learn our way into the 21st century, which is a time like no other in Earth's history. It is a world with over seven billion people, many living in crushing poverty, close to 200 sovereign nations, and a growing recognition that, yes, we all inhabit the same planet.

It is a world in which every person who has access to the news media — print, radio, television, internet or even community gatherings — is likely to be aware of climate change to some degree. Yet, as we see from the research cited above, most are torn and confused. And they have every reason to be. They are being confronted with threats on a scale unknown to people before us — even those who have lived for a half-century under the threat of nuclear holocaust.

And they are being asked to take on a responsibility greater than merely that of evading disaster: it is governing a world in jeopardy, and doing so for a long time to come.

Governance can no longer be defined simply as "what governments do." My dictionary gives several definitions of the word "govern," among them "to control, influence, or regulate (a person, action or course of events)." That covers a lot more than the doings of formally-organized governments with laws and leaders. Governance occurs everywhere in the natural world as well as in humans, and everywhere in private and social life as well as in the halls of governments. In the wild, a pack of wolves may govern the size of an elk population, and a horde of locusts may transform an ecosystem. In modern nations, governments may pass evolution-steering laws to protect endangered species, guide genetic research, and control epidemics.

Homo sapiens — also sometimes described as the symbolic species (Deacon, 1997) — have used their ingenuity to survive and govern in ways that other creatures cannot. We are also the learning species, able not only to gather and analyze information, but also to transmit it to others with ever-increasing speed. We have learned, reluctantly, about the evolution of life on Earth and — also reluctantly — about the ways that our progress touches the lives of countless other forms of life. On the basis of that learning we begin to take on a new responsibility for governing evolution — not because we know how to do it, but because it has become unmistakably clear that we do not know how not to.

Taking up our evolutionary responsibility — growing up, in short — will require us to have a broader and deeper understanding of our world, and I propose as the master discipline for this enterprise the movement called Earth System Science. It is a broad-based approach, now guiding research and study in many universities. It fosters exploring the entire planet with all its subsystems — the oceans, the land masses, the skies and all living creatures as one interacting system. It is Anthropocene in the deepest sense.

And I am encouraging my colleagues and friends to go forth into whatever forums to which they may have access, and open conversations about our integral connection to the planet — conversations focusing not on denial, but rather on learning, responsibility and hope.

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11

Climate Crisis and the Challenge of Collective Transformative Learning

Aftab Omer

Learning information often does not lead to action based on the information learned. The fact that climate change is happening now and that there is an impending climate crisis at a global level is irrefutable from the prevailing standards of "normal science". Scientists and laypersons alike are distressed that the extensive information we now have about climate change and its causes is not leading to large-scale, collective action that would mitigate its causes, as well as preparations for the social and economic upheavals that will result from climate crisis.

The dilemma of information not sufficiently leading to effective, collective action applies to many other serious global issues besides climate change. Information about genocide (the word "genocide" was first used during World War II) did not prevent the genocides that took place in Rwanda and former Yugoslavia. At the individual, personal level, there are numerous examples of this, such as cancer warnings having limited impact on cigarette smoking, and nutritional information having little effect on eating habits.

A teaching story about the mythic "holy fool" Nasruddin is illustrative:

- Nasruddin's neighbour asks him to guess what he is hiding in his hand. Nasruddin asks for a clue. The neighbour replies that what he has in his hand is "yellow on the inside and white on the outside; it looks like an egg and if you cook it, it gets hard." Nasruddin replies, "That's easy. It's a cake." The neighbour perseveres in trying to get Nasruddin to guess the right answer, and says "It's laid by a hen." Nasruddin replies, "Like I said, it's a cake."

By example, Nasruddin is demonstrating the failure to integrate information effectively enough to guide responsive action.

At an individual as well as the collective level of families, teams, communities, organizations, societies, and nations, there appear to be significant barriers in the utilization of information towards shaping collective action. We could characterize this state of human affairs as a *collective learning disability*.

The wall of identity

One barrier to the utilisation of information towards collective action - perhaps even the most pervasive barrier — is *identity*, both personal and collective. It may be imagined as a wall, separating information from action. Individual and collective identity grounds and stabilizes human experience and communities. Without identity, we find ourselves lost at sea, homeless and longing for harbour. Yet the conflicts that embroil so many individuals, communities, and nations around the globe are situated within the mindsets that constitute personal and collective identity.

The core beliefs, deep assumptions, mindsets, and specific perspectives that constitute identity act like lenses in shaping our perceptions. Given this, identity can become a barrier to turning information into necessary, effective, and creative action. The image of oneself as a smoker can become a barrier to stopping smoking. Even the image of oneself as already being ecologically conscience can become a barrier to the collective learning and action necessary to address climate change.

For example, Norwegians are ecologically minded in their daily lives, yet their country's economy is heavily based on producing and selling oil. The wall of identity constitutes resistance to both action and learning, and most significantly to *action learning*.

We can readily acknowledge that merely acquiring information does not bring about effective actions based on it. A different type of learning is necessary where information may guide emergent actions.

The bridge of emotion

In order for this other kind of learning to take place at individual and collective levels, it is necessary to engage emotions, particularly those associated with personal and collective identity. For information to be carried forward into effective action, the wall of identity needs to be replaced by the *bridge of emotion*. The gap between information and collective action can be bridged in both ordinary and extraordinary circumstances by emotion overcoming identity-constituted barriers to action. Contemporary neuroscience has confirmed that cognition and emotion entail each other, though are susceptible to dissociation.

Our educational methodologies have not yet institutionalized what we now know about the relationship between emotion and cognition. Emotion, as the word itself conveys, is linked to motion. Evolutionarily, motion is the root of action. For the human species, this relationship between emotion and action is complex and culturally mediated in intricate ways.

We can say that emotion and cognition express themselves through necessary action. In the case of climate change and climate crisis, deep emotions are necessarily evoked (e.g., fear and despair). These emotions need a collective context for conscious expression and integration. Given such an opportunity, creative action can then follow conscious emotional expression over time, engendering capacities for creative action as more painful information is consciously integrated, at both individual and collective levels.

A true story can be illustrative here: A young man was in the hospital with severe frostbite after having gotten lost while mountaineering. His physicians had advised amputating his leg below the knee, but the young man had not consented. The delay continued and gangrene became imminent. Only when his fiancée tearfully and intensely conveyed her upset about his delay, did he finally give his surgeon consent for the emergency amputation. Clearly the information given to him by his physicians regarding gangrene was not sufficient for him to act. His fiancée's emotion then served as a bridge to action.

Actionable knowledge: The role of transformative learning in sustaining complex collective action

The development and institutionalization of policy that is responsive to climate change at local, regional, and global levels may be presented as a process of collective transformative learning. This goes beyond acquiring information and skills to developing individual and collective capacities and capabilities. It is a shift from having information and skills, to becoming and being capable. Such learning entails a shift in perceptual lenses, enabling individuals and systems to inhabit new, more complex, and emergent landscapes.

Emotion by itself cannot sustain long-term creative and effective action. This requires that emotion be transmuted into emergent capacities. These capacities are what hold up the bridge of emotion. It is these human capacities, which emerge out of a conscious engagement with emotion, which enables collective action to be sustained by ongoing collective learning. The integration and expression of emotion develops capacity that is embodied at the individual level, and institutionalized at the collective level.

We need to recognize that there are other kinds of knowledge beyond information that are essential to individual and collective action. By facilitating the cultivation of capacities and capabilities, transformative learning enables informational knowledge to become actionable, as conveyed by figs. 1 and 2, below.

Cultural leadership: From exploitative globalization to generative globalization

While collective transformative learning has played a key role in the evolution of culture and the emergence of civilization, the conscious practice of this kind of learning is still quite limited in the critical domains of governance, business, and education. Collective transformative learning

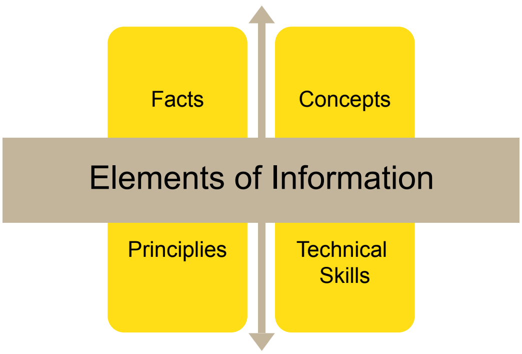

Figure 1 Elements of Information

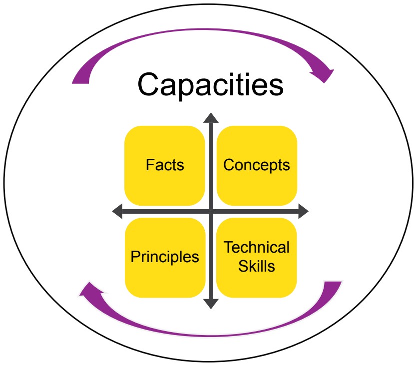

Figure 2 What about Capacities?

has an essential role to play in creating a just and sustainable future, shifting from exploitative globalization to generative globalization. High stakes, long term, multi-stakeholder collaboration is enabled and catalyzed by collective transformative learning.

Cultural leadership intensifies collective transformative learning. The ensuing disorientation and disruption of perspectives holds possibilities for creative collective action. Cultural leaders creatively transgress norms and rules and even taboos in ways that evoke emotions that may have been denied or suppressed. In this way, new avenues are opened for connecting cognitively apprehended information with the energy and direction of emotion, paving the way for creative action.

Cultural leadership is constituted by principled actions that create new and unexpected meanings. For instance, Gandhi was able to transmute his painful awareness of Britain's unjust, cruel, and exploitative taxation of the making and selling of salt into creative action. He focused on the salt laws, which symbolized British exploitation, and his creative action of making salt symbolized cultural sovereignty.

This shift from information hoarding to a true, collective transformative learning experience can help shift the global approach to climate change, breaking the current barriers of inaction.

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NURTURING A HUNGRY BOOMING HUMANITY

12

Where Will the Food Come From in a Hotter, More Crowded World?

Nina Fedoroff

My three years of service from 2007 to 2010 as science adviser to the US Secretary of State and to the administrator of the US Agency for International Development (USAID) took me to many different countries and gave me a broad overview of the problems facing our planet. By the end of that period, I had become deeply concerned that we had not even begun to address the critical issues of food and water anywhere in the world. My objective since has been to identify sensible ways forward toward increasing our ability to feed a still-growing population in the face of climate change.

There's much we need to do in the 21st century to even begin to come close to the notion of sustainable agriculture. We need to reduce the ecological impact of agriculture through pollution of air, land and water. We need to reduce its demand for fresh water, especially since 70-80% of fresh water is still used for farming. We need to adapt staple crops to a hotter, drier world in many populous places. While we strive to make all of these improvements, we need to double the food supply over the next couple of decades.

Can we feed 10 billion? I think that the answer is positive, but we will need to use the best modern science and modern technology. We need to "professionalise" farming everywhere in the world. We need to redesign agriculture as an integrated system of land, water, nutrients and energy. We need to apply much more sophisticated thinking and planning to the sustainable use of land, invent better irrigation and fertilization techniques, and manage and recycle nutrients on a much larger scale. We need to bring farming to the cities on the rooftops of buildings for cooling, heat management, and to decrease transportation costs for fresh produce. We need to think out of the box: new technologies, new crops, new land, and new water resources.

Biotechnology: prospects and problems

The good news is that over the past half century, we have developed the knowledge and the technical toolkit to tackle these daunting challenges to expanding food production in the face of a shifting climate and a growing population. The late 20th century witnessed a genetic revolution with the invention of recombinant DNA technology, the explosion of genome sequencing, and the development of techniques for the reintroduction of individual genes into plants and animals.

Today, it is possible to use these techniques to modify crop plants and domestic animals very precisely through adding, removing or modifying genes to improve their productivity. One of the most familiar examples is the introduction of a bacterial toxin gene from the soil bacterium *Bacillus thurengiensis* into a variety of plants, conferring resistance to important lepidopteran insect pests. Curiously, today only crops altered by molecular genetic modification are known as GMOs, as if none of the domestication and plant breeding that preceded it modified genes.

A recent example is the development of potatoes resistant to *Phytophthora infestans*, a fungus that causes late blight. This disease caused the Irish potato famine in the middle of the 19th century that killed a million people and drove another million to emigrate. Late blight affects potatoes all over the world, causing damage to crops worth billions of dollars. Using their growing understanding of plant disease resistance genes, researchers were able to identify and isolate a good resistance gene from a wild potato relative that makes tiny, inedible tubers. They then transferred the gene to consumer-favoured varieties that are susceptible to the fungus, making them resistant to it.

This could not be done by conventional plant breeding and it is a remarkable achievement. Right now, potatoes are drenched repeatedly with fungicides to control this terrible disease. Knowledge of the natural protective mechanisms has made it possible to use genes instead of chemicals to protect potatoes. Both farmers and consumers should be delighted, shouldn't they? Yet research on these potatoes has had to be done behind high wire fences and amid strident protests from people opposed to genetic molecular modification. The climate in Europe toward modern genetic modification remains extremely hostile. BASF, a company that is also developing genetically-protected potatoes, has recently decided to move all of its GM operations to the United States.

Fortunately, molecular modification — GM technology — is not dangerous. The European Union has invested more than 300 million euros in research on the biosafety of GMOs. Quoting from a recent report on 25 years of GM biosafety research:

> "The main conclusion to be drawn from the efforts of more than 130 research projects, covering a period of more than 25 years of research and involving more than 500 independent research groups, is that biotechnology, and in particular GMOs, are not per se more risky than e.g. conventional plant breeding technologies."

Every credible scientific body that has examined the evidence has come to the same conclusion. Urban myths about the dire health and environmental effects multiply faster than the crops. But not one has stood up to scientific scrutiny.

And there is good news, as well. Despite continuing controversies and anti-GM activism, GM crop acreage has increased rapidly worldwide, driven primarily by cotton, corn, canola and soybeans. In 2011, GM crops were grown in 29 countries on 160 million hectares. More importantly, 90% of the 16.7 million farmers growing biotech crops are smallholder, resource-poor farmers. The simple reasons that farmers migrate to GM crops is that their yields increase 5–25% and their costs decrease, in some cases by as much as 50%.

All of the effects so far, both expected and unexpected, have been benign. Less pesticide and herbicide use, fewer cases of pesticide poisoning, and — surprisingly — much less contamination of corn by poisonous fungal toxins released by the fungi that follow the insects as they bore into the corn.

But the rather widespread public rejection, fuelled by advocacy organizations like Greenpeace, has had a huge effect, promoting the development of ever more complex regulatory requirements. These regulations have effectively prevented the introduction of crops that would benefit the consumer.

After three decades of research and development, and despite all the promise of molecular methods, we have virtually no GM crops other than cotton, corn, canola and soybeans. These are all either non-food crops or primarily animal feed crops. All of them were developed by big biotech companies because they're the only ones that can afford the US$35 million or more it costs to bring just one new event, as each new modification is called, to market.

This is way out of proportion to the market value of specialty crops such as fruits and vegetables. It is far beyond the means of public sector researchers. Even the long-awaited Golden Rice is not yet available to farmers. Although it has been ready to distribute for almost a decade, it continues to be trapped in regulatory purgatory. Figuring out how to relax the regulatory stranglehold and achieve broader public acceptance of GMOs are very difficult problems, but they are social and political problems. The science is quite clear.

Increasing water use efficiency

Innovation in irrigation technology has progressed from wasteful spray, to low energy precision application, to drip irrigation to subsurface irrigation. Modern subsurface drip irrigation delivers water or water and nutrients, the latter termed fertigation, in response to information collected by moisture sensors. The objective is to only use the water and nutrients needed and only when they're needed, minimizing water use and nutrient pollution, as well as eliminating salt build-up from irrigation.

Hydroponic systems in greenhouses are both land and water efficient. Mirabel, a hydroponic lettuce farm in Montreal, for example, covers many acres, growing lettuce on floating styrofoam rafts on shallow water tanks year round, yielding five times the amount per square metre as soil-based seasonal agriculture can produce. Moreover, because the water tanks are completely covered, the only water lost is that due to evapotranspiration by the plants. This facility is computer-controlled, the water is recycled, its quality is constantly monitored and virtually no chemicals are used for pest and pathogen control.

Increasing nutrient use efficiency

Modern high intensity agriculture focuses on the production of one kind of crop at a time, be it hogs, cattle, corn or soybeans, on a very large scale.

This has huge efficiencies of scale — and huge inefficiencies. We use energy to pull nitrogen out of the air and extract other minerals from the ground to fertilize our fields, yet a significant fraction of it run off to pollute water, creating dead zones in places. We feed the grain grown in this way to animals raised at a very high density, commonly in closed structures. Such animals generate a great deal of waste rich in plant nutrients, which often itself becomes a pollutant.

Organic farming is a return to older farming approaches in which animals provide the fertilizer for plants. The principle of reintegrating nutrient flows is a sound one, but unfortunately organic farming as it is currently practiced under an arbitrary set of rules is simply inefficient. That is why organic produce costs so much more than produce grown by what have become convention modern farming methods. Indeed, the notion that we could feed a world of 7 billion, much less 9 billion, with organic agriculture is simply wishful thinking.

It is, nonetheless, extremely important to make better use of the nutrients in the agricultural system. We must use the most up-to-date science available. An example of a system that is both water and nutrient efficient is provided by aquaponics, which integrates aquaculture with vegetable growing. Developed in recent decades at the University of the Virgin Islands, it is a modern version of very old practices developed and used in many parts of the world.

Modern aquaponic systems, however, monitor water quality carefully. Solids are removed and nitrifying bacteria are used to convert the volatile ammonia that the fish produce to non-volatile nitrates before the water goes into the vegetable-growing tanks. Aquaculture today provides about half of the fish people consume, but much of it remains nutrient inefficient and polluting. The nutrient-rich waste from the fish is not managed and pollutes both fresh and salt-water bodies. The nutrient wastes can be managed in open bodies of water, not just in closed aquaculture systems, but this is not yet widely practiced.

Urban agriculture

Urban agriculture takes many forms and can be practiced on both small and large scales. Lufa Farms in Montreal, Canada, is the largest commercial effort to date. Lufa Farms is a 3,000 square meter greenhouse on top of an office building in Montreal supplying baskets of picture-perfect vegetables, grown hydroponically to discriminating urban customers. It provides opportunities for high-tech, small-scale businesses. Water use in this computerized greenhouse is minimal. Pests and diseases are controlled by biological means rather than through chemical use.

An intangible, but important benefit of urban agriculture is that it brings at least one aspect of food production back into the urban environment. Today's increasingly urban dwellers have little idea of what it takes to grow the perfect produce they buy. We see the consequences of that in the declining support for agricultural research and the inability to cut through the regulatory morass surrounding contemporary molecular modification strategies. Bringing agriculture to the urban environment is an important step toward raising awareness among our urban policymakers. It also creates new employment opportunities, decreases agriculture's ecological footprint and transportation costs, and delivers fresh produce year round.

Future challenges

The kinds of increases in water- and nutrient-use efficiency described above have been implemented on a relatively small scale. Major challenges are posed by the necessity to scale up such efficiencies to a global scale. Today, close to half of the grain grown worldwide is fed to animals. However, there's a clear disparity in the efficiency with which they convert what they are fed into body mass, technically called the feed conversion ratio (FCR). The FCR for beef is 5–20, for pork is roughly 3.5, and for chicken it is about 2. Fish and shellfish are the most efficient feed converters, with FCR's ranging from 1–1.8.

Then there are the water requirements. Producing a kilogram of grain requires 500–2,000 litres of water. A kilogram of beef requires 10 times as much, so it takes between 5000 and 20,000 litres of water to produce a kilogram of hamburger. At the other extreme are fish and shellfish, largely now fed on grain and fishmeal. They require little water beyond that used to grow the feed, since the water in which they are cultured, whether in aquaculture or in the wild, is largely reused. Yet the fact that feed for farmed fish and shellfish is increasingly based on plant protein and fishmeal has implications for the expansion of aquaculture, as well.

The US drought of 2012 underscored that higher temperatures and decreased rainfall can impact global food prices profoundly. The major crops that provide a substantial fraction of the world's feed and food – corn, wheat, rice, and soy – require significant amounts of water. Their productivity also declines rapidly as temperatures increase beyond their optima of 25-30 °C. Since climate change will inevitably bring more such local extremes of temperature and water deficit, it is exceeding important to explore alternative sources of feed for both animal husbandry and aquaculture.

Marine aquaculture already makes a substantial contribution to the global supply of animal protein and uses salt water, generally unusable for either urban or conventional agriculture. Developing approaches that allow the effluent nutrients to be used to grow useful biomass, and to clean up the water before returning it to the sea, are major future challenges wherever marine aquaculture is practiced on this scale. Fresh water aquaculture has similar challenges. Overall, however, it is likely that aquaculture will make an increasing contribution to both water-and nutrient-efficient animal protein production.

One of the world's biggest long-term agricultural challenges is the supply of animal fodder and grain for feed. It is very unlikely that feed and fodder crops can ever be grown economically under glass. Hence, there is a need to develop crops that can maintain their productivity at higher temperatures with less water. Drought and salt tolerant varieties of several of our major grains crops are under development. However, although such variants of our traditional crops will be somewhat more tolerant of hot and dry conditions, as well as salty soils, it is unlikely they will ever grow on salt water in the desert.

Developing crops tolerant of such extremes is possible, but must begin with plants that evolved under such conditions. There are many plants, technically called halophytes, which grow at high salinities and at temperatures higher than those optimal for our temperate crops. An example of a halophyte that is already in the feed and food chain is *Salicornia spp*, a salt-marsh plant commonly known as sea beans, sea asparagus, or samphire. It is also is used as a feed for lambs, marketed as salt-marsh lamb in Europe.

Distichlis or saltgrass is another interesting species with potential as a fodder grass and a grain crop. Unlike Salicornia, which accumulates salt in intracellular vacuoles, it secretes salt, which means that the plant material itself is not salty. Although the use of halophytes for feed and grain has been discussed for many years, little progress has been made in their domestication. It is high time we use modern genomic tools to domesticate species with high tolerance to the abiotic stresses anticipated in the future. We have learned a good deal about the genes and genetic changes involved in domestication in recent decades. Now is the time to take up the challenge of applying that knowledge to the domestication of new species.

Impediments to success

Overall, the technical prospects are good for increasing the global food supply in a warming climate while decreasing the ecological footprint, as well as the water and energy requirements, of agriculture. What stands in the way of success?

Governments have been under-investing in agricultural research for decades. Half of us live in cities now and know only that food comes to the store in trucks from somewhere. We invest a tiny fraction of each biomedical research dollar in agricultural research. We also continue to over-regulate — or even completely prevent — the use of most modern methods of crop improvement. Only the big commodity crops can support the costly development of a GM crop and only the big biotech companies can afford to bring a GM crop to market.

Additionally, private investment in primary agriculture is not popular. This makes it difficult to raise the capital needed to bring high tech agriculture to the less developed world, where land is still relatively plentiful and yields are low. Finally, there are the persistent problems of inequitable distribution, price speculation, and competition from other uses of biomass. But these are not scientific or technical problems. They are policy, regulatory, financial and social problems.

Will we be able to solve them? I don't know.

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SEKEM–Greening the Desert

Helmy Abouleish

The world is facing multiple crises, ranging from economic to social and environmental. Its prevailing model of economic value generation has failed to protect people or provide economic prosperity, social justice or better rural livelihoods. Instead, it fuels poverty, drives environmental degradation, and exploits natural resources.

Egypt is particularly affected as it struggles with a weak and unequal economy, and finds itself located in a region especially susceptible to climate change. The agricultural sector plays a major social and environmental role in the economy of Egypt. It provides the majority of jobs for over a third of the country's labour force and works to ensure food security in a climate of rising food prices. Its environmental impact, however, is its darker side. Over three quarters of Egypt's fresh water resources are used for agriculture. Conventional large scale farming systems can cause soil erosion, pollution, and desertification.

This makes it absolutely essential and urgent for the world to turn away from standard agricultural practices and adopt more sustainable approaches to farming. However, can they produce enough to feed the world at an affordable price?

Concurrently, more sustainable business approaches are needed to achieve social justice and economic success beyond the agricultural sector. Can entrepreneurs contribute not only to their self-sufficient economic well-being but also to the development of individuals and therefore to social cohesion?

Sustainable development

SEKEM was established by Ibrahim Abouleish over 35 years ago about 60 km northeast of Cairo in rural Egypt. On returning to Egypt after 21 years of study and work in Austria, he noticed how Egypt's socio-economic fabric had deteriorated. His response was to develop a new vision for development in his country which he summed up as:

> "Sustainable development towards a future where every human being can unfold his or her individual potential; where mankind is living together in social forms reflecting human dignity; and where all economic activity is conducted in accordance with ecological and ethical principles."

This vision integrates ecology with economic, societal and cultural life and is the guiding principle of all SEKEM activities as shown in the figure below.

Figure 1a The Round House, first building at SEKEM in 1978

Figure 1b The Round House 30 years later

> This is the Sustainability Flower, which serves as the conceptual framework for performance monitoring and evaluation at SEKEM. It is the basis for a comprehensive management system, integrating the four dimensions of sustainable development (ecology, economy, society, culture), and generating annual reports on progress and achievements.

In the course of 35 years, SEKEM and its suppliers converted 20,000 feddan (–8.400 hectares) of desert land into organic agriculture, created 2,000 jobs, sequestered over one million metric tons of CO_2–equivalents, and saved 20–40% of water used compared to conventional agriculture.

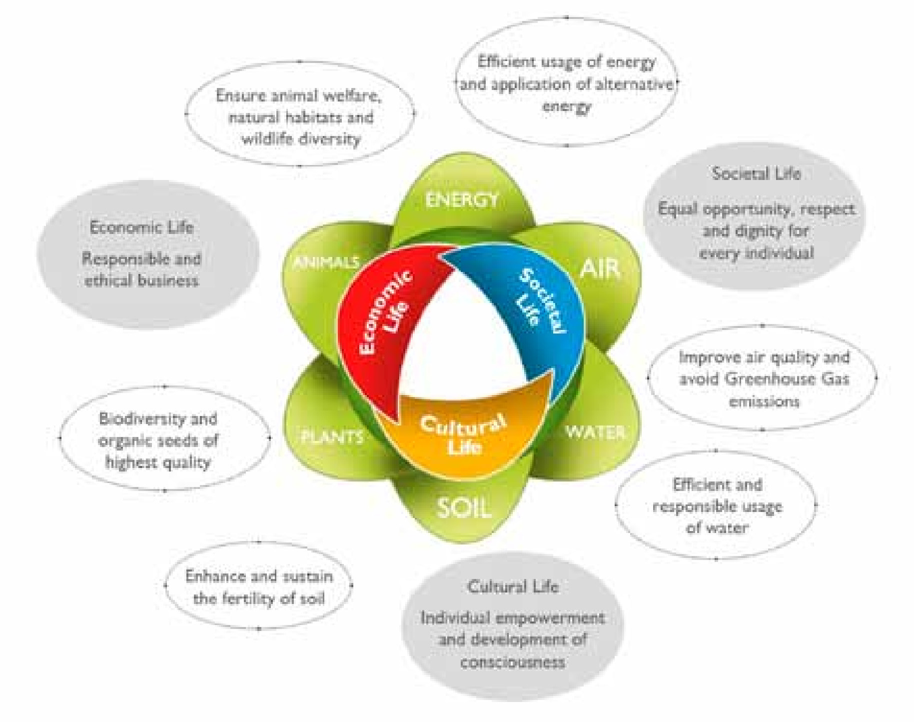


Figure 2 This is the Sustainability Flower, which serves as the conceptual framework for performance monitoring and evaluation at SEKEM. It is the basis for a comprehensive management system, integrating the four dimensions of sustainable development (ecology, economy, society, culture), and generating annual reports on progress and achievements.

It continuously increases its yields and has decreased pesticide use in the Egyptian cotton industry by 90%.

Ecological approach

SEKEM's business model is based on biodynamic agriculture, a form of organic agriculture that views the farm as "a self-contained, self-sustaining ecosystem responsible for creating and maintaining its individual health and vitality without any external or unnatural additions. In practice, soil, plants, animals and humans together create this image of a holistic living organism."

SEKEM applies biodynamic agricultural methods, including the extensive use of compost, to turn deserts into living and healthy soil. It entails eco-intensification where fertilization, pest control and irrigation are implemented innovatively through compost tea, the use of predators and applying subsurface irrigation technologies. The use of resilient crops and natural predators render external inputs, such as chemical fertilizers and pesticides, needless. Biodynamic agriculture is based on the notion of creating close nutrient cycles. SEKEM rears livestock to produce its own compost, grows cereals to feed the livestock, and uses crop rotation to enhance soil fertility. The surplus is sold in supermarkets and organic shops both nationally and internationally.

There are numerous benefits to biodynamic agriculture. Healthy soils with a high content of solid organic matter have an increased water holding capacity, by up to 70%, and are more protected from erosion. Compared to common practices, the increased energy efficiency, lower greenhouse gas emissions and increased soil carbon sequestration make biodynamic agriculture a superb tool to mitigate climate change. SEKEM has sequestered emissions of over one million tons CO^2–equivalents since its inception over 30 years ago.

Through diversification methods such as agro-forestry and crop rotation, the risk of crop failure is being minimized. Intercropping and the absence of chemical inputs increase biodiversity. Today, more than 60 bird species, over 90 varieties of trees and shrubs, and a broad range of small animals such as hedgehogs, lizards, snakes, mongoose, and foxes reside on the SEKEM farms, which used to be deserts.

Excursus: 100% organic Egypt study

The cost factor

One crucial question posed when considering switching from standard agricultural practice to organic farming is: Does it entail higher costs?

The SEKEM model of organic, resource-efficient, soil-protecting and sustainable agriculture requires, on average, 10–30% more manual labour than conventional agricultural production. Employing more workers usually leads to overall higher expenses. Also, organic products on supermarket shelves always cost more than the conventional alternative.

The logical conclusion would be that organic production is more expensive than business-as-usual production. But is it indeed the case?

The answer is no. Such a narrow economic view fails to take into account fiscal and socio-economic externalities which are not internalized in the market price of organic products. To take Egypt as an example, there are energy and water subsidies which promote resource-intensive practices. Resource-efficient practices such as biodynamic agriculture do not benefit as much (if at all) from these subsidies, and thus suffer from a disadvantage with the resultant market distortions.

The indirect cost-saving effects of more sustainable farming systems are also missing from this calculation. Healthy soils with a high content of solid organic matter increase the water-holding capacity, decrease water consumption, and inhibit erosion. Compared to business-as-usual agricultural production, biodynamic agriculture's increased energy efficiency, lower greenhouse gas emissions, and increased soil carbon sequestration make it a superb tool to mitigate climate change.

Resilient crops, crop rotation, and diversification methods such as agro-forestry (an efficient form of eco-intensification) minimize the risk of crop failure. Intercropping and the absence of chemical inputs increase biodiversity. Moreover, lower expenditure on external inputs makes financial resources available to cover the costs of higher employment, thus promoting rural livelihoods. Biodynamic agricultural methods are also healthier as they do not expose farmers, animals, soil, air, or surface water to hazardous chemicals.

To quantify the cost-saving effects of sustainable farming systems and their potential to mitigate and adapt to climate change is somewhat difficult. However, the scientific community and economic analysts agree there will be a tremendously positive economic impact. Furthermore, the savings to be made on the cost of national healthcare when chemical pesticides and fertilizers are replaced by natural predators and compost is another important factor to be taken into account. The health of farmers significantly improves and the population can enjoy a wide variety of foodstuffs that do not contain any chemical residues.

Considering all the cost aspects, from labour, machinery and subsidies to environmental and health cost savings, organic agriculture is already cheaper today. As energy prices rise, water becomes scarcer and climate change more severe, only sustainable farming systems will be viable and affordable.

Feeding the world

In 2050, mankind will have to produce enough food for nine billion people. The availability, access and affordability of sufficient nutrients are the crucial criteria of food security that have to be taken into consideration when choosing the farming system of tomorrow.

Availability

The long-established belief that external inputs, such as chemical fertilizers, are necessary in order to substantially increase food production is seriously being challenged. An increasing number of scientists, policy panels and experts, such as Olivier de Schutter, the United Nations' Special Rapporteur on the Right to Food, now claim that resource-conserving, low external input techniques have a proven potential to significantly improve yields. In traditional farming systems in developing countries and in regions where soils are degraded, yields can be increased up to 180%.

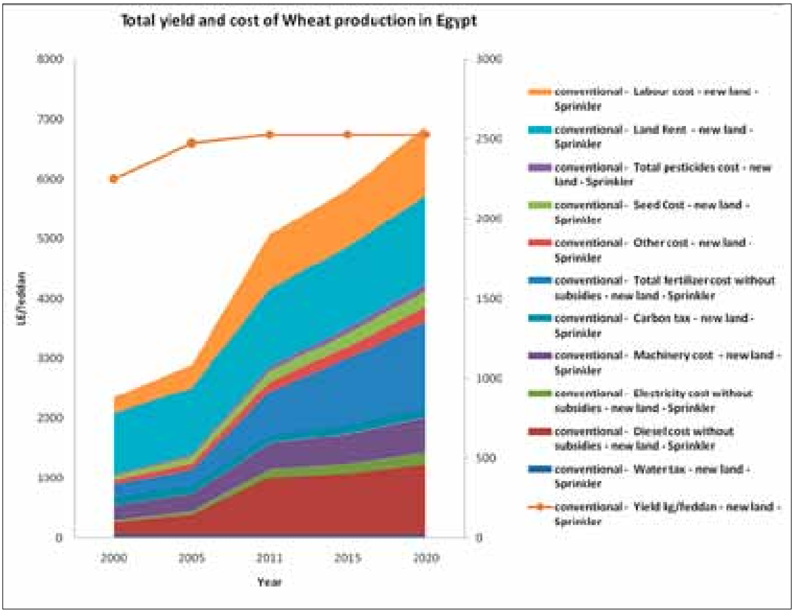
Access and affordability

The rural areas where the greatest yield increases can be achieved through eco-intensification methods, such as agro-forestry, are often the regions where poverty and hunger are widespread. Increased yields would therefore directly tackle access to food and nourish the farming population. As sustainable farming systems are more labour-intensive, a substantial amount of jobs would be created which, in turn, would enable many more people to buy foodstuffs for their families.

The integrated value chain of SEKEM

The year 2011 has been one of crises for all Egyptian businesses. While the crisis had an impact on SEKEM, it also showed how resilient SEKEM is. This resilience is inherent to the business model that SEKEM pursued and developed over several decades until today.

SEKEM focused on developing its business beyond farming or processing and into developing an integrated value chain. The value chain consists



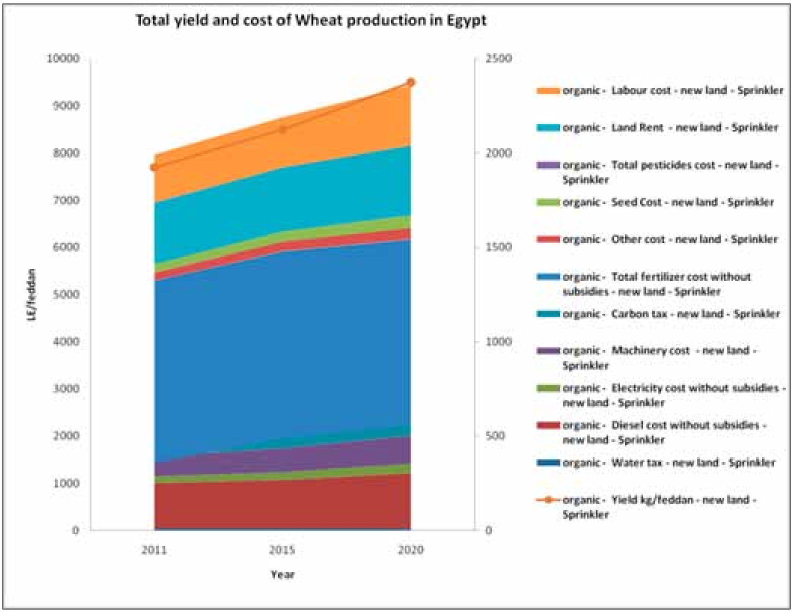


Figure 3 The Soil & More study analysed seven important commodities in Egypt regarding its true costs and yields. All commodities, wheat as one example, will become cheaper while yields have more potential to grow than under business-as-usual.

of a seed breeding programme, several facilities to produce compost, and growing and harvesting herbs and foodstuffs. These raw materials are then processed and further refined into end consumer products to be distributed to wholesalers and retail stores by SEKEM's own transport fleet.

Although SEKEM still purchases a significant share of raw materials from suppliers, the integrated value chain helped it to become less dependent on external suppliers and processors. Furthermore, the geographical proximity of its various facilities reduces risk and costs generated by transportation and storage requirements.

The integrated value chain of SEKEM

SEKEM is engaged in the food and beverage, pharmaceutical and textile sectors. The diversified product portfolio and the market leader position that it holds in the organic products niche market in Egypt further strengthens it in times of crisis for apparent reasons. The food and beverages sector and the pharmaceutical sector proved particularly resilient in 2011 despite the generally struggling economy.

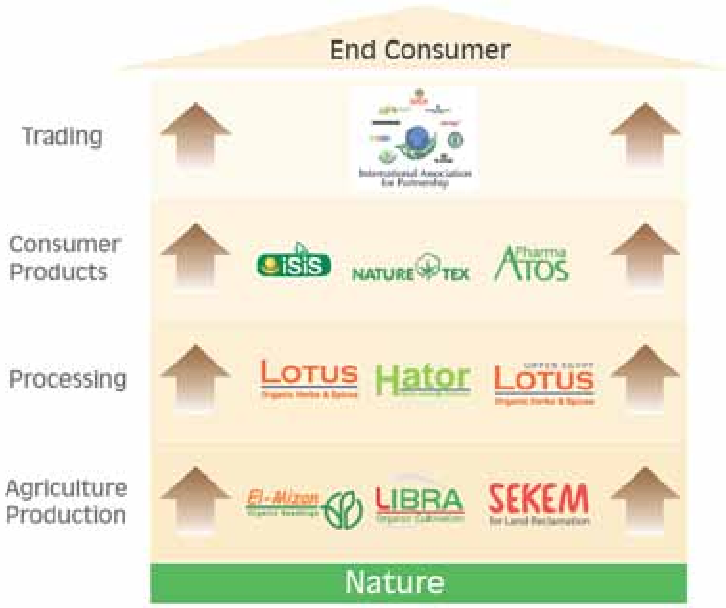


Figure 4 The integrated value chain of SEKEM

A living, learning community

The place of the individual in society shapes our social relationships while the laws of a society determine individual opportunities. In a fair and just society, the individual human being is recognized to have innate rights, is equal to all others in front of the law and is granted similar opportunities for participation. A just cooperation of human beings worldwide can be regarded as the main prerequisite for peaceful development, today as well as in the future.

SEKEM is living this vision by providing for about 2,000 employees in the SEKEM Group and the SEKEM Development Foundation. It ensures safe workplaces through numerous certifications and a code of conduct. Women are actively empowered in the organization. For example, NATURETEX currently carries out a gender-sensitive value chain analysis for its products, a joint project with the German Agency for International Cooperation (GIZ). We are also working to increase the number of women in managerial positions in the future. Additionally, religious tolerance is provided through a sufficient number of praying rooms in close distance.

Cultural life

Without human development, the best ideas cannot be realised. To promote human development, the SEKEM Development Foundation (SDF) was founded in 1983. It supports and operates a broad range of educational, social and cultural institutions. There is a kindergarten, various programmes for socially disadvantaged children, schools and a vocational training centre, which together educate about 600 children and students. SDF provides health services through a medical centre which serves over 30,000 people in surrounding villages. It also supports cultural and artistic development.

Heliopolis Academy, a research body of the SDF, conducts research in the fields of medicine, pharmacy, renewable energy, biodynamic agriculture, arts and social sciences. All of these programmes create jobs, provide better learning opportunities and healthcare for the people in the villages surrounding the main SEKEM farm and improve social inclusion of children with special needs, thus contributing to the alleviation of poverty, fighting social exclusion, and improving literacy. This also ensures the integration of SEKEM within the wider social community of the region thereby contributing to cultural understanding between the local population and SEKEM staff who frequently come from widely different backgrounds.

Finally, the old and static educational system needs to be infused with the concepts of sustainable development and social entrepreneurship in order to spawn young entrepreneurs that create jobs that help the country in all aspects of its development. This is the approach of Heliopolis University for Sustainable Development, which SEKEM co-founded and was officially launched in October 2012.

Conclusion

Today's prevailing agricultural and economic paradigms need to change. In the developed world, industrial agriculture achieved high productivity levels primarily through the extensive use of chemical fertilizers, pesticides, herbicides, water and fuel. Traditional agriculture, mostly in developing countries, often results in deforestation and the excessive extraction of soil nutrients. Sustainable modes of agricultural production represent the only solution that can provide sufficient quantities of affordable and nutritious food for our growing global population.

However, the model of economic production and business as a whole needs to be infused and transformed with the concept of sustainable development in order to stay competitive in the future and safeguard natural resources, the very basis of our existence. In these times of change, as we have recently experienced in Egypt, the window is open for renewed and intensified efforts to promote sustainable solutions to the great challenges that we face.

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14

The Uncertainties of Genetically Modified Plants

Constantin Canavas

Debates on genetically modified plants (GMP) for food use have strongly variable intensity and focus in the different countries involved in their development and application. In Europe, the focus of the controversy has shifted during the last years from health and environmental safety issues to legal and economic issues. These range from labelling food products containing GM organisms to monitoring GMP, tolerance levels and traceability of contamination of GM-free farms through GM seeds.

Such issues yield significant economical criteria for decision making by the various actors (cultivators, seed providers, governments). However, impact assessment remains the central issue. Here precisely, the discourse is dominated by controversial arguments.

A typical example is the paradoxical situation in respect with the commercial cultivation of GM maize MON 810. This initially authorised crop has since been banned in seven countries of the European Union (EU) with reference to the safeguard clause, article 23, Guideline 2001/18/EG. The European Food Safety Authority (EFSA) claims that there is no available evidence on negative environmental or human health impact specifically related to this commercial cultivation (www.efsa.europa.eu, 21 May 2012).

However, France, Germany, Austria, Greece and other countries hold on to the political decision to ban the cultivation of the GM crop, claiming that the EFSA assessment does not adequately consider all evidence available.

This discrepancy reveals the manifold character of assessing cultivation of GMP — especially when focusing on the multitude of perspectives of the several actors (Potthof, 2012). The particular expert discourse of biotechnologists cannot answer political questions, such as dealing with conflicts among several societal actors. Nor can it attenuate conflicts associated with the vulnerability of a given economy or society. In fact, the need of broadly participatory procedures for political decisions for or against cultivating GMP in a specific environment has been underlined even within the biotechnological expert discourse (Huttner, 2010).

This article does not adopt a specific impact assessment. Moreover, it follows the criticism from the perspective of participatory technology assessment, which claims that decision making on basis of contradictory, insufficient or controversial scientific evidence demands political principles such as the principle of precaution (Mann, 2010).

The acceptability of GM products for food use and the marketing decisions of GMP providers, however, do not necessarily derive from the expert discourse on safety issues concerning GMP for food use. Consumer behaviour in the global market repeatedly induce procedures and reaction patterns of the actors in the GMP network which do not comply with the optimistic predictions of GMP seeds providers and their evidence on GMP safety. In the case of farmers in a vulnerable economic network (e.g. in a developing country) the impact of such turbulences might be serious – if not disastrous.

Dependence on new technologies

The issue of vulnerability in the case of developing countries is related to the dependence of the national economy upon imported products provided by new technologies and the possibility to export primary products as a trade balance.

When dealing with GM crops, this dependence is based upon imported or exported patented GMP and GMP derivates, as well as upon transfer of knowhow, technology and infrastructures related to these products — such as special herbicides and pesticides. The vulnerability issue precisely links the economic relationship that social groups involved in production and distribution of crops in a country maintain with their habitat to national and supranational institutions and networks of food supply.

This article is motivated by the extreme sensitivity experienced by globalised bio-safety networks towards even the smallest disturbances. On this basis, bio-hazards associated with unwished contamination through GMP may imply economic disasters and serious, irreversible environmental degradation in developing countries because of their specific vulnerability.

During the last two decades numerous international conflicts, in respect to regulations which allegedly still hinder an unlimited "free market" of commodities, have seen developing countries under extreme political pressure from Western countries. The latter would "cover" or openly support companies which almost monopolise GM crops systems and try to obtain and maintain control over crucial nodes of the agriculture infrastructure in the developing world.

The above considerations imply that sovereign political decision on the basis of multi-criteria assessment of the technological innovation, as well as political participation of the societal groups in the decision making, are necessary prerequisites for a societal benefit through the use of such novel products like GMP. However, in the case of GMP, the risks undertaken by the decision makers are very complex in their nature and unequally distributed.

Whereas the GMP providers undertake a purely monetary risk concerning revenue and control of market segments, the countries importing this technology undertake the whole risk. This covers the sovereignty upon and the sustainability of their own crops production, the impact on the export trade towards countries where food based on GM crops might be or become undesirable, as well as with the environmental impact of the novel crops and the health impact of the GM food.

The perspective addressed here is that of decision makers in the field of agriculture – farmers and/or governmental institutions — in a developing country such as Egypt. Some authors claim that "for Egyptian farmers, using *Bt* (GM) maize seems an easy decision to make" (Massoud, 2010, p. 205). The following cases of experiences with GMP (including GM *Bt* maize) in a transnational context should demonstrate that such a claim is not at all evident.

Control systems in practice

Perhaps the most spectacular — if not the most prominent — case is concerned with serious juridical conflicts and costly compensations in respect to contaminations of conventional, GM-free rice, with the genetically modified rice type LL 601™ produced by Bayer Crop Science. The GM rice traces found in 2006 in conventional American rice exported to Europe induced a chain reaction of responses on a worldwide level. It provoked serious issues in the international political relations, and cost the parties involved (producers, merchants, insurance companies, etc.) over US$600 million. The series of events can be summarised as follows (Lorch, 2006):

The public part of the story began in January 2006, when an exporter dealing with rice of the company Riceland Foods in the United States found contamination through "unknown" GM rice in conventional rice stored in the US for export. The GM contamination was identified as associated with resistance to herbicides of the Liberty Link family, which, at that time, were used commercially in the US in growing maize, soy, raps and cotton — but not rice. Riceland Foods conducted systematic tests, and found contaminations in several stored rice loads. In June 2006, Bayer Crop Science confirmed that the contamination corresponded to GM rice LL 601, which, however, was not authorised for commercial use.

Between August and September 2006, a chain of international reactions followed. First, information concerning the contamination was diffused (with extraordinary delay) by the US authorities towards the European Union and other countries. This was immediately followed by import bans in Japan and the EU, which caused a flow of accusations by rice cultivators and exporters in the US against Bayer Crop Science, claiming compensation for the economic losses.

Meanwhile, the GM rice LL 601 was traced in European markets. The EFSA attested that no toxic hazards were associated with the GM contamination. However it held that a comprehensive risk analysis was at that time impossible because of lacking information. In an atmosphere of negative publicity, imported rice loads were sent back from the EU and Japan to the US. The price of export rice there fell by more than 10%.

Intensive investigations revealed that the contamination was most probably due to traces of experimental cultivation of GM rice LL 601 conducted by American universities in Puerto Rico in the years 1998–2001 in cooperation with Aventis Crop Science. The experimental cultivation lead to no favourable results, and the research project was abandoned after 2001. Therefore it was a complete coincidence that the institutions involved and the seed provider, Bayer Crop Science, had stored records and seeds from the experimental project — material that was used five years later as the basis for identifying the GM contamination.

This example demonstrates how small disturbances in the globalised bio-safety system — even under the best conditions conceived and implemented in order to avoid harmful impact — may provoke serious economic disturbances. The case study is significant for interpreting the effectiveness of bio-safety mechanisms when confronted with GMP. It leads to the conclusion that the weak point when handling GM crops is not just the non-effective quality control. Moreover, the discrepancies result from inadequate political control in dealing with technological innovation.

Whether this inadequacy is a result of pending conflicts among stakeholders on a political level can not be discussed here. As a matter of fact, several similar cases have been repeatedly reported in recent years — most of them concerned with animal feed. In summer 2009, animal feed was sent from the EU back to the US because it contained GM contamination through species not authorised for the European market (MBU, 2009/2010). The interpretations and claims of the stake holders have a constant pattern: The providers and lobbyists of GMP demand for abandoning maximum limits of GM contaminations in crop shipments, whereas the European proponents of organic farming as well as consumer associations hold zero-tolerance on GM contamination.

What lessons can be learnt from this case regarding the implementation of bio-safety in a developing country? First, there are the undeniable deficiencies in the traceability of GM contaminations in the globalised distribution network. Such an experience provokes defensive reactions in societies where GM food is broadly undesirable. These reactions are on a political level and are not controllable by the dominant expert discourse on risk assessment (tuned by GM seed providers, but also by EFSA) with its limited and politically unsatisfactory assumptions on the impact horizon.

US farmers and traders could buffer the unexpected losses through an effective insurance system — but what would have been the outcome of the conflict for the involved exporters if the contamination had taken place, let us say, in Egypt?

Protection, precaution and safeguarding in the EU

The next case regards GM maize MON 810™, a variety developed and commercialised by Monsanto for animal feed. This GM maize produces an insecticide against lepidopteran insect pests. In 1998, Monsanto obtained authorisation to cultivate MON 810 for commercial use in the EU. In 1999 and 2003, new conditions concerning authorisation of cultivating GMP for commercial use were established in the EU. The new legal frame created the need for all products, including those with previous authorisations, to adapt to the new conditions. Monsanto did not show willingness to comply with the new conditions, such as additional monitoring and their additional costs. This attitude led several countries to ban free-land cultivation of MON 810 inside their territory with reference to the safeguard clause, article 23, Guideline 2001/18/EG, such as Austria (1999), Greece (2005), Hungary (2005), Germany (May–December 2007), and France (January 2008).

This case illustrates political response patterns intended to define national bio-safety (Breyer et al., 2008). Such reaction patterns are related to the fact that the protection of health, environment and biodiversity engenders conflicts with GMP cultivation on a local level. Here, the role of the public (layperson citizens and social groups) becomes more important than the global expert discourse of impact evidence.

Given this reality, farmers cultivating GMP take the risk of having to cope with the consequences of strategic, economically-motivated decisions of the seed providers. Farmers in developing countries also suffer from extremely high economic vulnerability due to the negative attitude and the reactions in certain regions regarding the cultivation of GMP. This demands a reassessment of the economic risks associated with GMP in both local and national level. This cautious behaviour should take into consideration possible irreversible environmental impacts in case of uncontrolled contamination of conventionally-treated fields through GMP and GM seeds.

Company decisions under acceptability pressure

The last case regards the development of a potato type with genetically modified starch content, Amflora™ (BASF). After 13 years of juridical controversy, BASF obtained the approval for free-land commercial cultivation of Amflora in the EU in March 2010. A few months later, the German Federal Constitutional Court classified "green biotechnology" (involving GM techniques for plants, food and feed) as high risk technology.

In January 2012, BASF stopped further development of GM plants in Europe. The company justified this decision as a reaction to the atmosphere evoked by the above comment and by assessing that there exist "no perspectives for successful commercialisation of GM plants in Europe in the next years". This decision was commented, even by the press favourable to "green biotechnology", as "capitulation" of the industry involved in the development of GMP (Freytag, 2012). It is easy to imagine the implications of such decisions on similar activities in developing countries. What would be the impact of this BASF decision on the export of GM Amflora potato produced, let us say, in Egypt and exported to the EU?

Conclusion

The major argument in the above considerations is that disturbances in the transnational commercial network of GMP, GM food and GM animal feed, like those provoked by European reaction patterns, may have a disastrous impact on the economy of a developing country involved in such a network (Gaskell, 2004). This specific vulnerability is of economic nature, and is more accentuated in cases where political control mechanisms are not transparent enough and do not fulfil the public reliability criteria from the laymen perspective.

In that sense the decisions of policymakers in these countries should be taken in an extended horizon of risk assessment — beyond the expert, evidence-based discourse — especting procedures of societal participation. International bio-safety agreements, such as the Cartagena Protocol. are not a remedy for everything.

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15

Education for Sustainable Development

Sewilam, H., McCormack, O., Osório-Peters, S., and Mader, M.

Introduction

Egypt is facing enormous environmental challenges that cause a myriad of health problems. High air pollution makes Cairo one of the most polluted cities in the world. Egypt suffers from water insufficiency due to limited water resources and inefficient use. Industries are estimated to generate at least 10 tonnes of solid waste each minute.

The country is in urgent need for sustainable development (SD) rather than the current course of development that leads to further deterioration of the environment, exhaustion of natural resources and introduction of more diseases. The UN Agenda 21 identified education as an essential tool for achieving sustainable development.

Along those lines, Egypt needs to introduce Education for Sustainable Development (ESD) to its school education system. The current teaching methods in Egypt are based on rote learning and old techniques of in-class learning which can stifle the children's creativity rather than foster critical thinking early on in education.

Lessons do not establish the link between the surrounding world and local problems. Instead, the curricula taught are hardly useful and irrelevant to practical skills. As educators, we are thoroughly aware that rote learning is often not retained in the long-term. ESD concepts can usually be introduced into the education system without increasing budgets. If we succeed in introducing aspects of sustainable development into the classroom, it will yield better student understanding, retention, and application in the future.

This paper introduces a European Commission-funded project aiming to tackle specific education problems; a) poor school curricula and their irrelevancy to the surrounding community in Egypt; b) poor teachers' qualifications; c) lack of attractive and innovative teaching methodologies; d) lack of models that bring schools, universities, ministries, private sector and civil society together to work for the future of educating our children and ensuring a sustainable society.

EduCamp

With funding from the European Commission, RWTH Aachen University in Germany launched the Education for Sustainable Development beyond the Campus (EduCamp) project. It brings together 20 partners representing different stakeholders, including European and Egyptian universities such as Limerick University (Ireland), Graz University (Austria), the Egyptian Ministries of Education and Higher Education, seven Egyptian universities, Bibliotheca Alexandrina, three NGOs and two international organizations. Their general mandate is to "promote and implement Education for Sustainable Development (ESD) nationwide and beyond all education levels".

To overcome the identified problems, five specific objectives have been set out over the three years period of the initiative:

- Developing "Teaching ESD Resource Kits for Schools" to provide activities for students and teachers that link the existing curricula to the surrounding community and focus on ESD and sustainable consumption and production (SCP).
- Developing innovative ESD teaching methodologies that shift the focus from rote learning to interactivity and involvement of the students.
- Developing the School Teachers' Training Programme (STTP) to enable teachers to use the produced materials and techniques.
- Establishing seven centres of excellence inside the partner universities to promote ESD and SCP in Egypt and provide training services and consultation for Egyptian schools.
- Developing an EU-Egypt virtual environment to enable schools and universities to share knowledge and exchange experiences on ESD and SCP.

Analysis of needs

To promote ESD in an Egyptian setting with a special focus on water, energy, biodiversity and agriculture, it was necessary to carry out a needs analysis to answer:

- To what extent do the national school curricula in Egypt tackle ESD topics? What are the needed improvements?
- What skills are teachers missing to deliver ESD-related content?
- What type of teaching methodologies and equipment are necessary to facilitate the ESD process?

The analysis has been carried out in six governmental schools across six different Egyptian governorates. It focused on the curricula of grades 5 to 9. The three main issues studied (curricula, teaching methods and facilities and environment) are summarised as follows:

Mapping of School Curricula

The review of the curricula showed that — like many other countries — the Egyptian school curricula follow a traditional, subject-oriented approach (Arabic, mathematics, social studies, sciences, etc.). It does not provide much space for interdisciplinary approaches.

The school curricula provide good basic knowledge in many fields. However, it fails to link the learning experience to practical uses related to the surrounding community. Egyptian school teachers need support in order to make use of new teaching methodologies. Although several school kits have already been developed and used in Egyptian schools, ESD-oriented approaches are missing.

The mapping of the curricula was then extended by the involved Egyptian experts to the books and teaching materials present in governmental schools. This identified the content needed to link the curricula to sustainable development of the surrounding community. It also helped determine specific weaknesses and strengths in the curricula of Arabic, mathematics, social studies and sciences.

Teaching Methodologies

To understand the teaching process, 20 students and 20 teachers from the six schools answered specially-prepared questionnaires and interviews. Analysis of the results showed that the education process is largely traditional didactic teacher-centred.

The majority of the teachers saw final exam results as the main driving force for education and focused on textbook teaching. The overwhelming majority of students agreed. They indicated that their main aim for studying was to score high marks in final exams in order to pass to the next grade. They stressed this left no time for further researching, contemplating or exploring what they learn and translating it to real life.

School Facilities and Surrounding Environment

Over two thirds of interviewed students and 61% of the teachers believe their lab facilities are unsatisfactory. Only 15% of students go on field trips in the surrounding community during the academic year and less than a fifth of teachers take their students on such trips. Nearly 90% of the students indicated that what they learn has no connection to the surrounding community in general and SCP/ESD in particular. However, 43% of the teachers claim to develop initiatives for their students to draw links between education and their environments based on personal effort.

ESD Kits

Based on this research, five teaching and learning kits on education for sustainable development were produced to enable the schools to incorporate sustainable development into school curricula. The kits were developed for teachers who teach 10-year-old to 14-year-old children.

In all five kits, there are more than 200 various interdisciplinary activities linking the existing curricula to the surrounding community. Each activity includes a full guide for implementation and teaching methodology. The activities include innovative group work, field trips, discussions, experiments, games, research and assignments that fall into any of the following fields:

Sustainable Development

This cluster of school activities introduces students to the concept of unsustainable and sustainable behaviours and encourages them to explore how they can become more sustainable within their own lives, homes, communities and country. It teaches students about key scientific principles and cycles that are essential for a sustainable world, and encourages them to challenge their own consumption behaviours and that of their community.

Agriculture

The agriculture cluster deals with farming and agricultural production and food consumption patterns. Organic waste and composting are addressed as well as impacts of climate change on agriculture, exports and imports and food supply in Egypt.

Biodiversity

These activities introduce ecosystems and their types, food chains and the overall interconnectedness of plants and animals. They deal with the concepts of protected areas and the links between biodiversity and culture, health and society. Finally, they deal with population growth and pollution and how it can affect the environment.

Energy

This cluster focuses on renewable and non-renewable sources of energy along with their worldwide distribution and impact. The increased worldwide demand on energy and the challenges it poses are addressed, as well as introducing the students to scenarios of a future without oil.

Water

This cluster addresses the water cycle and extreme events such as draughts, floods, sea level rise and the melting of the glaciers. Water scarcity, pollution of water and water rights are explored. Additionally, the activities deal with water availability in Africa in general and more specifically with the current debate on the waters of the Nile River.

Innovative teaching methodologies

Innovative teaching methodologies attempt to move teaching and learning away from traditional didactic teacher-centred approaches that frequently dominate our classroom environment. Instead, innovative approaches are student-centred and place the learner at the centre of the learning experience. These active approaches are central to the objectives of *EduCamp*, with all of the teaching kits including fun, interesting, student-focused approaches such as debates, games and experiments.

The advantages of student-centred teaching approaches have long been documented in educational literature. Some 2500 years ago, the Greek playwright Sophocles argued that "one must learn by doing the thing; for though you think you know it you have no certainty, until you try."

Those in support of such approaches argue that meaningful learning can only take place when individuals organize knowledge for themselves. Limited learning occurs when students are provided with pre-packaged material from a teacher. Involving students in a more active role results in deeper learning (Kolb, 1984; Adler, 2000) as well as being more motivating, enjoyable and intellectually stimulating for students (Smyth et al., 2006).

Placing the student at the heart of the learning experience is key for sustainable development. Teaching is, after all, "an activity in which the

Examples for School Activities and Teaching Methodologies

In one activity in the teaching kit Our World Level 1 (Grade 5 and 6), students take part in a play titled "Why Frogs and Snakes Don't Play Together". The play portrays a chance meeting of a baby frog and a baby snake in the woods one day. They form a friendship and have a lovely day playing together. Later, when they each tell their parents about their new friend, they are both told to never play together again. Following the play, students participate in a group discussion where they debate the main theme they can derive from the activity. This is followed by a class discussion about prejudices and stereotyping — hence leading to a greater understanding of diversity, respect for differences and living in harmony.

Another example, this time from the teaching kit Agriculture Level 3 (Grade 9), students are confronted with the current challenges facing the agricultural sector in Egypt. They are tasked to prepare two posters, one representing the challenges and the second outlining innovative solutions that could help overcome these challenges by 2020. This activity can be linked to the agriculture and the water kits above.

teacher is sharing in a moral enterprise, namely, the initiation of (usually) young people into a worthwhile way of seeing the world, of experiencing it, of relating to others in a more human and understanding way" (Pring, 2006). This concept is closely linked to education for sustainable development.

The United Nations Economic Commission for Europe (UNECE) Strategy for Education for Sustainable Development highlights the need to direct educational practices towards participatory and solution-orientated methods which would facilitate the development of systematic, critical and creative thinking. What better way to develop such knowledge, values and skills than through innovative teaching approaches?

In order to behave in a sustainable manner, one needs the ability to communicate, to work in teams, to ask critical questions, to challenge one's own and others behaviours, to think in a holistic manner, to consider long term issues and be capable of taking action. One will not develop such knowledge, values and skills by sitting at a desk listening to a teacher, but rather by interacting, debating and discussing such issues with their peers. The following two examples clearly show the central role played by innovative teaching approaches in the teaching kits.

Centres of excellence

Another core activity of the *EduCamp* project is the Training of Trainers (TOT) programme, where Egyptian university professors are trained on sustainability issues. They then train public school teachers on ESD, the developed ESD school kits and modern teachings methodologies that are tailored for Egypt. The aim is to raise awareness within the Egyptian society about the relevance of sustainable development as well as offer high quality education by supporting and empowering teachers in public secondary schools in Egypt.

After the completion of the *EduCamp* training programme, the professors will train the teachers at seven newly established centres of excellence located at seven Egyptian universities. By understanding the ESD kits and using the activities in their classrooms, the teachers will experience participatory and student-centered teaching methodologies. The learning situation for the students will improve, which will in turn motivate and empower the teachers further to become more engaged to overcome daily challenges at their schools and reorient their teaching approach to ESD (UNESCO, 2007).

The *EduCamp* Training of Trainers Programme includes nine training modules, which take place between March 2012 and May 2013. Each module lasts five days and is conducted by the *EduCamp* project partners in Egypt, Austria, Germany, Ireland and Portugal. More than 60 university professors from Egypt will be trained in this programme. Eventually, this should help spread ESD exponentially across the Egyptian school system.

Besides training teachers, the centres of excellence will also ensure the developed ESD kits are regularly updated. They will act as nodal points to network various educational stakeholders, such as universities, schools, NGOs, companies as well as local and regional governments and ministries. They should act as role models for other universities who are interested in opening similar centres.

ESD Virtual Environment (ESD-VE)

ICT is recognized as a strategic enabler in the process of developing innovative solutions to address problems such as reducing dissemination cost and facilitating knowledge sharing among stakeholders (Sewilam & Alaerts, 2012). Therefore, *EduCamp* has developed the ESD virtual environment as an integrated online tool for storing, updating and sharing information (web-based content, documents and multimedia) on existing ESD/SCP knowledge and e-training tools.

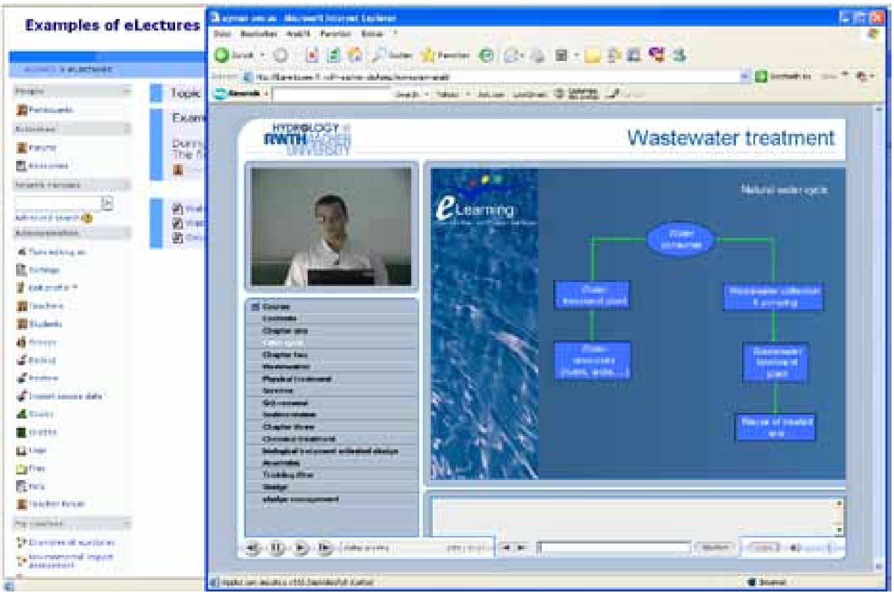

Figure 1 Example of the online trainings offered by the ESD-VE

The ESD-VE was used as the official communication and knowledge sharing platform for this project. Special modules are being developed to allow sharing of the training materials and courses online for other groups who were not able to physically participate in the training events. The ESD-VE is developed to enable the involved individuals and organizations to:

- ***Share knowledge and best practices*** by providing the user with background information on the topic, material related to the training modules, relevant publications, guidelines for ESD and SCP, additional relevant materials and information on the next phases of *EduCamp*.
- **Receive *online training*** on specific topics through online lectures and video conferencing.
- ***Communicate online*** through discussion forums and other social communication channels.
- **Access *different projects' activities and plans*** which provides the user with information on current and future activities.

The Way Forward

In the next phase of the project, the kits will be translated to Arabic. The TOT programme will be developed further by organizing trainings in Austria, Germany, Ireland and Portugal. After the first round ends in May 2013, the trainers will be offering the same training programme to the Egyptian teachers by the second half of 2013. Each centre will work with at least 30 local schools. The centres will establish a network of ESD centres which will apply for acknowledgement from the United Nations University to be acknowledged as new regional centres of expertise in Egypt.

EduCamp comes at a very critical phase of Egyptian history and amidst a turbulent political situation. However, the project is recognized as one of the most significant initiatives to improve the Egyptian education system and link school curricula to the country's sustainable development, consumption and production.

Acknowledgement

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16

Teaching Genes to School Children and Farmers

Mittur N. Jagadish

Introduction

In the last several years, urban India has played a major role in the country's trillion dollar economy and helped raise GDP growth to around 8%. The urban cities are home to many successful multinational companies of Indian origin and several individuals who are amongst the richest people in the world.

On the other hand, the harsh conditions of rural life in India are driving a high number of farmers and labour workforce to emigrate to nearby (already highly polluted) towns and cities. There are significant infrastructure difficulties, such as unreliable water and electricity supplies. Many villages do not get more than a few hours of electricity a day, which is required to pump water from wells for use in irrigation. The power supply is so unreliable that many farmers get up in the middle of the night to pump water, even if it is just for an hour or two.

Despite the cleaner air of the rural areas, people are settling in towns and cities, in search of more reliable income, better access to schools and amenities for their children and a better life for their families. This results in a double pronged attack. The first is increasingly crowded towns and cities and continuous deterioration of urban life. But more importantly, it is causing a drastic reduction in agricultural productivity and animal welfare, which are fundamental for food, feed and fibre security in India.

The population of farmers with the skills required for agriculture is continuously thinning. By and large, farmers' children are not so keen on village life anymore. The challenge lies in reversing this trend and making the villages attractive enough for people to stay, and attract people back from the towns to contribute to rural welfare and uplift.

To be successful in doing this our focus needs to be on creating a better ecosystem in the rural sector. That is, ensure that rural folks lead their lives with the trust and confidence of reliable access to food, healthcare, education and regular income. This requires investment of ideas, skills, money and time into better agriculture technologies and practices, infrastructure development, healthcare and child education.

While governments are continuously establishing numerous schemes to meet various challenges, it is never sufficient or swift enough. They continue to provide enormous rural subsidies and waive loans almost every year to rescue farmers but this cannot be sustainable in the long term. The majority of farmers are being reduced to a very weak and slothful position in society, annually seeking handouts and easy escapes.

For this trend to change towards creating confidence and self-reliance amongst rural folks, everyone needs to pitch in various ways in a collective or an individual manner. There are technologies available to make rural life less stressful. Sharing knowledge and information of technologies such as energy generation from natural sources, biotechnology, organic farming, improved agronomic practices, and effective water and soil management, can help farmers make their own decisions. Finally, scientists must develop ways to decipher the advantages and disadvantages of all scientific and technological developments at an early stage.

Genes in biotech crops

This scientific and technological development includes identification of beneficial genes from nature and utilization of such genes in crops to overcome challenges in agriculture. The challenges frequently faced by the farmers include pest and disease attack, labour unavailability, drought, salinity and fertilizer usage.

For example, one biotech crop, namely *Bt* cotton, is developed to control certain types of pests and has been enormously successful in India for over 10 years (James 2010, Manjunath 2011). On the other hand, *Bt* Brinjal which has also been developed using similar genes, source and methods (Bhagirath Choudhary 2008; Bhagirath Choudhary and Kadambini Gaur 2009), continue to wait for government approval. Due to opposition raised by anti-GM lobby group with non-scientific reasoning, many state governments are not permitting to even have field trials of scientifically and carefully developed crops (Kameshwara Rao, 2010, 2011; Priyanka Golikeri 2012).

Biotech crops undergo several years of development, performance assessment and environmental safety tests. *Bt* Brinjal has the capacity to reduce insecticide use by 77% – making it environmentally friendly – and increase yield by 116% over other hybrids and 166% over open pollinated varieties. This could result in a net income increase of about Rs. 7000 (US$129) per acre for the farmer (James 2010, ISAAA).

Herbicide tolerant cotton and corn varieties developed by industry are in the pipeline for regulatory approvals and when cleared will save an enormous amount of labour time and hardship in villages. GM cereal crops (such as maize, sorghum and rice), vegetables (such as cabbage, cauliflower, okra, and tomato) and legumes (groundnut, pigeon Pea) are in the pipeline awaiting approvals to undergo trials or for cultivation (IGMORIS, ISAAA websites). Yet it is not clear when the moratorium on *Bt* Brinjal is going to be lifted and approvals for conducting trials on various other biotech crops will be given (Priyanka Golikeri 2012).

Delays in introduction of new technologies that have been tested, proven and put into practice for over 15 years elsewhere will only strengthen traditional agriculture in the good cultivable soils of India. This means farmers will miss out on the cultivation of plant species that are virtually labour free, require less fertilizer and are somewhat disease free and drought tolerant.

On the other hand, an appropriate blend of new technologies (Shashidhar, HE 2008, Jones 2011, Bruce 2012) and good agricultural practices offers tremendous advantages to India's goal of becoming a major food basket for the world (Jagadish, MN 2012). India has the potential to proudly contribute towards cutting poverty by half by 2015 – a major Millennium Development Goal.

Ironically, many infrared or electromagnetic field radiation emitting electronic technologies such as cell phones and laptops; non-biodegradable materials such as plastic and electronic goods; chemical inventions such as pesticides and drugs seem to be readily accepted by society, while biotech crops developed in a more stringent manner to provide long term benefits to the rural sector are not.

Indian teens' potential in a village high school

Carrying the richness of a pioneering civilization for thousands of years, India is today seen by many as a very "young" country. The term "young" here applies to the large number of youth we are fortunate to have in contrast to many developed nations being termed as "aging". The core strength of India rests in the villages and in the untapped potential of millions of children.

Schools, specifically in villages, provide great opportunities to initiate an appreciation of science and technology amongst children and their parents or guardians, a majority of whom are engaged in farming and labour. However, a sound infrastructure and a serene environment need to be there to effectively engage children, staff and rural folks in a bi-directional conversation. Such efforts are being put in a village for transformation and the centre for this change is the local high school. The real game changers in this endeavour would be the youth.

In an environment that allows teens to expand their talents and inner strengths, combined with new skills taught and hard work, the sky is the limit to what they can contribute to the present and future of India. High schools are great entities to identify and nurture talent. In our efforts, the hub for development and transformation is the modest SKRS High School, which has a teaching staff of eight members and ~125 students coming from 12 villages.

The school is located in Mittur village in the Kolar District, Karnataka State in southwest India. It is a state government-aided school with basic support from the state in the form of provision of staff, midday meals and bicycles. The building and its associated infrastructure is maintained by the village folk. The SKRS High School enrols children graduating from primary and middle schools in Mittur and other surrounding villages, providing an opportunity for continuous education for all children in the region.

Driven by the potential of networking, and recognizing gaps that exist between urban and rural living conditions, many like-minded volunteers from Bangalore and other cities with various complementary skills started heading to SKRS High School. They set up various activities that can tap into the teens' potential for positive growth.

Figure 1 Workshop on MAPs (Medicinal and Aromatic plants) and an awareness session on plant tissue culture.

This has begun to create a more vibrant environment in the school and, in turn, the village of Mittur and the surrounding region. The ultimate measure of success lies in reverse migration – stopping and reversing the flow of people from the rural towns to urban areas.

This is critical if the agriculture sector in India is to feed the country's burgeoning population, expected to exceed 1.5 billion by 2030. This will come with its own set of challenges, and understanding the concepts of new technologies, their appropriate usage and innovative ideas for further development will be essential to face them.

When we started looking at how to develop SKRS High School, we knew we must take a student-focused approach. We needed to focus on the overall development of youth which encompasses a balanced integration of quality education, health and hygiene, creativity and leadership attributes.

Figure 2 SKRS High School in Mittur and its environment for learning and sharing.

To create a better ecosystem for learning and sharing, we needed a holistic approach to all these issues:

Civil infrastructure

- Maintenance of the school building (built in stone for longevity) and infrastructure, including procuring the surrounding land from village donors;
- Building of a long lasting stone fencing around the school to provide safety, security, and privacy;
- Construction of a shelter in the school for prayers and assembly;
- Continuous upgrading to provide full access to wheelchair users;
- Building of a multi-purpose hall to serve as a kitchen, store room and dining hall.

Health and hygiene

- Access to free monthly dental and eye clinical services by expert doctors from Bangalore, complementing the state primary healthcare centre facility;
- Health check-up for girls and boys by volunteers that include haemoglobin levels, personal hygiene, sanitation methods and follow up where required in agreement with parents/guardians;
- Involvement of mothers for better awareness-raising;
- Installation of biosand water filtering systems to provide safe drinking water for staff and children. This is now being extended to many households.

Fostering science and technology passion

- Frequent visits by science professionals and scholars, both national and international, who interact with students and staff;
- Started setting up a science park to teach concepts such as the sundial clock and the telescope;
- Creation of a kitchen garden for students and staff to grow vegetables and flowers;
- Provision of a radio and currently working towards providing internet access;
- Conducting a workshop on genes and plant propagation to better understand the beneficial power of genes and new traits in plants and another on medical and aromatic plants.

IT and energy infrastructure

- Provision of a few computers by an IT company and relevant gadgets by well-wishers;
- Installation of alternative energy sources such as solar panels and a bicycle pedal power generator;
- Supply of 28 LED lamps along with batteries to children for (re)charging at school and using at home for studies. This has proven to be highly motivational to attend school;
- Installation of rechargeable (solar or pedal) LED lamps in class rooms for evening classes and general learning;
- Provision of fans, water connections, a solar steam cooker and a peanut roaster.

Waste management:

- Initiation of waste collection, segregation and management plans;
- Provision of garbage collection bins and familiarising the children and staff with waste segregation;
- Installation of green washroom facilities with mechanisms for water and refuse recycling.

Leadership and ownership

- Setting up eight student clubs under the sponsorship of individual teachers and leadership of a student secretary. The focus of the clubs are on:
  - Safety
  - Nature and environment
  - Debate
  - Arts and crafts
  - Singing, dancing and acting
  - Kitchen garden
  - Animal welfare
  - Sports
- Initiation of training sessions on leadership, ownership, accountability and team building.

Conclusion

Introspection will trigger identification and ownership of national and international challenges at the local level, which in turn will certainly generate solutions. In recent years, Mittur as a village is trying to set an example in the Indian district of Kolar in sparking children's interest in technology, new ideas and alternative methods for becoming responsible individuals.

These children will be part of the generation carrying India and the world forward with better understanding of new technologies such as biotechnology, renewable energy and electronic communication. In turn, they will be objective in their understanding of new developments and better positioned to weigh them against the existing challenges, thus assisting in their decision making process.

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17

Meeting an Increasing Global Food Demand

Teunis van Rheenen and Jenna Ferguson

Introduction

In 2011, the world's population reached 7 billion, and it is projected to grow to more than 9 billion by 2050 (UN, 2011). Over the next several decades, this growth, combined with climate change, more frequent natural disasters, and increasingly scarce natural resources could have dire repercussions for food insecure populations.

There are already 900 million undernourished people in the world and more than 2 billion people suffering from micronutrient deficiency (Fan *et al.* 2012). This projected growth in the human population will undoubtedly contribute negatively to the already declining ratio of arable land to human population. On average, arable land declined by roughly 40% between 1960 and 2000.

In developing African nations, however, the decline of arable land during these four decades was more drastic, reaching 55% (Croplife International, 2010). By 2030, nearly 4 billion people are expected to suffer from severe water stress. Additionally, for the first time in history, more people live in urban areas than in rural areas. This coincides with an already steadily declining rural population, which means a further decline in the agricultural workforce (Croplife International 2010).

Moreover, as much of the overall projected population growth will be concentrated in low-income countries, where significant challenges to satisfying basic needs already exist, the production and access to adequate, safe, and nutritious food for all will remain an issue of the highest priority for nations worldwide (Fan et al. 2012).

Food Security Challenges

Food emergencies and crises grab the attention of nations worldwide and are often declared when a cataclysmic event takes place — such as the severe drought that devastated the Horn of Africa in mid-2011. A closer look behind food emergencies, however, reveals a food security status that cannot be attributed to any single event or isolated determinant.

A complex web of factors contributes to food security — or lack thereof — at the local, national, regional, and global level. Elements of the 2007–2008 global food crisis can be seen in the current global food price situation, in which expanding biofuel production and rising oil prices are driving food prices higher (Fan, Torero, and Headey, 2011).

This is a result of several main challenges to global food security: population growth and demographic changes; biofuel expansion and rising energy prices; high and volatile food prices; increasingly limited natural resources; climate change; poverty and undernutrition; and underinvestment in evidence-based, pro-poor policies.

Population growth and demographic changes

Population and income growth will drive food demand in the coming decades. Emerging middle classes in developing countries can afford to consume more fruits and vegetables and, in particular, more meat, which requires much more water and land to produce. Intensifying food production can boost the food security of millions of poor people. However, increasing food production can also contribute to problems such as land degradation, water pollution, depletion of water resources, and new pest problems (Fan et al. 2012).

In addition, as people demand more perishable and processed foods, food safety risks along the supply chain increase. More intensive crop and livestock farming may intensify this risk through contamination with chemicals or pathogens (Chenevix-Trench et al. 2012). Fig. 1 below breaks down the estimated population growth (to more than 9 billion by 2050) by looking at both the percentage of growth by region and the ratios of growth between rural and urban populations.

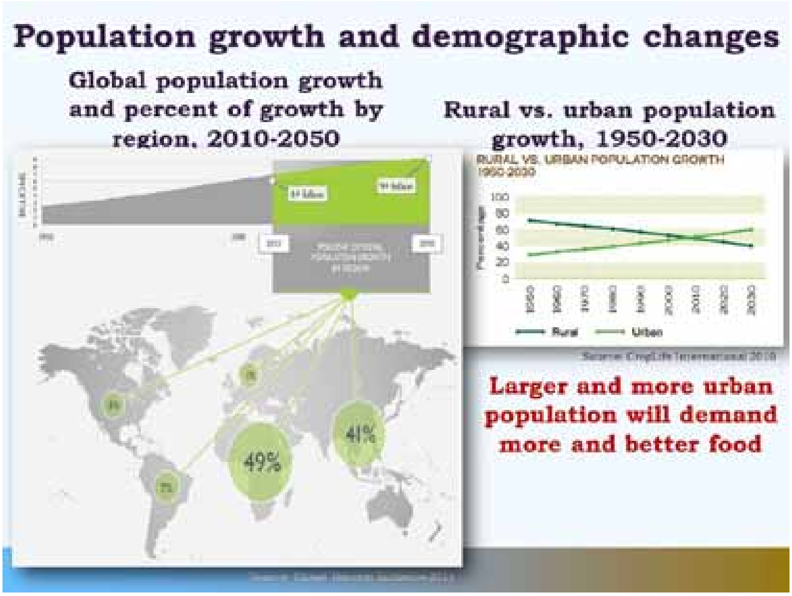

Figure 1 Population growth and demographic changes. Source: Fan 2011.

Biofuel expansion and rising energy prices

Biofuel subsidies and mandates, such as those in place in the United States and the European Union, have shifted farm production toward the cultivation of biofuel crops and resulted in maize crops being increasingly used for ethanol production. Biofuel mandates enacted in other countries, including India and Peru among other emerging economies, are similarly contributing to diversion of agricultural land used for food or feed growth to biofuel production. See fig. 2 for a look at biofuel production trends in Brazil, the US, and the EU, along with some policy recommendations.

This response to an increasing demand for crops for fuel puts new and significant pressures on both agricultural markets and food prices. The first of these pressures is a growing demand for ethanol and biofuels (driven by rising incomes and changes in demographics). Increasingly limited resources (including nutrients, land and water) and temporal restrictions (the time required to increase the production of crops for fuel) also aggravate the problem. Finally, it creates a new and growing link between energy and food markets. What had traditionally been a supply-side only link — electricity

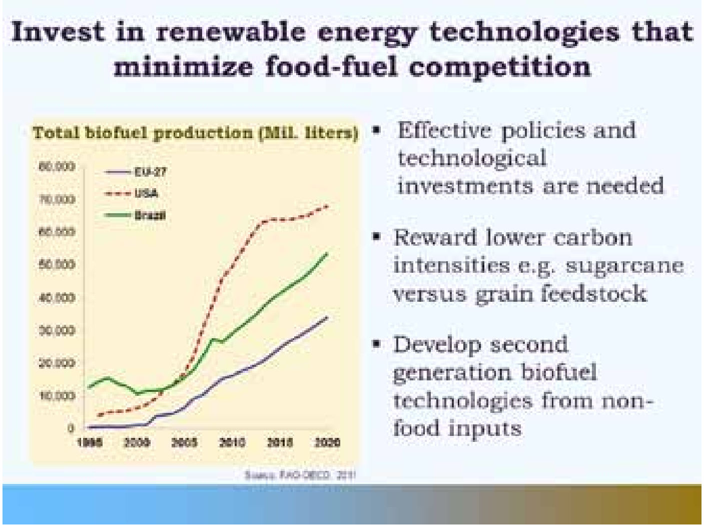

Figure 2 Biofuel production trends and policy recommendations. Source: Fan 2011.

for irrigation systems and petroleum for fertilizer production — is now also an expanding demand-side link. Additionally, demand for ethanol not only contributes to driving down maize stock and driving up maize prices, but also drives up livestock prices (Fan, Torero and Headey, 2011; von Grebmer et al. 2011).

High and volatile food prices

In the developing world, the poorest households spend as much as 60 to 80% of their incomes on food purchases (WFP 2012). Under these conditions, spikes in food prices — particularly in staple foods, such as cereals — have devastating repercussions (Fan, Torero and Headey, 2011).

Excessive price volatility is equally harmful to the world's poorest consumers. The poor have little capacity to cope with excessive food price volatility or rapid price increases. Additionally, poor agricultural producers tend not to fare much better because the periods of rising food prices are usually accompanied by an increase in input costs as well.

These circumstances have the adverse effect of distorting long-term planning and diminishing incentives to invest in resources, technologies and practices that enhance agricultural productivity (Fan, Torero, and Headey, 2011).

Increasingly limited natural resources

Land degradation places acute stress on already limited natural resources. Soil erosion, overgrazing, deforestation, rising salinity and desertification seriously compromise future agricultural productivity. This is especially so in Asia, where arable land is already sparse, and in Latin America and Africa, where the cultivation of land reserves poses its own threat to the environment (Fan et al. 2012).

Food production intensification, such as the Green Revolution, offers an opportunity to improve food security without expanding agricultural areas. However, production intensification practices can have unintended and adverse effects on the environment that include land degradation, water depletion and pollution and new pest problems (Fan et al. 2012).

Currently, it is estimated that approximately 1.3 billion people worldwide inhabit fragile lands that are characterized by low levels of agricultural productivity and present little possibility for agricultural intensification (Fan et al. 2012). Water scarcity further aggravates precarious environmental conditions.

Approximately, one third of the world's population already live in water-scarce areas. By the year 2050, under "business as usual" conditions, water stress will put at risk 52% of the global population, 49% of global grain production, and 45% of global gross domestic product (Veolia Water and IFPRI 2011).

Climate change

Climate change will likely raise local temperatures and increase the frequency of extreme weather events, which places significant stress on farmers with limited capacity to cope. It will increase food prices and contribute to excessive food and fuel price volatility (von Grebmer et al. 2011; Fan et al. 2012).

Extreme weather events and natural disasters such as droughts and floods can have a direct negative impact on agricultural production, resulting in significant yield losses in both the short and long term. As climate change scenarios predict increasing weather variability, the outlook for food prices shows a steadily rising trend (von Grebmer et al. 2011). In fact, simulations conducted by the International Food Policy Research Institute (IFPRI) show that under both optimistic and pessimistic population growth scenarios, food prices are likely to rise on account of climate change (Nelson et al. 2010).

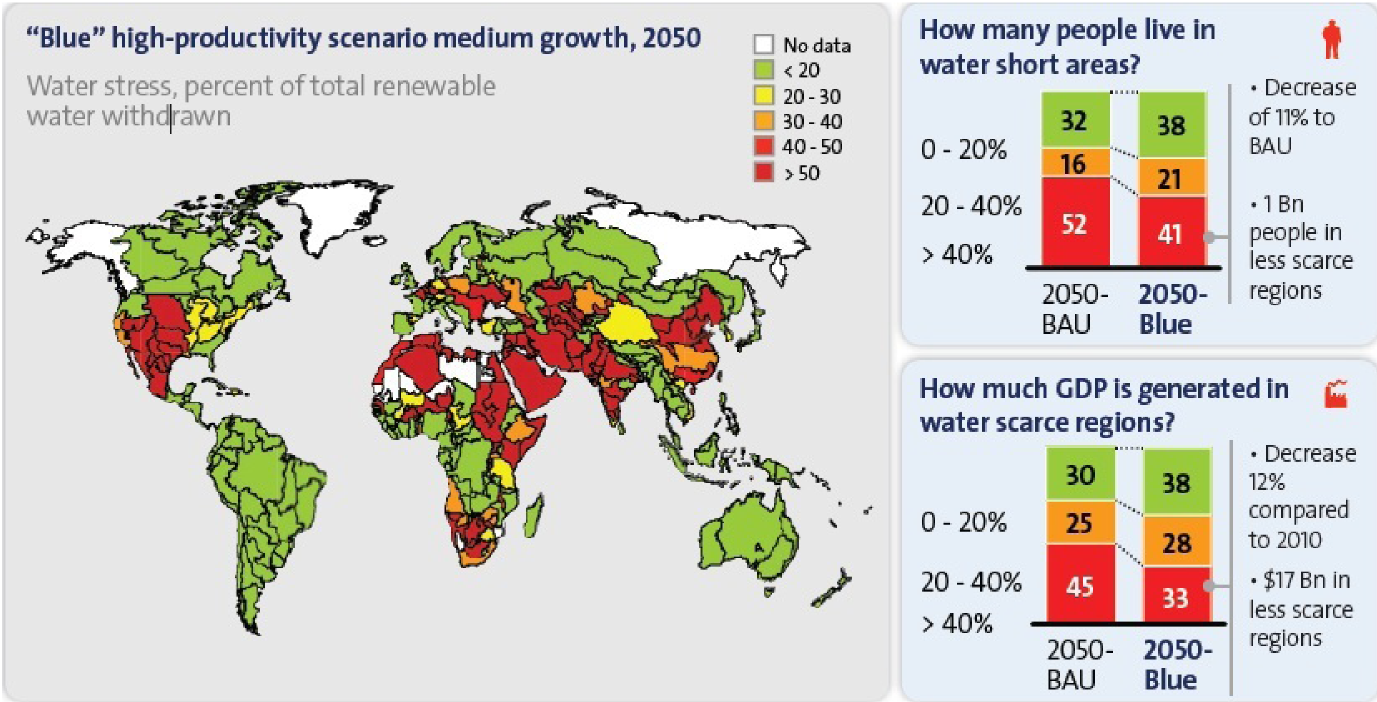

Figure 3 Physical and economic water scarcity. above shows a comparison in the year 2050 between a "business as usual" (BAU) scenario and a "blue world" scenario, which is characterized by high water productivity. Source: Veolia Water and IFPRI 2011.

Poverty and undernutrition

Poverty remains a primary cause of hunger, and the cycle of poverty and hunger is often perpetuated by the effects of undernutrition (Shah, 2012). Undernutrition that occurs during the 1,000-day period between conception and a child's second birthday places children at risk for lifelong impairment that is largely irreversible (Ruel, 2010).

The effects of undernutrition may include poor health, poor physical development (such as stunting, wasting, and underweight), poor cognitive development, and even early death (Ruel, 2010). Undernourished children are likely to become less productive adults who complete fewer years of schooling and earn lower incomes than children who were well-nourished (CEPAL/PMA 2007; Ruel, 2010).

On account of undernutrition, developing countries can experience, on average, a 3% annual loss in gross domestic product, but this could rise to as high as 6% in individual cases (CEPAL/PMA 2007). Additionally, women who were undernourished as children are at increased risk of giving birth to underweight babies, contributing to an undernutrition trap (von Grebmer et al. 2010). Undernutrition, therefore, can have long-term effects not only on individual well-being but on widespread poverty as well.

Underinvestment in evidence-based, pro-poor policies

Growth in the agriculture sector promotes overall economic growth and effectively reduces poverty more than growth in other sectors of the economy (Pratt and Diao, 2008). Smallholder farmers dominate the agriculture sector. Without appropriate policy investments, these farmers risk remaining without adequate access to agricultural inputs, markets, credit, and basic infrastructure and services (Ahmed et al. 2007; Fan, Torero, and Headey, 2011).

Poor smallholder farmers also tend to live and farm in adverse ecological zones. Thus, effective national agriculture research and weather-based crop insurance policies are crucial for improving smallholders' well-being and food and nutrition security (Fan, Torero, and Headey, 2011).

How to Respond

The factors listed above demonstrate the urgent need to develop a comprehensive approach to strengthen global food and nutrition security while protecting natural resources. Such an approach requires integrating multi-sector policy responses designed to meet the diverse range of dynamic, interactive, and, in some cases, entrenched food security challenges.

These policy responses must address the drivers of food price volatility and food and fuel price increases and the effects of climate change, while demonstrating a commitment to improve the livelihoods and health of the world's poorest and undernourished. Table 1 lists some examples of initiatives and reforms that, if given proper prioritization and funding, could set a course toward greater global food security.

Table 1 Examples of food security policy responses

Food price increases and volatility	• Revise biofuel policies. • Develop biofuel technologies from non-food sources. • Regulate financial activities in food markets. • Share information on food markets. • Build up food reserves. • Implement a global emergency physical grain reserve.
Climate change and the environment	• Enforce strict climate change and greenhouse gas regulations. • Enforce practices for the sustainable management of natural resources.
Pro-poor agricultural growth	• Invest in sustainable small-scale agriculture. • Invest in rural infrastructure. • Invest in microfinance schemes.
Social protection	• Improve emergency preparedness. • Strengthen the provision of basic services, such as education, healthcare and sanitation. • Promote social protection through better-targeted, cross-sector safety net programmes. • Scale up successful health and nutrition interventions.

Source: Fan, Torero, and Headey 2011; von Grebmer et al. 2011.

Conclusion

The adoption of nexus thinking (an approach based on the interconnections between disciplines and sectors), investment in multidisciplinary research, and implementation of integrated systems approaches are essential for tackling increasingly complex and inter-connected food and nutrition security challenges on a global scale.

Problems of food and nutrition security are longstanding, which now, as we approach the Millennium Development Goals deadline of 2015, urgently require new solutions that make the best of the links among sectors, disciplines, services, and institutions. For any amount of progress to be made, it needs to take place simultaneously within markets, institutions, agriculture, nutrition, health, the economy, sustainable development and climate change adaptation and mitigation strategies.

Recent trends in agricultural research programmes, social protection schemes, and health interventions demonstrate a significant shift toward more integrated approaches to human development. This trend will likely set a new course of doing business in developing communities worldwide.

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18

The Global March of "Conservation Agri-Culture"

Amir Kassam

Introduction

In ancient times, agriculture was recognized as being made up of two parts. 'Agri' related to the field environment (the natural resource base) and 'culture' related to the way it was managed for production and taken care of (Pretty, 2002). By this we mean the social and cultural values that informed social institutions to organize and support action by producers and the community.

Values that informed behaviour and social institutions were conditioned by the knowledge that existed then as derived and formulated through experiential processes and from observation, experimentation, logic and philosophical inquiry. The culture part embodied the knowledge, values and social norms that enabled production to be practiced along the lines considered to be the most acceptable or appropriate politically, socially, economically and environmentally for the individual land owners, producers and the community.

The knowledge system and the commercial and political elites of various blends, including the religious ones that existed then, determined, as they do today, the productive capacity of agricultural land and what could be produced and how much. Sustainability was a desired objective, but one rarely achieved because what constituted ecological sustainability in production systems was not fully understood and therefore not integrated into production systems.

Agriculture as it was then practiced was under constant threat from land degradation and loss of productive capacity. The root cause of this has been mechanical tillage with hand hoe and spade, animal-drawn 'ards' and chisel ploughs, disc harrows/ploughs or mouldboard ploughs. They all destroy soil structure and porosity, pulverize the top soil layer and reduce soil organic matter. They also cause top soil erosion and disrupts soil biodiversity and food webs.

Communities that did not practice tillage, protected the soil and its biological health with mulch cover and manure and had a diversified production system with crop rotations achieved sustainability of production. A good example is Peru's Colca Valley, where the farmers have cultivated the pre-Inca stepped terraces for more than 15 centuries.

According to David Montgomery (2007), "The cultivated Peruvian soils are full of earthworms and have higher concentrations of carbon, nitrogen, and phosphorus than native soils. …under traditional soil management these Peruvian soils have fed people for more than fifteen hundred years".

In contrast, the notion of ecological sustainability and resilience has not been adequately pursued and integrated as an imperative into production systems management at the practical level. Today, over 90% of cropped agricultural land uses tillage as the basis of soil preparation for crop establishment. It has become increasingly intensive since the introduction of the mouldboard plough in the 1930's and eventually contributed to the creation of dust bawls in Midwest USA, Australia, Russia and Central Asia.

The machinery companies, along with agrochemical and seed companies, have promoted their products on an assumed premise that modern farming equated solely with intensive tillage and the use of high levels of agrochemicals to 'feed and protect' the crops. They pushed for the use of new seeds that are responsive to mineral fertilizers and grown within a fixed agronomy and crop management that insisted on high seeds rates and plant densities.

Conservation agriculture

People educated in the global North have been taught that this form of agriculture is what world agriculture must adopt everywhere to ensure food security. The agriculture development community, particularly industrialised country donors and the scientific institutions they support, has been promoting it in the global South as the only way forward.

The paradigm philosophy built around this assertive consensus is based on the socio-economic assumptions that the private sector will be the provider of the inputs that will raise and maintain agricultural productivity. Any agriculture development initiative must accept this as the model for raising productivity and incomes, and enhancing the corporate and business sector to provide the supply chain and market services for agricultural products.

There have been some exceptions to this paradigm of tillage-based agricultural development, such as Arnold Faulkner, who wrote the book Ploughman's Folly in 1943, and Masanobu Fukuoka who wrote the book One Straw Revolution. There are also many pioneer farmers in the USA in the 1930's and 1940's, and others in Brazil and elsewhere in Latin America in the 1970's who switched to no-till farming as a means to control erosion and land degradation.

Ploughman's Folly was an important milestone in the development of conservation agricultural practices. Faulkner questioned the wisdom of ploughing and explained the destructive nature of soil tillage, stating that "no one has ever advanced a scientific reason for ploughing."

Further research in the UK, USA and elsewhere during the late-1940's and 1950's made no-tillage farming possible, and the practice began to spread in the USA in the 1960's. It then spread to Brazil, Argentina and Paraguay in the 1970's. In 1973, Shirley Phillips and Harry Young published the book No-tillage Farming, the first of its kind in the world, and this was followed in 1984 by the book No-Tillage Agriculture: Principles and Practices by E.R. Phillips and S.H. Phillips.

The modern successor of no-till farming — now generally known as conservation agriculture (CA) — goes much further. It involves the simultaneous application of three practical principles based on locally-formulated practices which have to coincide in time and space and have to be applied permanently to develop synergies (Friedrich et al., 2009; Kassam et al., 2009):

1. Minimum mechanical soil disturbance; this translates into the practice of low disturbance no-tillage and the respective low disturbance direct seeding. Soil disturbance in all operations has to be avoided as much as possible, allowed only in very specific conditions where it does not exceed 25 % of the soil surface and not wider than 15 cm in bands.
2. Maintenance of a permanent organic soil cover; this comes in the form of mulch from crop residues, other organic mulch materials or living crops, including cover crops. The level of soil cover should ideally be 100% of the soil surface, but never less than 30% and should always supply sufficient organic carbon to maintain and enhance soil organic matter levels.

3. Diversification of crop species grown in sequences and/or associations; this refers to rotations and sequences of annual crops, mixed-, inter- or relay-cropping, cover crops in perennial orchards or plantation crops, including legumes for their nitrogen effect.

The individual CA principles have been practiced by farmers in different places for a long time (Derpsch, 2004; Montgomery, 2007). What is unique about the modern concept of CA is the conjunction of all three principles that are applied simultaneously through locally-devised and tested practices. For production intensification, these core CA practices need to be strengthened by additional best management practices:

1. The use of well-adapted high quality seeds;
2. Enhanced and balanced crop nutrition, based on and in support of healthy soils;
3. Integrated management of pests, diseases and weeds;
4. Efficient water management.

Thus, CA, in conjunction with good crop, nutrient, weed and water management, is at the heart of FAO's new agricultural intensification strategy (FAO, 2011).

CA is an example of a set of agro-ecological innovations that emerged more from the farming community rather than from the scientific community. CA requires the social engagement of the rural producers in translating its principles into practice for harnessing its increased productivity and its, social, economic and environmental benefits.

Farmers the world over depend on natural resources that make agriculture possible. That is why they are opposed — culturally and instinctively — to the exhaustive exploitation of the land, the waste of water or the destruction of forests. From a social anthropological viewpoint, CA challenges the acceptance of the genocentric interventionist tillage paradigm with its heavy agrochemical input as being the norm and a base upon which to build sustainability and alleviate poverty of smallholder farmers.

Underpinning ecological sustainability

There is a deeper and more worrying flaw in most of our so called modern research, education and development institutions. This is the unquestioning faith in the technological paradigm, including the ecological and socio-economic assumptions that put market and business interests before public and environmental interest.

Worse still, most of those in the education, research and private sector who are involved in promoting this modern technological paradigm of agriculture do not even have basic understanding of the root cause of degradation of agricultural land. The current mainstream production paradigm is based on an interventionist tillage approach that promotes the belief that agro-ecosystems can only be exploited through the use of intensive tillage, genetically enhanced modern cultivars and agrochemicals with standardized or fixed crop management.

The alternative paradigm is based on an 'agro-ecological' approach which promotes harnessing desired output and productivity as well as other ecosystem services needed by society and producers. CA is a successful example of an agro-ecological production paradigm which is increasingly replacing the old interventionist tillage-based paradigm.

The agro-ecological approach is opposite in concept and principles to the interventionist modern farming approach which is practiced with:

1. Intensive high disturbance mechanical soil tillage;
2. A soil system that is constantly forced to function in a biologically sub-optimal condition due to low organic matter, compaction and erosion;
3. A soil surface that is left bare and exposed to weather elements;
4. Normal soil-mediated ecosystem functions disrupted or destroyed;
5. Mono-cropping or a cropping system that does not promote crop diversity or biodiversity in general;
6. Standardized crop management based on excessive inputs of derived agro-chemicals.

This interventionist approach is now known to constitute an efficient recipe for ecosystem ill-health, death and destruction, where land becomes disconnected from the environmental services it must provide to society and loses its productive capacity.

In his well-researched book *Agri-Culture: Reconnecting People, Land and Nature*, Jules Pretty states that "the Roman agricultural writers such as Cato, Varro and Columella spoke of agriculture as two things: *agri* and *cultura* (the fields and the culture). It is only very recently that we have filleted out the culture and replaced it with commodity."

In the preface, Pretty states that "our old thinking has failed the rest of nature, and is in danger of failing us again. Could we help to make a difference if we changed the way we think and act? The time has come for this next agricultural revolution."

In *Dirt: the erosion of civilizations*, David Montgomery tells how humankind over the millennia has been degrading the soil resource base, at a rate faster than it can be replenished, through tillage-based agriculture. Despite technological and scientific advances, ecological sustainability has generally eluded humankind over much of its agricultural landscape, in the North and in the South (Montgomery, 2007).

Much of the world agriculture is continuing along the trajectory described by Montgomery. Since WWII, however, high disturbance interventionist agriculture has reached a point where tillage-based agriculture is not able to sustain crop and land productivity under high or low inputs. Tillage agriculture as generally practiced internationally is inherently incapable of delivering key ecosystem services that are needed by society even with the most modern agricultural technologies and production inputs.

Furthermore, our intensive-tillage paradigm does not allow agricultural land to recuperate and self-repair under use, nor to respond adequately to global challenges posed by poverty, climate change, increased food and energy prices and water scarcity. Worst still, the current mainstream production paradigm discriminates against the resource poor smallholder farmers whose welfare is of core concern to the development-assistance community. Instead, it generates negative externalities whose economic, social and environmental costs are borne by the society.

Some experts have described the 1980's as the lost decade for development because of the financial crisis. Others consider it the time when the development-assistance community was reminded of the ineffective top down approaches to development and the imperial culture that had been dominating much of the mainstream development efforts.

For example, the works of Robert Chambers *Putting the Last First* and Michael Cernea's *Putting People First* served as loud wake up calls to development-assistance stakeholders regarding their 'us and them' linear strategies, often formulated without any input from the potential beneficiaries and therefore devoid of any analysis of the socio-cultural needs and impacts of their proposed interventions. This was like "putting the cart before the horse", or even worse "putting the horse on the cart".

Global spread of CA

CA is a prime example of the agro-ecological paradigm for sustainable production intensification now adopted by FAO as seen in *Save and Grow* (FAO, 2011). Empirical evidence shows that farmer-led transformation of agricultural production systems based on CA is gathering momentum globally.

The minimum mechanical soil disturbance, organic soil cover, and crop species diversification, which are hallmarks of CA, are now estimated to be practiced globally on about 125 million hectares (some 9% of global arable cropland) across all continents (Table 1) and all agricultural ecologies. Some 50% of this land is located in the developing world. During the last decade, cropland under CA has been increasing yearly at a rate of about 7 million hectares, mainly in the Americas, Australia, and, more recently, in Asia and Africa (Friedrich et al., 2012).

Table 1 Area under CA by continent (www.fao.org/ag/ca)

Continent	Area (hectare)	Percent of World Total
South America	55,464,100	45
North America	39,981,000	32
Australia & New Zealand	17,162,000	14
Asia	4,723,000	4
Russia & Ukraine	5,100,000	3
Europe	1,351,900	1
Africa	1,012,840	1
World total	124,794,840	100

For the farmers, the initial drivers for adoption of CA are mostly erosion or drought problems, as well as economic pressure. However, drivers of change that are valid for large-scale farmers are different from small-scale ones. Water erosion has been the main driver in Brazil, wind erosion and cost of production in the Canadian and American Prairies and drought and economic issues in Australia and Kazakhstan.

More recently, concerns about the economic and environmental unsustainability of traditional approaches to agriculture internationally, including small-scale farming in Africa and Asia, has stimulated governments to seriously consider CA. Under these principles, both small- and large-scale farmers in most agro-ecologies can raise productivity and harness environmental services, avoid and recuperate from land degradation and respond to climate change.

In all above cases, farmers' organizations were the main instrument to generate and spread the knowledge that eventually led to mobilising public, private and civil sector support. More recently, the pressure from erosion and drought problems, along with the increasing costs of energy and production, has garnered government support to accelerate the adoption of CA. This led to the relatively fast adoption rates in Kazakhstan and China, as well as several African countries like Zambia and Zimbabwe.

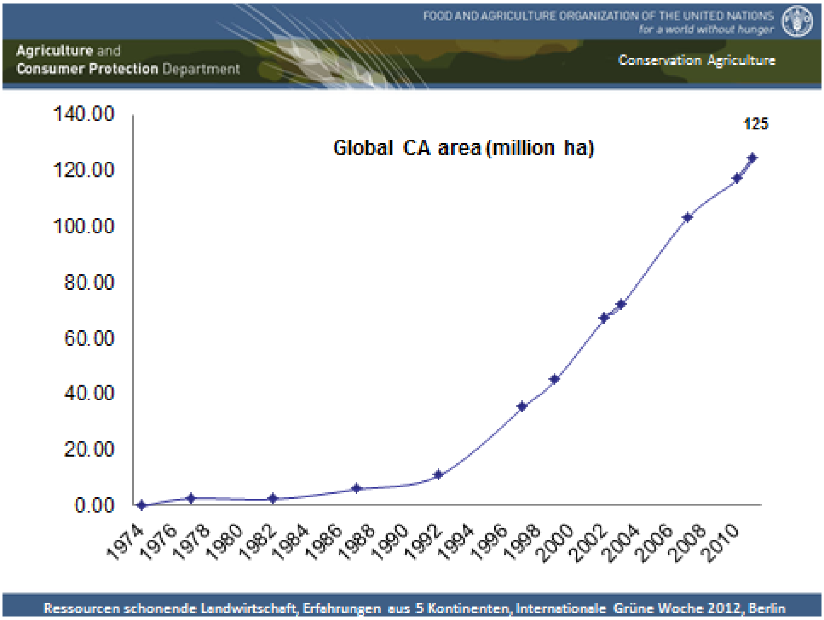

Figure 1 The global spread of Conservation Agriculture

Experience and empirical evidence across many countries show that the rapid adoption and spread of CA requires a change in commitment and behaviour of all concerned stakeholders. For the farmers, a mechanism to experiment, learn and adapt is a prerequisite. Policymakers need to fully understand the large and long term economic, social and environmental benefits to producers and society. Further, the transformation calls for policies that provide incentives and required services to farmers to adopt CA practices and improve them over time.

Conclusion

The world now needs to accelerate the spread of CA as a mainstream production approach. The quickest and most efficient way to do this is to 'put farmers first' so that they can devise locally-adapted CA practices. Public and private sector institutions should support them with the policies needed to facilitate their work.

This is already happening in countries such as Brazil, Argentina, Paraguay, Canada, USA, Australia, New Zealand, Kazakhstan, India, China, South Africa, Zambia and Zimbabwe. CA cannot be delivered as a reductive technology, but rather as a set of locally-devised practices applied simultaneously to the agro-ecosystem as a whole and socio-culturally underpinned by the farmers' innovative skills.

There is a huge opportunity for the private sector to engage in this transformative process. However, it must not engage with preconceived notions of what production inputs the farmers must have, but rather what inputs will permit the mainstreaming of CA and its benefits to farmers and society.

Today, we have more reasons than ever to drive the needed paradigm change in agriculture socially. This applies to the developing world as well as the industrialised world. Social research for sustainable production intensification and for environmental stewardship is a reality, and must become a greater force of good for all mankind. Otherwise, we will continue to impose unnecessary hardship on the less fortunate people because our global economic system is incorrectly designed, leaving 1.5 billion people around the world hungry.

However, the current knowledge and innovation system is serving the dominant tillage-based and out-of-date Green Revolution production systems. The shift to replace the old interventionist approaches with the alternate agro-ecological paradigm will require, as the Romanian social scientist Michael Cernea urged in an interview, "people who have not only brains but who can fight, people who have not only knowledge but also have conviction, and people whose anthropological knowledge is accompanied by a moral dimension."

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19

Access to Food, Access to Life: Food Security and Bio-economy

Joachim von Braun

The root of food insecurity

Food security — the availability of and access to sufficient and healthy foods and good nutrition — is central to the well-being of nations and people. Food insecurity has increased during the inter-linked food and economic crises of 2007–2008, and again in 2011-2012.

The food crisis actually overlapped with the onset of the economic recession, and may have had some role in its onset due to the inflationary forces of food and energy prices to which macro policies reacted.

The food prices crisis is the consequence of neglected investment in agriculture in many developing countries and inappropriate agriculture energy subsidisation policies in industrialised countries. It was finally triggered by adverse weather events and exasperated further by export restrictions (von Braun 2008).

Volatile food prices continue to undermine the food and nutrition security of the poor. With the extreme price increases for wheat and maize in 2010–2011, we were observing the continued volatility in the global markets. Low levels of grain stocks trigger speculative demand for grain as a commodity asset category, further driving volatility upwards.

The food crisis had large economic ripple effects. In 2010–2011, the inflation of food and energy prices had become a worldwide macro-economic threat, especially in Asia. It accounted for more than 60 to 70% of total inflation in many countries. Another adverse economic ripple effect of the crisis is loss of trust in trade and the re-emergence of self-sufficiency policies in many nations, which means benefits from trade are foregone, and externalising domestic fluctuations in supplies are further increasing volatilities in international markets.

The expansion of biofuel production in the past decade has indisputably created new linkages, trade-offs and competition. It has also introduced new food security risks and challenges for the poor. Indeed, rising demand of biofuel feedstock has introduced a fundamental change in world food price determination.

The amount of grains diverted to ethanol production has more than tripled from 2004 to 2008 and this became one cause of the food crisis. Biofuels promotion and subsidy policies need to take food security consequences into account. When food prices are high, such subsidies for biofuel production should be frozen, reduced, or subjected to a moratorium on biofuels from grains and oilseeds until prices come down.

Second generation biofuel technologies are in the making, but may be a long time away from becoming reality. If they are "smart," these technologies may partly overcome the food-fuel competition and lessen the negative effects on the poor. But trying to counter institutional failures, such as excessive subsidy policies for biofuels, with mainly investments in technical domains will not work.

Food and agriculture increasingly embedded in the bio-economy

Food security partly depends on availability of food. However, such availability of food, which is part of biomass production, is determined increasingly by new competitive uses of biomass for energy and industrial raw materials. Producing more food for food security is confronted with new challenges. Agriculture and the food economy become part of the larger bio-economy.

This puts biomass and the bio-economy — the emerging sector that produces, transforms, and uses biomass — at the centre of sustainable economic development and any green growth strategy — one that focuses on efficient resource management while protecting the environment and appropriately valuing ecosystems services.

Langeveld et al. (2010) define a bio-based economy as the "technological development that leads to a significant replacement of fossil fuels by biomass in the production of pharmaceuticals, chemicals, materials, transportation fuels, electricity and heat." Bio-economy is the aggregate of all industrial and economic sectors and their associated services which produce, process or in any way use biological resources (plants, animals or microorganisms). It entails biomass based and non-biomass based (e.g. produced by industrial biotechnology) organic materials.

Defined as such, bio-economy is a large cluster of economic sectors, often the largest — even in some industrial economies — in terms of GDP and employment. New technologies thread their way into all of the above sectors and their value chains to different degrees. The largest sector of the bio-economy, in terms of total output, employment, etc, is typically the food and feed production and processing sectors. World food consumption is demanding more products that are rather biomass intensive, such as animal products. A comprehensive integration of animal production into efficient value chains is an essential part of the bio-economy.

Achieving sustainable development in a green growth strategy will have to rely on alternative sustainable sources of energy and raw materials, mostly away from fossil fuels. Biomass is likely to play a key role in this context. The challenge will be to frame this reliance on biomass without undermining the long term productivity of agriculture and ecosystems. Addressing this challenge will require a systemic approach identifying:

- The consequences of substituting the consumption of finite resources by the use of biomass and other renewable resources;
- The needs to move towards production systems that prevent waste, relying more on recycling, more efficient use of limited resources and increased use of renewable resources.

The fast growth in the world biofuel production is indicative of bio-economy in the making. This particular sector, however, has so far not dealt with its negative externalities. Science innovations might change that, however, and possibly even in the foreseeable future. In low income countries the challenge is different. For instance in Ethiopia, biomass is still by far the dominant energy source, providing about 80% of primary energy. Here, the challenge is to make better use of biomass with new technologies — in other words, leapfrogging into a knowledge-based bio-economy.

Climate change looms in the background (Nelson et al. 2010), and provides powerful incentives for investment in the bio-economy in three ways. First, there is a current need to establish a different energy base, which will include biomass. Secondly, it threatens a future of declining crop productivity and rife with production risks. Finally, emerging greenhouse gas (GHG) mitigation markets or related taxation policies are increasing the incentives for biomass production for GHG sequestration.

The new value chain paradigm of knowledge-based bio-economy is much more a system rather than a chain. For the bio-economy to make significant progress, there needs to be increased efficiency in the whole system by actually transforming interlinked biomass value chains into biomass "value webs". Until now, the technological options have for the most part been pursued in a traditional manner of isolation, by individual inputs and production areas such as animals or plants.

Sustainable and fair use of land and soil

The increased food prices have increased commercial pressure on land and implicitly on water resources for agriculture. It is therefore not surprising that farmland prices have risen throughout the world in recent years. The amount of land that is presently used for agricultural purposes cannot be substantially increased, as either cultivation makes no economic sense due to low potential yields, or expansion would negatively impact the environment and climate.

The preferred way of increasing productivity is, therefore, to intensify farming sustainably on the land that is already used for agriculture. There must also be further advances in crop varieties by breeding techniques.

We must note that soil is a non-renewable resource at risk of depletion despite having high relevance for food security and development. We need a "net-zero degradation" goal. Appropriate instruments and policies need to aim for that efficiently and effectively.

This calls for attention to the economics of degradation issues. Land not only has a market value, but there are non-market values to consider, such as ecosystems services and water systems. Policy must address both of these values, including land rights aspects, to foster sustainable and well functioning land use systems that protect soils.

Viewed globally, soil may be one of the most important terrestrial resources for carbon storage (Lal et al. 2012). Research should focus on maintaining or improving the quantity and quality of productive soils. To achieve this, new national and international concepts of land use need to be devised. By means of innovative research approaches to locally adapted crop cultivation, which include an economic analysis, alternative farming scenarios must be developed which allow priorities to be set for land use.

Strong demand for biomass has become an international issue, reflected by the rapid expansion of foreign direct investment in land acquisition, especially in Africa, to grow food and biofuels to secure supply. An unregulated market, in which power rather than efficiency and rules often guide transactions, needs more policy attention. Otherwise the poor and powerless will suffer from these developments.

The emerging market for biomass from land and forests and its underpinnings needs sound institutional arrangements and codes of conduct. While the global expansion of land markets is mostly driven by domestic players, there is also growing transnational acquisition of land by financially strong investors. Some of these act directly or indirectly on behalf of nations that attempt thereby to improve their food security in view of domestic scarcity of land and water (von Braun & Meinzen-Dick 2009).

Key elements of a code of conduct for foreign land acquisition should include respect for existing land rights, including customary and communal rights. Those who lose land should be compensated. Sound and sustainable agricultural production practices should guard against depletion of soils, loss of critical biodiversity and significant diversion of water from other human and environmental uses.

When national food security is at risk (for instance, in case of an acute drought), domestic supplies should be given priority. Foreign investors should not have the right to export during an acute national food crisis. An enforceable code of conduct, not just some voluntary guidelines, is needed to protect the local poor and create a climate conducive to investment in this critical area. Foreign direct investment in agriculture is an opportunity, but it must not marginalise the poor or add environmental damage.

Pragmatic approaches for assessing economics of land and soil degradation should start with easy-to-understand productivity losses and related market value losses, while also factoring on-side and off-side effects of degradation. Raised awareness about costs of inaction against land and soil degradation is needed for a comprehensive food security strategy in a bio-economy context.

Science for food security in a bio-economy context

Science has made a tremendous contribution to the quality and quantity of food in the 20th century. Technological breakthroughs, and their adoption on a large scale, have had high positive social pay-offs. They have been a critical component in preventing Malthusian predictions of population growth outpacing agricultural production, and in instigating the Green Revolution in Asia in the 1960's and 1970's. Advances in biotechnology have not yet sufficiently increased crops' nutritional value, their suitability to subtropical and tropical weather conditions and their resistance to diseases and pests, but have the potential to do so.

Strong and new forces of change are transforming the world food equation and are also increasing the need for technological innovations. On the demand side, consumption of both staple and high-value products is surging due to income growth, changing food preferences of urban middle class and subsidised biofuel production. On the supply side, however, the response to this surging demand has been slow and insufficient.

The agricultural supply required to ameliorate this situation will need to come not from area expansion, but from higher yields and increased productivity in the livestock sector, both of which should be driven by further technological innovation. Neglecting investments in science for agriculture will further widen the gap between the rich and the poor. Indeed, more investment in science for agriculture is needed to facilitate and enhance inclusive economic growth. Important domains are:

- Bio-economy demands new biomass types optimized for several applications. Crops must be improved to ensure this optimization. Plant breeding is necessary to meet these challenges.
- Biofuels: sugar-ethanol will not be enough to achieve energy and climate goals. Plant breeding can lead to dedicated lignocellulosic crops that can be converted into ethanol, or other products, with higher energy input/output ratio.
- Oil crops: plant breeding to produce enhanced vegetable oils for industrial applications by introducing different fatty acid profiles in the plant. This could simplify the refining or chemical modification of the oil. Alternatively, breeding can develop plants with new specialty fatty acids, not normally present in food oil crops.
- Challenges to be met in the bio-refinery sectors — the processes of transforming biomass into a wide range of value-added products (chemicals, materials, food

and feed) or energy (biofuels, heat or power). This has been much less studied so far than the sector of primary biomass production, and should include recycling too.

- Products based on industrial biotechnologies that can produce cellulosic biofuels, enzymes, green plastics, renewable chemicals, and push the frontiers of synthetic biology. These innovations can relieve the pressure on land-based food, feed, fibre, and energy production.

Regarding needed science policy actions, we must distinguish between those that are largely in the domain of national governments and those that are best handled at the international level, requiring the attention of global actors. Dissemination of new technology in agriculture requires large upfront investments in the foundations of effective technology utilization at national levels, such as rural education, infrastructure setup and extension of services.

However, public research and development (R&D) investments in agriculture have been stagnating since the mid 1990's until recently when that trend was broken due to the world food crises. Exceptions are few, such as rapid expansion of R&D in China and Brazil.

At the global level, a science and technology initiative is needed to prevent further rising agricultural prices. The agenda of such a global initiative should focus on increasing agricultural productivity, sustainability of agricultural practices, food quality and health, while promoting sustainable natural resources management.

The initiative must also directly address nutrition insecurity by breeding new varieties of staple crops that are rich in micronutrients which allow the poor to receive necessary amounts of vitamin A, zinc and iron via their regular staple-food diets. This "bio-fortification" provides a means of reaching malnourished populations in relatively remote rural areas and delivering naturally fortified foods to people with limited access to commercially marketed fortified foods or supplements.

If investments in public agricultural research were doubled, agricultural output would increase significantly and millions of people would emerge from poverty (von Braun et al. 2008). If these investments were targeted at the poor regions of the world — such as sub-Saharan Africa and South Asia — overall agricultural output growth would increase by 1.1% a year and lift about 280 million people out of poverty by 2020.

Conclusion

Prioritization, sequencing, transparency and accountability are crucial for successful implementation of agriculture, food and nutrition policies for food security in the emerging bio-economy context. More and better investments are needed, but will only make their full contribution when the governance of agriculture, food and nutrition is being strengthened at international and national levels.

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Towards Global Food Security: The 21st Century Challenge

Malcolm Elliott and Fiona Pring

Introduction

The Reverend Thomas Malthus observed in his *Essay on the Principle of Population* (Malthus, 1798) that sooner or later population must be checked by famine and disease. Malthus' concerns about the dangers of population growth were expressed by his words "The power of population is indefinitely greater than the power in the earth to produce subsistence for man".

Malthus' fears were not quickly realized because the Agricultural Revolution, which started in Britain in the 15th century and continued through to the 19th century, delivered huge increases in agricultural productivity and net output, which broke the historical food scarcity cycles. These improvements were reinforced by the increasing ability to buy and transport food over much longer distances so that the impacts of local crop shortages could be ameliorated.

The British Agricultural Revolution was closely duplicated by many countries in Europe and their colonies. One of the keys to the Agricultural Revolution was the development of ways to keep and improve arable land to counteract the loss of plant nutrients from the soil. Higher yielding crops were then grown on better soil to deliver higher yields per acre.

Almost 200 years after Malthus expressed his fears, Paul Ehrlich (1968) wrote in *The Population Bomb* that "mass starvation" due to "burgeoning population growth" was inevitable. "It is now too late to take action" to avoid hundreds of millions of deaths in developing countries, he declared. He insisted that nothing could be done to stop all those people dying from hunger, because there were simply too many mouths to feed. It was already game over, he said.

Norman Borlaug was as concerned about population growth as Ehrlich, but instead of making doom-laden prophecies about mass death, he decided that the best course of action to stop people starving would be to help them produce more food. His Green Revolution enhanced agricultural productivity so much that he has been credited with saving the lives of one billion people who would otherwise have starved. Borlaug was awarded the 1970 Nobel Peace Prize in recognition of this success.

Borlaug's Nobel Peace Prize Lecture was titled "The Green Revolution, Peace, and Humanity." In that lecture he observed that "most people still fail to comprehend the magnitude and menace of the 'Population Monster'. Growth has been especially fast since the advent of modern medicine. If it continues to increase at the estimated present rate of 2% a year, the world population will reach 6.5 billion by the year 2000 unless man becomes more realistic about this impending doom." He observed that "it is time that the tide of the battle against hunger was changed for the better — but ebb tide could soon set in if we become complacent." The harsh reality of that warning was recognised in the early part of 2008 when the price of wheat and maize doubled and that of rice tripled, leading to food riots in 20 countries and becoming a major contributor to the Arab Spring.

The 21st Century Challenge

Just as Borlaug warned, humankind's numbers continue to increase so rapidly that, according to the United Nations' demographers, the world's population reached seven billion at the end of October 2011. The UN FAO estimated that, even in 2010, more than a billion people went to bed hungry or starving every night.

It seems that Malthus' and Ehrlich's much derided prophesies that population increases would far outstrip gains in food production may be coming true, albeit later than they expected. Meanwhile, the world's population continues to rise by 1% a year so that it is likely that by 2060, the population will peak at 10 billion.

Borlaug's concern that the Green Revolution would reach its limits before the world's population stopped growing has been justified. The problem of feeding the world is exacerbated by the fact that the enhanced economies of

China, India and Brazil are coupled with a growing demand for meat. This switch from predominantly vegetarian fare to meat-eating has disastrous consequences for the global demand for crop yield enhancement. We are confronted by the need to grow much more food on less land, with less water for irrigation, and to use less fuel and fewer agrochemicals so that the impact of agriculture on biodiversity can be reduced.

This crisis must be considered in the context of global climate change. *Achieving Food Security in the Face of Climate Change,* a report from the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), entitled , emphasizes through seven key recommendations that an integrated approach must balance how much food we produce toward the outcome of nutritional security in the face of changing climate, and how much agriculture will contribute to further climate change.

The Way Forward

It is apparent that agriculture must be "sustainable." This means that agricultural practices across time and space must be in constant balance, meeting human needs with healthy outcomes within the boundaries of our natural resource base. There is also growing recognition that agriculture's demands on the Earth system require new knowledge-intensive approaches that are founded on principles that guide local practices to manage specific, albeit uncertain, circumstances.

While there are many approaches to improve and stabilise agricultural yields and livelihoods and the resilience of agricultural systems, the mandate of food security cuts across the debates. Borlaug himself championed the application of cutting edge science to crop production. He noted that advances in molecular biology have provided new tools for crop improvement including molecular marker aided selection (MAS) and genetic engineering (GM).

MAS improves the efficiency of breeding programmes and genetic engineering allows us to accomplish breeding objectives not possible through conventional breeding approaches. MAS is not controversial and is now routinely used in crop improvement programmes but the "anti-science zealotry" has slowed the adoption of GM crops in some countries.

Clive James, Borlaug's deputy director during his time at CIMMYT, has provided detailed reports of the progress of GM technology since their first application to agriculture in 1996. He notes that there has been a steady increase in the area planted to GM crops since they were first used in the USA in 1996 on an area of 1.7 million hectares. In 2011 GM crops were planted on 160 million hectares in 29 countries of which 19 are developing countries. This means that GM crops are the fastest adopted crop technology in the history of modern agriculture.

James cited a study which featured the benefits accrued from the planting of GM crops. The value of increased crop production from planting GM crops between 1996 and 2010 was estimated to have been US$78 billion. They affected savings of 443 million Kg of pesticides and thus contributed to environmental sustainability. In 2010 alone GM crops helped reduce CO_2 emissions by 19 billion Kg (equivalent to taking approximately 9 million cars off the road). They helped conserve biodiversity by saving 91 million hectares of fragile lands from being opened up for agriculture. In addition, they helped alleviate poverty by increasing incomes for 15 million small farmers who are among the poorest in the world.

In spite of these obvious benefits, there is unjustified opposition to the growing of GM crops. Numerous respected international scientific organizations have emphasized that GM crops and the foods prepared from them are as safe as foods prepared from conventional crops.

A major roadblock in the rapid adoption of GM crops is the prolonged process of regulatory approval. There is an urgent need for appropriate science-based and cost and time effective regulatory systems that are responsible and rigorous but not onerous for small and poor developing countries.

The need for such changes is illustrated by the case of "Golden Rice". It was developed in the public domain by Potrykus' group in 2012 in Switzerland to help reduce vitamin A malnutrition in rice-dependent poor societies. Proof-of-concept for the engineered biosynthetic pathway was completed by February 1999. Product development beyond the basic research was not supported by the public domain.

The project was only rescued because of support from the private sector. Problems related to intellectual property rights involved with the basic technology were solved within half a year. Product optimisation by the private sector was donated to the Golden Rice Humanitarian Project. The putative impact of Golden Rice was calculated to be up to 40,000 lives saved per year for India alone.

Despite the substantial support for Golden Rice, it will not reach the farmer before 2013. If Golden Rice were not genetically engineered (GE), variety development and registration would have been completed by 2002. This difference in time between traditional variety development and that of a GMO-based variety of more than ten years is due to nothing else but routine, regulatory requirements. This difference translates, on the basis of the calculated impact of vitamin A deficiency, into far more than 400,000 lives lost. This is especially difficult to accept for the case, where no risk to the environment or to the consumer can be claimed even hypothetically.

Frustrated by such "anti-science zealotry", Norman Borlaug and Jimmy Carter wrote in the *Wall Street Journal* dated October 14, 2005, that:

> "More than half of the world's 800 million hungry people are small-scale farmers who cultivate marginal lands. New science and biotechnology have the power to address the agro-climatic extremes. Their use lies at the core of extending the Green Revolution to these difficult farming areas. However, agricultural science is increasingly under attack by groups and individuals who, for political rather than scientific reasons, are campaigning to limit advances, especially in new fields such as genetic modification (GM) through biotechnology. Despite this opposition, it is likely that 250 million acres will be planted to GM crops in 2005. However, the debate over biotechnology in the industrialized countries continues to impede its acceptance in most poor, food-insecure countries."

A turning point for GMOs?

Scientists from Rothamsted Research have used their knowledge of natural plant defences (Beale et al. 2006) to underpin a GM strategy to test whether wheat that can repel aphid attacks works in the field.

Aphids cause significant damage to plants and reduce farmers' yields by damaging crops and spreading plant diseases. Currently, cereal aphids reduce yields of wheat by sucking sap from plants and by transmitting barley yellow dwarf virus. In the UK they are controlled by treating the crop with broad spectrum chemical insecticides. Unfortunately, repeated use of the insecticides often leads to resistant aphids and kills other non-target insect species including the natural enemies of aphids, which could have a further impact on biodiversity.

One approach used by scientists at Rothamsted Research to overcome this problem in wheat has been to use an alarm pheromone, which aphids produce to alert one another to danger. This pheromone, (*E*) farnesene, is also produced by some plants as a natural defence mechanism and not only repels aphids but also attracts their natural enemies, such as ladybirds. The scientists have genetically engineered a wheat plant which produces high levels of this aphid repelling pheromone in order to help promote sustainable 'green' agriculture.

This promising research had reached the stage of field-testing under rigorously controlled conditions when the anti-GM group *Take the Flour Back* threatened to destroy the wheat crop by what it termed "decontamination". The researchers at Rothamsted mounted a strikingly successful counter-campaign against the protesters (Lynas, 2012). The scientists wrote a sincere, emotional open letter to the public and recorded a YouTube video with several members of the team pleading for the protest not to go ahead, while correcting various misconceptions held by the activists. With support from the charitable trust *Sense About Science,* a petition was started, which gathered over 6,000 signatures in a little over a fortnight — with pro-science comments from members of the public representing all walks of life, from housewives to air traffic controllers.

A generally supportive media environment was especially important in the eventual success of Rothamsted's campaign. With the issue framed not as pro or anti-GM in principle, but around whether or not it is ethically acceptable to destroy scientific experiments, many commentators were supportive. Despite initial timidity from government, the relevant UK minister eventually issued a supportive quote, whilst the funders BBSRC also contributed. In the run-up to the planned destruction of the test plants the issue achieved significant media prominence, with the researchers making appearances on news programmes across broadcast networks.

Rothamsted also invited *Take the Flour Back* to meet its scientists in a public debate, even booking a London-based venue for the purpose. However, the activist group declined to participate, although a Dorset-based hobby farmer and alternative-lifestyle campaigner did appear on TV opposite Rothamsted's Professor John Pickett and *Sense About Science*'s

Tracey Brown. On the day of the planned destruction, *Take the Flour Back* were barely able to mobilize 150 protesters, more than a dozen of whom were brought from France on buses. Their attempts to reach the site were easily rebuffed by police deployed around the perimeter of Rothamsted Park, where the protest was held.

Also of note was a smaller counter-protest mobilised via social networks like Twitter under the hashtag #geeksinthepark. This may have been the first time in the world that concerned members of the public organized and attended a protest to defend a GM test site against attempts by environmental activists to destroy it. The social media campaign was organized with no contribution whatsoever from Rothamsted Research.

These matters are necessarily subjective. Many of those interested in the GM debate in the UK agreed that the failure of *Take the Flour Back* — and Rothamsted's success in communicating the value of its biotechnology work — seemed like a turning point. But the successes of the early anti-GM movement and the plethora of regulatory responses it provoked still weigh heavy on the work of scientists trying to use this technology more widely for the benefit of the environment and food security. Rothamsted has made an important advance and it is up to other researchers in the area to take communications equally seriously.

Another very important development has been recently reported. Greenpeace and its allies have successfully blocked the introduction of golden rice for over a decade, claiming that it "may have environmental and health risks" without ever elaborating on what those risks might be. Even after years of effort, the Golden Rice Humanitarian Project, led by Ingo Potrykus, the Rockefeller Foundation and others were unable to break through the political opposition to golden rice that was generated directly by Greenpeace and its followers.

Recently the Bill and Melinda Gates Foundation has taken a lead role, in collaboration with the International Rice Research Institute in the Philippines, in breaking through these barriers and bringing golden rice to market. Field trials are now underway in the Philippines and Bangladesh with the hope of introducing it to the market by 2015.

Since the invention of golden rice in 1998, between 4 million and 8 million additional children have become blind, nearly half of whom have already died. Greenpeace continues to oppose these field trials by openly and aggressively spreading misinformation about golden rice ever since it was first invented and has continued to do so at every opportunity. Academies of science around the world endorse the use of biotechnology, including genetic modification, to improve the nutrition and productivity of our food crops. There is no evidence of any possible harm from these improvements.

It seems that the tide is turning against the anti-science zealots at last. A ComRes survey for *The Independent* newspaper revealed that public opinion is shifting in favour of the development of genetically-modified crops. 64% of the public agreed that the government should encourage experiments on GM crops so that farmers can reduce the amount of pesticides they use.

This is a dramatic change from the situation in the 1990's, when anti-science zealots caused strong public opposition to GM crop products by their references to "Frankenstein foods" and by demonising multinational firms such as Monsanto. The findings should encourage scientists to follow the example of the Rothamsted group who carefully explained the real benefits of development of GM crops to deliver sustainable crop protections.

Rapid Dissemination of Research Outputs

This paper records the authors' contribution to a session at BioVision Alexandria 2012 which was organised to celebrate the launch of *Agriculture and Food Security*, a journal dedicated to the delivery of reports of new science outcomes focused on agricultural and food systems, as well as new approaches to addressing critical human dimensions, new technologies, new ways of thinking and new ways to measure and manage attributes across dimensions and scales.

Manuscripts submitted to the journal are reviewed by internationally recognized experts in the appropriate fields, selected in part from the editorial board. Reviews of submitted manuscripts are rapid and the suitability of manuscripts for publication is assessed solely on criteria of scientific excellence. The journal features research outcomes within the field of food security with a particular focus on research that may inform more sustainable agriculture and food systems that better address local, regional, national and/or global food and nutritional insecurity.

The journal considers cutting-edge contributions across the breadth of relevant academic disciplines, including agricultural, ecological, environmental, nutritional and socio-economic sciences, along with public health and policy. The broad, holistic scope of the journal is intended to make it accessible to a large and diverse audience, from research scientists working at the forefront of agricultural technologies, to policymakers, to the farmers as the key producers of food, and to the general public. Through showcasing innovations in sustainable agriculture in an open access journal, scientists can make their research available to those whose countries it may benefit the most.

The journal provides a venue for papers addressing the science of food security issues. With a visionary scope that encompasses plant research, fisheries science and animal husbandry in agriculture; tackles environmental issues and economic issues; considers nutritional security and public health; and looks forward to a productive and prosperous future, research published in *Agriculture & Food Security* will be applicable to both the developing and developed world.

The open access format of the journal facilitates the rapid dissemination of research output. With free access to published articles for anyone with an internet connection, it provides a forum to engage and unite scientists, economists and policy makers to tackle the challenges of global food security.

Conclusion

The world has some seven billion inhabitants, with more than one billion of them suffering from hunger (deficiency of calories and proteins), while more than two billion people have micronutrient (vitamins and minerals) deficiency. Each year nine million people die because of hunger and malnutrition (one every 3.5 seconds) — and five million of them are children.

This crisis is rapidly worsening and must be resolved by, *inter alia*, a dramatic increase in crop yields. Cutting edge science, particularly molecular approaches to crop improvement, are addressing the crisis. However, they will only be able to deliver their full benefits for humankind when "green" groups such as Greenpeace and Friends of the Earth accept the worldwide scientific consensus that GM food is just as safe to eat as any other (Lynas, 2012).

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An Agroecological Route to Agricultural Development

Norman Uphoff

It is appropriate that the UN's Millennium Development Goals (MDG) begin with the goal of eradicating extreme hunger and poverty (MDG 1). While there has been remarkable progress made in reducing these two scourges of humankind, to enable those among us who are poorest and most vulnerable to transcend their current miserable conditions requires unprecedented efforts and innovative strategies.

Great strides toward this goal were made during the latter decades of the 20^{th} century under the banner of the Green Revolution, but the momentum of its technologies has stalled in recent decades. Per capita production of cereals in the world peaked almost 30 years ago, a population growth has exceeded the growth in cereal productivity; and total cereal production has not increased much since the mid-1990s.

With available technologies and with higher farm gate prices that give producers more incentive, global food production could have been increased considerably. But this solution would have made even more desperate the situation of those men, women and children who remain hungry and poor. Reducing poverty and hunger toward MDG 1 will depend on making further gains in *productivity* — more output per unit of input — rather than boosting food supplies in response to higher prices.

The Green Revolution was successful in reducing the real price of food *by about half* over a four decade period. But in recent years, the world has seen a resumption of food price rises, with unacceptable increases in the number of poor and hungry as well as with unsettling impacts on political stability. It has been suggested, with some justification, that the slowdown in crop productivity gains over the past several decades has been due to a slackening of investment in agricultural research, a trend now being reversed.

But we should consider whether this slackening of productivity growth has resulted, a least in part, from the prevailing paradigm for agricultural research and development encountering *diminishing returns*. Practically all enterprises become less productive at the margin as they expand and age. It is likely that the stock of improvements that can be made with our current Green Revolution assumptions and technologies has been drawn down, having harvested the 'low-hanging fruit' that this particular paradigm for guiding agricultural R&D can yield.

The Green Revolution had many successes, but it is reasonable to ask how well the agricultural sector will be served by continuing to do more of the same, even if the development is undertaken somewhat differently and hopefully better (Conway 1998). If there are some inherent limitations in a Green Revolution strategy, what should we be planning and doing for an encore? What may be done beyond the Green Revolution? (Uphoff 2007).

The Green Revolution's paradigm was constructed with two principal elements:

1. Making improvements in crop varieties (genotypes), selected to be responsive to increases in agrochemical inputs and water and amenable to mechanised, energy-intensive production, and
2. Increasing external inputs, particularly inorganic fertilizers with a focus on nitrogen , but also agrochemical means of crop protection.

Proponents of biotechnology propose that the new tools of molecular biology can reverse the current yield stagnation, working within the Green Revolution paradigm by focusing on genetic potentials and input responsiveness as well as on resistance to biotic and abiotic stresses. They may be correct, but a number of significant trends will condition and constrain such an agricultural strategy in this new century.

In particular, continued heavy reliance on nitrogen fertilizers to drive up food production further is increasingly questionable:

1. The diminishing returns from increasing applications of synthetic N are seen in China, where at the start of its Green Revolution, the application of 1 kg of N fertilizer would, on average, produce 20 kg of paddy at the margin. That ratio has now become about 1 kg of N to produce 5 kg more of paddy, and it continues to diminish (Peng et al. 2006). Farmers' response has been to apply even more fertilizer to squeeze out further increments in yield even if these come at great economic and environmental cost.

2. Research with smallholders in Western Kenya has found that their marginal economic returns from applying N fertilizer are negative unless or until the levels of organic carbon in their soil reach at least 3% (Marenya and Barrett 2009). For N fertilizer to be productive, there needs to be at least some minimum level of 'life in the soil.' With subsidies that lower the price of fertilizer plus active promotion by extension services, farmers can be induced to use N fertilizer. But this is not economically justifiable without adequately-organic management of soil systems.
3. The promotion of input use in general has been heavily subsidized by governments and donor agencies seeking to keep food production ahead of population growth, not fortunately slowing. Most governments and donors now are less willing and/or less able to continue such expenditures, so further expansion of fertilizer and agrochemical use must meet market tests.
4. Further, expanded use of N fertilizer will come at serious environmental as well as economic costs. The former chair of the UK's National Environmental Research Council has characterised increasing reactive N in the biosphere as "the third major threat to our planet, after loss of biodiversity and climate change" (*Nature*, 24 February 2005). A transnational evaluation in Europe has estimated that the costs (negative externalities) arising from build-up of reactive N, mostly from inorganic fertilizer, amount to as much as €320 billion (US$437 billion) a year (Sutton et al. 2011).

These and other considerations make it reasonable, even urgent, to assess alternative routes to higher agricultural production and productivity for the achievement of MDG 1. A number of alternatives which include agroforestry, conservation agriculture and integrated pest management can be grouped under the heading of *agroecology*. This does not seek to meet agricultural objectives by dealing with crops or animals as separate species, to be respectively improved through breeding endeavours that facilitate their increased growth by utilization and optimization of external inputs.

Agroecological alternatives

In contrast, agroecological approaches deal with *ensembles* of plant and animal species, ranging from the microflora and microfauna that we cannot see to the familiar crops and livestock that we can. This perspective is concerned with the *interactions* among species to capitalize on energy and nutrient flows and to conserve on energy and nutrient stocks (Altieri 1995; Gliessman 2007; Uphoff 2002).

The scientific foundations for agroecological development are being strengthened by a growing recognition of the contributions that are made to the growth and health of plants and animals (including ourselves) by uncountable numbers and still mostly-unknown species of microorganisms. These constitute what is referred to as the *microbiome*, which exists in, on and around both plants and animals.

The human microbiome is starting to get more attention (Turnbaugh et al. 2006) as we become aware that our bodies contain probably 10 times as many microbes as we have human cells in our bodies. This means that 90% of the cells in our bodies are not *our* cells.

These benign microbes perform many beneficial services for humans and other animals. For example, they facilitate digestion, synthesise vitamins, develop the immune system and resist pathogens.

Plants also show similar interdependence with and dependence on their microbiomes which extend from the soil to plant roots (the rhizosphere) as well as to their above-ground organs (the phyllosphere). The soil biota can fix and also recycle nitrogen, solubilise phosphorus and many of the micronutrients, produce phytohormones, induce systematic resistance and compete with, inhibit and even kill pathogens (Bonkowski 2004; Doebbelaere et al. 2003; Frankenberger and Arshad 1995; Turner and Haygarth 2001; Whipps 2001). A profusion of microorganisms not just in the soil but throughout plants is the normal and even necessary condition for their existence, not something deviant or pathological (Partida-Martinez and Heil 2011).

Some recent paradigm-shifting research shows that soil microbes, when residing in rice plants' leaves and sheaths, contribute to greater growth of roots and canopy, higher levels of chlorophyll and rates of photosynthesis in the leaves and higher yield (Chi et al. 2005). Further research has shown that soil rhizobia, when residing in above-ground tissues, can affect, in beneficial ways, the expression of rice plants' genetic potentials, up-regulating and down-regulating the expression of various specific genes (Chi et al. 2010). The roles of symbiotic microbial endophytes thus deserve more attention than these organisms have received in the past (Uphoff et al. 2012).

Growing knowledge about soil ecology and plant-soil-microbial interactions makes the study and practice of agroecology more dynamic. It underscores a series of 'what if?' questions:

- *What if* we can improve food production using existing crop **varieties**, either 'improved' or 'traditional,' and without requiring the heavy use of **fertilizers** and other agrochemicals?
- *What if* this would be possible with reduced requirements for **water**, either with less irrigation or less need for rainwater, because of the better growth and functioning of root systems and the abundance of soil biota holding 'green water' in the soil?
- *What if* resulting crops were more resistant to various **stresses**, both biotic (pests and diseases) and abiotic (drought, storm damage, and extreme temperatures), all likely to increase as a consequence of present and impending **climate change**?
- *What if*, specifically in the case of rice, crops would have a shorter **growing season** (crop cycle) and had higher **milling outturn**? (The latter is the kilograms of edible polished rice obtained from a given amount of harvested paddy, a bonus on top of farmers' increase in paddy rice.)

The System of Rice Intensification

All of these desirable outcomes are already being achieved with an agroecological strategy for rice production, the System of Rice Intensification (SRI), whose principles and practices are now being extended to many other crops (Uphoff 2012a,b). SRI was developed in Madagascar some 30 years ago, but only started to spread elsewhere in Asia, Africa and Latin America over the last dozen years. The ability of its recommended methods to evoke more productive phenotypes from practically all genotypes (varieties) has been seen now in over 50 countries.

By changing the way that plants, soil, water and nutrients are managed, with the effect of enhancing the abundance and diversity of soil biota (Anas et al. 2001), SRI methods can produce rice plant phenotypes that are more productive and robust, as seen in figs. 1 and 2, manifesting potentials that have seldom, if ever, been seen before.

While the agronomic methods (discussed below) for getting such results are simple, they alter some practices that farmers have followed for generations, even millennia. They appear counter-intuitive in that more plant growth and more yield are achieved by reducing rather than increasing inputs. By improving the expression of genetic potentials, they are tapping productive possibilities already contained in rice genomes.

Initially it can be difficult to get farmers to accept what seem like unreasonable or risky methods. However, when farmers can see yield gains increased by 50 to 100% — or sometimes even gains of up to 4 times more if farmers are operating at low levels of production — most become willing to try the changes.

Understandably, there has been some controversy over these methods and their reported results, e.g., Dobermann (2004), Sheehy et al. (2004), Stoop and Kassam (2005), McDonald et al. (2006), and Uphoff et al. (2008). The controversy has been receding in recent years as evidence builds up that these practices and principles are essentially just good basic agronomy, nothing magical or mystical. In 2011, five farmers in one village of Bihar state of India matched or exceeded the previous world record for paddy yield. One set a new record of 22.4 tonnes/hectare, officially measured and recognised (Diwakar et al. 2012).

This yield achieved by farmers using SRI methods refutes, for the first time, criticisms that the unprecedented high yields previously reported from SRI management were biologically impossible (Dobermann 2004;

Figure 1 A Cambodian farmer in Takeo province showing an SR rice plant grown from a single seed. This plant was selected at random, not necessarily the largest plant in the field, which had previously given paddy yields of 2-3 tonnes/hectare. This SRI field when harvested gave a yield calculated at 6.72 tonnes/hectare. One area had a crop-cutting yield rate of 11 tonnes/hectare. Picture courtesy of Y.S. Koma, CEDAC.

Sheehy et al. 2004). Governments in China, India, Indonesia, Cambodia and Vietnam, where two-thirds of the world's rice is produced, have satisfied themselves that the methods are beneficial, based on their own evaluations and on farmers' experience. They are now actively promoting the spread of SRI. There is also less ground for objection as the research literature on SRI continues to accumulate.

The original practices developed for SRI include, in addition to growing seedlings in an unflooded nursery so that they benefit from aerobic soil conditions from the start (Salohke and Mishra 2008):

- Transplant young seedlings, 8–12 days old, to better preserve the plants' growth potential.
- Avoid trauma to the roots so there is minimum transplant shock, transplanting quickly and shallow, not inverting the root tips which temporarily halts growth.
- Give plants wider spacing, one plant per hill and in a square pattern, to give both roots and canopy ample room to grow.
- Keep paddy soils moist but unflooded; continuous saturation suffocates the roots (and beneficial aerobic soil organisms).

Figure 2 Two rice plants held by a Cuban farmer that are the same variety (VN 2084) and same age (52 days after sowing in the same nursery). The plant on the right was transplanted as a young seedling into an SRI growing environment, with wide spacing, increased soil organic matter, and active soil aeration from mechanical weeding that stimulated root growth and aerobic soil organisms. Picture courtesy of Rena Perez.

- Actively aerate the soil with a mechanical hand weeder to control weeds and benefit the roots and soil biota. This alone can boost yield by 1 or more tonnes/ hectare.
- Enhance the organic matter in the soil as much as possible, with compost, mulch or other biomass. For more information see.

These practices have been amplified and modified in many ways. For example, establishing SRI crops by direct seeding instead of transplanting, where labour is scarce or expensive; or adjusting water management practices to utilize SRI principles in unirrigated (upland) rice production. In some parts of eastern India, rainfed SRI has given average yields of 7 tonnes/ hectare, which would please most irrigated rice farmers.

SRI principles have been applied with conservation agriculture (no-till), growing rice on raised beds and using specially designed machines to permit large-scale SRI production with 70% savings of both labour and water and with high yield (Sharif 2011). The objective and effect of all these practices, original and derived, is to stimulate root growth and the abundance and diversity of soil biota, raising the productivity of land, labour, water, seeds and capital all at the same time.

Relevance in a changing climate

As noted above, the plants that result from such agroecological management are better able to resist the effects of biotic and abiotic stresses that are likely to increase with climate change (Uphoff 2011).

- In Bihar state of India in the 2010 main season, when there was one of the most severe recent droughts, technicians working with the state government's rural livelihoods promotion agency, made crop-cuttings from rice fields side-by-side, where one had been managed with SRI methods and the other with standard practices. The average yield from the latter, calculated from 74 comparisons, was 1.6 tonnes/hectare, while the SRI yield was 3.2 tons. Despite the drought, this was one-third higher than the state's usual average yield with normal climate (data from Bihar Rural Livelihoods Promotion Society, personal communication).
- In Sichuan province of China, where the provincial department of agriculture started promoting SRI in 2004 with 1,133 hectares, and the SRI area in 2010 had expanded to over 300,000 hectares. The average yield increase over this period was 1.7 tonnes/hectare. Of relevance here is the fact that the highest SRI

increases over the provincial average yield were in the drought years of 2006 and 2010 (Zheng et al. 2011). It has been seen by others that the net yield advantage of SRI methods has been greater in drought years.

At the other end of the climate spectrum, SRI-managed plants have been seen to resist storm damage from wind and rain that can cause lodging. There is some scientific confirmation of this, showing that there is less lodging when plants are transplanted at a younger age, are more widely spaced, and grown in unflooded soil (Chapagain and Yamaji 2010). Visual evidence is, however, also persuasive.

Fig. 3 shows two adjacent paddy fields in Indonesia. Both had been hit successively by a brown planthopper (BPH) attack and then a tropical storm. The field on the left was planted with a modern variety, using chemical fertilizer; the field on the right was growing a traditional rice variety with organic SRI methods. The double impact of biotic and abiotic stresses reduced yield from the field on the left to almost nothing, while 800 kg of paddy rice was harvested from the field on the right (1000 m^2). This yield of

Figure 3. Two adjacent rice fields in East Java, Indonesia, after both fields were hit first by a brown planthopper (BPH) attack and then a tropical storm. These stresses caused 'hopperburn' and serious lodging in the field on the left. This was planted with an improved variety (Ciherang) and was chemically fertilized. The field on the right, which was managed with organic SRI methods and grew a traditional variety (Sinantur), sustained no damage. Picture provided by the farmer who managed the field on the right, Ms. Miyatty Jannah, Crawak village, Ngawi province, East Java.

8 tonnes/hectare was more than what was usually attained with improved varieties and agrochemical inputs on irrigated fields.

There is also some experimental evidence that SRI rice plants can withstand cold stress. In trials managed by researchers at the Acharya N. G. Ranga Agricultural University (ANGRAU), India, in kharif season 2006, SRI plots gave a yield of 4.16 tonnes/hectare despite a cold spell of 5 days with ambient temperatures below 10 °C. This low temperature stress reduced the yield from the experiment's control plots to 0.21 tonnes/hectare (Adhikari et al. 2010).

We also have some reports from farmers in India and Bangladesh that SRI plants are more resistant to the damage of flooding — obviously within some limits — although there are no systematic data to report.

These effects, like the other kinds of crop protection, are related principally to the benefits that plants under SRI management get from developing larger, better-functioning root systems, given little attention in most contemporary plant and soil science.

Extension of agroecological principles and methods to other crops

One of the most encouraging things to come out of experience with SRI methods is the extent to which farmers and the NGO supporters working with them have adapted and extrapolated these methods to other crops. The increases in yield, shown in Table 1, have been quite remarkable.

Table 1. Summary of results reported from farmers' fields (Source: Uphoff 2012b)

Crops	Yield increases
Finger millet	3-4x
Legumes	50-200%
Maize	75%
Mustard	3-4x
Sugarcane*	20-100%
Teff	3-5x
Turmeric**	25%**
Vegetables	100-270%#
Wheat*	10-140%

* 30% irrigation water savings were reported; most SRI crops are rainfed.
** 66% water saving; farmers' net income is doubled
# Increases per plant, not adjusted for area production

Figure 4. Farmer and son in Tigray, Ethiopia showing the high tillering capacity of teff plant (held by father) grown by transplanting with wide spacing and enhanced soil organic matter compared with a plant from traditional broadcast sowing (held by son). Photo courtesy of Hailu Araya, Institute for Sustainable Development, Addis Ababa.

Use of these agroecological ideas and practices has progressed most with wheat through the System of Wheat Intensification (SW), as positive results have been reported from India, Nepal, Ethiopia and Mali. They have been adapted to sugarcane (SSI) by Indian farmers (ICRISAT-WWF 2009), with dissemination now beginning in Cuba. Other crops to which SRI concepts and methods have been adapted include finger millet, sorghum, maize, mustard, and teff (in Ethiopia — see fig. 4).

Discussion

Agroecological methods are still being developed and evaluated, but there are still barriers to getting them considered, let alone adopted. There has been an unfortunate conflation of agroecological farming with 'organic farming,' which gets dismissed by supporters of 'modern agriculture' with the assertion that 'organic agriculture cannot feed the world.' It has been argued that reliance only on organic nutrient supplements gives necessarily inferior yield results, but this reductionist argument illogically contends that if organic agriculture cannot meet all food needs, it should not be increased for meeting *many* and maybe *most* such needs.

The rejection of organic production strategies has been challenged by several studies (Badgeley et al. 2007; Pretty et al. 2006; De Schutter 2011). But in any case, agroecological SRI should not be considered as necessarily, only or always organic.

As seen above, SRI management for rice and other crops has been given many demonstrations that agroecological practices, with their enhancement of soil fertility and their fuller expression of crops' existing genetic potentials, can outperform conventional modern practices, even with intensive provision of inorganic nutrients to the soil.

When the five farmers in Darveshpura village in Bihar, whose record-matching or record-setting yields were noted above, used conventional crop management methods with the same hybrid varieties on their farms and in the same soil and climate, their yields were almost triple the state average yield for paddy rice, but less than half the yield that they got with SRI management.

Agroecological practice should be understood as basically more 'pro-biological' than 'anti-chemical.' SRI is *pragmatically* organic rather than *doctrinally* organic, although some agroecological practitioners are against any use of synthetic inputs. Agroecology can embrace integrated nutrient management (INM) which seeks to support crop and soil nutrition through optimizing combinations of nutrients from organic and inorganic sources. Agroecological strategies need not be fully organic. However, by giving precedence to increasing and supporting 'the life in the soil,' they will usually favour using all, or mostly, organic nutrient inputs.

Thus far, there has been only miniscule investment in research and development for agroecological management, probably just a few percent of what has been expended on energy-intensive, input-dependent modern agriculture.

It can reasonably be argued that present limitations on vegetation and other biomass for making compost, mulch and other means to enrich soil organic matter are very great. But there have been negligible efforts to integrate biomass production into farming systems, or to utilize waste or fallow areas for such production (biomass under most conditions is a fully renewable resource). Little has gone into designing and producing better tools and implements for the collection, transport, processing and application of organic matter for the soil. This is a huge gap in current research programmes, mostly because there are no commercial interests backing such R&D, nothing like those that promote further research on inorganic production strategies.

Agroecological production strategies, substantially if not fully organic, are not likely to replace 'modern agriculture' in the foreseeable future. The balance among alternative strategies in future decades will be shaped not so much by policies or even by research activities as by changing economic and environmental influences which in turn affect policy and research priorities. If our concern is MDG 1, how to help the poor and the hungry meet their immediate needs for income and food, many of the high-tech solutions for raising production and removing constraints are tangential to such a goal.

Agroecological approaches to combating hunger and poverty such as SRI and other derived crop management strategies can be made immediately available to hundreds of millions of the world's deprived at low cost and with little risk. The production and use of more biomass as part of a biologically-driven strategy can pose some short-run constraints, but it should be possible to alleviate these to a considerable extent.

Not having sufficient supplies now to meet all conceivable demand is hardly an acceptable reason to continue ignoring and even dismissing agroecological alternatives, especially if we are aiming not just for aggregate production targets but are concerned with getting benefits of increased food production to those who need this most. SRI and related experience indicates that these methods can produce enough surplus for rural production to also benefit the urban poor.

SRI experience in South Asia is showing that very small areas of arable land can be sufficient to meet the basic food security needs of poor households, even with average, far from best, SRI and SWI yields.

- The Food Facility Programme of the EU and FAO operating in the Far Western Region of Nepal, one of the most food insecure parts of this poor country, has calculated that a family of five using SRI methods could meet its basic food needs with just 0.15 ha (FAO-EU 2011).

- Through a detailed evaluation of SRI methods with almost 30,000 poor households in Jharkhand Stat, the National Bank for Agriculture and Rural Development in India concluded similarly that a family of five with SRI management could meet its food needs with 0.15 ha (NABARD 2012).
- In Cambodia, innovative smallholding farmers having only 0.66 ha of land on average have begun capitalizing on the productivity gains made possible by SRI. Now that their staple food needs can be satisfied with less land, they take up to half of their rainfed paddy land out of rice production and convert this area to other, more remunerative uses. They construct ponds and canals for fish and other aquatic production on about 15% of the area, and upland gardens and areas for vegetables, fruits, legumes, chickens and other products on the rest. The investment cost over several years was US$305, while average net income was raised to US$394 (plus increasing household consumption of more nutritious foods). A manual giving details on these transformations has been produced by the NGO CEDAC (Lin 2007).

Such experiences show that with farming systems that are more intensive and informed by agroecological principles, households having only small amounts of land can achieve food security and begin the ascent from poverty.

There are strong interests and good reasons for continuing and further improving the presently dominant paradigm for agricultural production. However, these cannot justify opposition to the evaluation and demonstration of agroecological alternatives to genocentric, energy-intensive, input-dependent agricultural production.

Certain farming systems may not be appropriate or tenable for all farmers or for all agroecosystems, but that does not mean that they should not be accepted and utilized where they can improve productivity of whatever resources poor households have available.

The experience and results from SRI do not argue against making further genetic improvements or against the use of any and all external inputs. Rather, they suggest that to meet MDG 1, we can make great progress, right away and at low cost, saving water and buffering against climate change, by giving more attention to crop management, especially to the nurturing of roots and soil biota.

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22

The Contribution of Biotech Crops to Food, Feed and Fibre Security and Sustainability

Clive James

Introduction

The year 2010 marked the 15th anniversary of the commercialization of biotech crops, also known as genetically modified (GM) or transgenic crops, now more often called biotech crops. The experience of these 15 years of commercialization has confirmed that the early promise of crop biotechnology has been fulfilled.

Biotech crops have delivered substantial agronomic, environmental, economic, health and social benefits to farmers and, increasingly, to society at large. The rapid adoption of biotech crops since 1996 reflects the substantial benefits realized by both large and smallholder farmers in industrial and developing countries which have grown biotech crops commercially. Between 1996 and 2010, developing and industrial countries contributed to a record 87-fold increase in the global area of biotech crops from 1.7 million hectares in 1996 to 148 million hectares in 2010.

Adoption rates for biotech crops during this period were unprecedented and, by recent agricultural industry standards, represent the highest adoption rates for improved crops.

This high adoption rate reflects farmer satisfaction with the products that offer substantial benefits such as more convenient and flexible crop management, lower cost of production, higher productivity, health and social benefits, a cleaner environment and decreased use of conventional pesticides. This collectively contributes to more sustainable agriculture.

There is a growing body of consistent evidence across years, countries, crops and traits generated by public sector institutions that clearly demonstrate the benefits of biotech crops. Biotech crops also offer substantial economic advantages to farmers compared with corresponding conventional crops. The severity of weeds, insect pests and diseases varies from year-to-year and country to country, and hence location will directly impact pest control costs and the economic advantages of biotech crops in any given time or place.

Despite the continuing debate on biotech crops, particularly in countries of the European Union (EU), millions of large and smallholder farmers in both industrial and developing countries have continued to increase their plantings of biotech crops by double digit adoption growth rates almost every year since 1996, because of the significant multiple benefits that biotech crops offer. Around 15 million farmers in 29 countries grew biotech crops in 2010 and derived multiple benefits that included significant agronomic, environmental, health, social and economic advantages.

The International Service for the Acquisition of Agri-biotech Applications' (ISAAA) 2010 Global Review (James, 2010) predicted that the number of farmers planting biotech crops, as well as the global area of biotech crops, would continue to grow in 2011. Global population was approximately 6.5 billion in 2006 and is expected to reach approximately 9.3 billion by 2050, with around 90% of the global population residing in Asia, Africa, and Latin America.

The latest projection by the UN is that the population will continue to grow until the end of this century when it will plateau at 10.1 billion. In 2010, around one billion people in the developing countries suffered from hunger, malnutrition and poverty.

Biotech crops represent promising technologies that can make a vital contribution, but are not a panacea, to global food, feed and fibre security. Biotech crops can also make a critically important contribution to the alleviation of poverty, the most formidable challenge facing global society to address the Millennium Development Goals (MDG) to cut poverty, hunger and malnutrition by half by 2015. This is also the year that marks the completion of the second decade of commercialization of biotech crops, 2006-2015.

Biotech crops, fastest adopted crop technology

2011 was the 16th year of commercialization of biotech crops and growth continued after a remarkable 15 consecutive years of increases; a double digit increase of 12 million hectares, at a growth rate of 8%, reaching a record 160 million hectares. This 94-fold increase in hectarage between 1996 and 2011 makes biotech crops the fastest adopted crop technology in the history of modern agriculture.

The most compelling and credible testimony to biotech crops is that during the past 16 years, millions of farmers in 29 countries worldwide made more than 100 million independent decisions to plant and replant an accumulated hectarage of more than 1.25 billion hectares — an area 25% larger than the total land mass of the US or China.

Countries adopting biotech crops

In 2011, 29 countries planted biotech crops. It is noteworthy that 19 were developing and only 10 were industrial countries (see Table 1 and Figure 1). The top 10 countries each grew more than 1 million hectares, providing a broad-based worldwide foundation for diversified growth in the future. Some 60% of the world's population live in the 29 countries planting biotech crops.

Developing countries grew nearly 50% of global biotech crops in 2011 and for the first time are expected to exceed industrial countries hectarage in 2012. This is contrary to the prediction of critics who, prior to the commercialization of the technology in 1996, prematurely declared that biotech crops were only for industrial countries and would never be accepted and adopted by developing countries.

In 2011, the growth rate for biotech crops was twice as fast and twice as large in developing countries, at 11% or 8.2 million hectares, versus 5% or 3.8 million hectares in industrial countries. During the period 1996-2010, cumulative economic benefits were the same for developing and developed countries (US$39 billion). For 2010 alone, economic benefits for developing countries were higher at US$7.7 billion compared with US$6.3 billion for developed countries (Brookes and Barfoot, 2012).

The five lead developing countries in biotech crops are China, India, Brazil, Argentina and South Africa. Collectively, they grew 71.4 million hectares (44% of global) and together represent about 40% of the global population of 7 billion, which could reach 10.1 billion by 2100. Remarkably, Africa alone could escalate from 1 billion today (~15% of global) to a possible high of 3.6 billion (~35% of global) by the end of this century — global food security, exacerbated by high and unaffordable food prices, is a formidable challenge to which biotech crops can contribute but are not a panacea.

Brazil, the engine of biotech crop growth

Brazil ranks second only to the USA in biotech crop hectarage in the world with 30.3 million hectares, and is quickly emerging as a global leader in biotech crops. For the third consecutive year, Brazil was the engine of growth globally in 2011, increasing its hectarage of biotech crops more than any other country in the world — a record 4.9 million hectare increase, equivalent to an impressive year-over-year increase of 20%.

Brazil grows 19% of the global hectarage of 160 million hectares and is consolidating its position by consistently closing the gap with the US. A fast track approval system allowed Brazil to approve eight events in 2010, and as of 15th October 2011, an additional six events were approved in 2011. Brazil approved the first stacked soybean with insect resistance and herbicide tolerance for commercialization in 2012.

Notably, EMBRAPA, a public sector institution with an annual budget of ~US$1 billion, gained approval to commercialize a home-grown biotech virus resistant bean, (rice and beans are the staples of Latin America) developed entirely with its own resources, thus demonstrating its impressive technical capacity to develop, deliver and approve a new state-of-the art biotech crop.

The US, the lead producer of biotech crops

The US continued to be the lead producer of biotech crops globally with 69 million hectares (an average adoption rate of ~90% across its principal biotech crops), with particularly strong growth in maize and cotton in 2011. Alfalfa is the fourth largest hectarage crop in the US (~8 million hectares) after maize, soybean and wheat. The year 2011 also saw the resumption of the planting of RR®alfalfa, which currently occupies ~200,000 hectares and strong farmer-demand augers well for the future. Adoption could reach as high as 35% to 50% by around 2015 and higher thereafter.

Table 1 Global Area of Biotech Crops in 2011: by Country (Million Hectares)**

Rank	Country	Area (million hectares)	Biotech Crops
1	USA*	69.0	Maize, soybean, cotton, canola, sugarbeet, alfalfa, papaya, squash
2	Brazil*	30.3	Soybean, maize, cotton
3	Argentina*	23.7	Soybean, maize, cotton
4	India*	10.6	Cotton
5	Canada*	10.4	Canola, maize, soybean, sugarbeet
6	China*	3.9	Cotton, papaya, poplar, tomato, sweet pepper
7	Paraguay*	2.8	Soybean
8	Pakistan *	2.6	Cotton
9	South Africa*	2.3	Maize, soybean, cotton
10	Uruguay*	1.3	Soybean, maize
11	Bolivia*	0.9	Soybean
12	Australia*	0.7	Cotton, canola
13	Philippines*	0.6	Maize
14	Myanmar*	0.3	Cotton
15	Burkina Faso*	0.3	Cotton
16	Mexico*	0.2	Cotton
17	Spain*	0.1	Cotton, soybean
18	Colombia	<0.1	Maize
19	Chile	<0.1	Cotton
20	Honduras	<0.1	Maize, soybean, canola
21	Portugal	<0.1	Maize
22	Czech Republic	<0.1	Maize
23	Poland	<0.1	Maize
24	Egypt	<0.1	Maize
25	Slovakia	<0.1	Maize
26	Romania	<0.1	Maize
27	Sweden	<0.1	Potato
28	Costa Rica	<0.1	Cotton, soybean
29	Germany	<0.1	Potato
	Total	160.0	

* 17 biotech mega-countries growing 50,000 hectares, or more, of biotech crops

** Rounded off to the nearest hundred thousand

Source: Clive James, 2011.

RR®sugarbeet, the fastest adopted biotech crop, continues to have a 95% adoption, equivalent to ~475,000 hectares. Resistance to corn rootworm was reported in the US and collaborative studies to assess the event are underway.

It is timely to again stress that adherence to good farming practices, including rotations and resistance management, are a must for biotech crops as they are for conventional crops. Finally, and importantly, from a regulatory viewpoint, virus resistant papaya from the US was approved for consumption as a fresh fruit in Japan effective 1st December 2011 (Japan MAFF, 2011).

In India, Bt cotton has transformed cotton production

In 2011, India celebrated a decade of successful cultivation of *Bt* cotton, which has achieved phenomenal success in transforming the cotton crop into the most productive and profitable crop in the country. India's *Bt* cottons are unique in that they are hybrids and not varieties, as used by all other countries planting *Bt* cotton.

In 2011, plantings of *Bt* cotton in India surpassed the historical milestone of 10 million hectares for the first time, and occupied 88% of the record 12.1 million hectares of cotton crop. The principal beneficiaries were 7 million farmers growing, on average, 1.5 hectares of cotton each.

Historically, the increase from 50,000 hectares of *Bt* cotton in 2002, when *Bt* cotton was first commercialised, to 10.6 million hectares in 2011 represents an unprecedented 212-fold increase in 10 years. India enhanced farm income from *Bt* cotton by US$9.4 billion in the period 2002 to 2010 and US$2.5 billion in 2010 alone (Brookes and Barfoot, 2012).

Thus, *Bt* cotton has transformed cotton production in India by increasing yield substantially and decreasing insecticide applications by ~50%, while it contributed to the alleviation of poverty of 7 million smallholder resource-poor farmers and their families in 2011 alone. Approval of *Bt* brinjal (eggplant) is pending in India whilst the Philippines is planning for an approval in 2012/13, hoping to benefit from the substantial reductions in pesticide applied to this very pest-prone but popular vegetable, referred to as the "queen of the vegetables" in India.

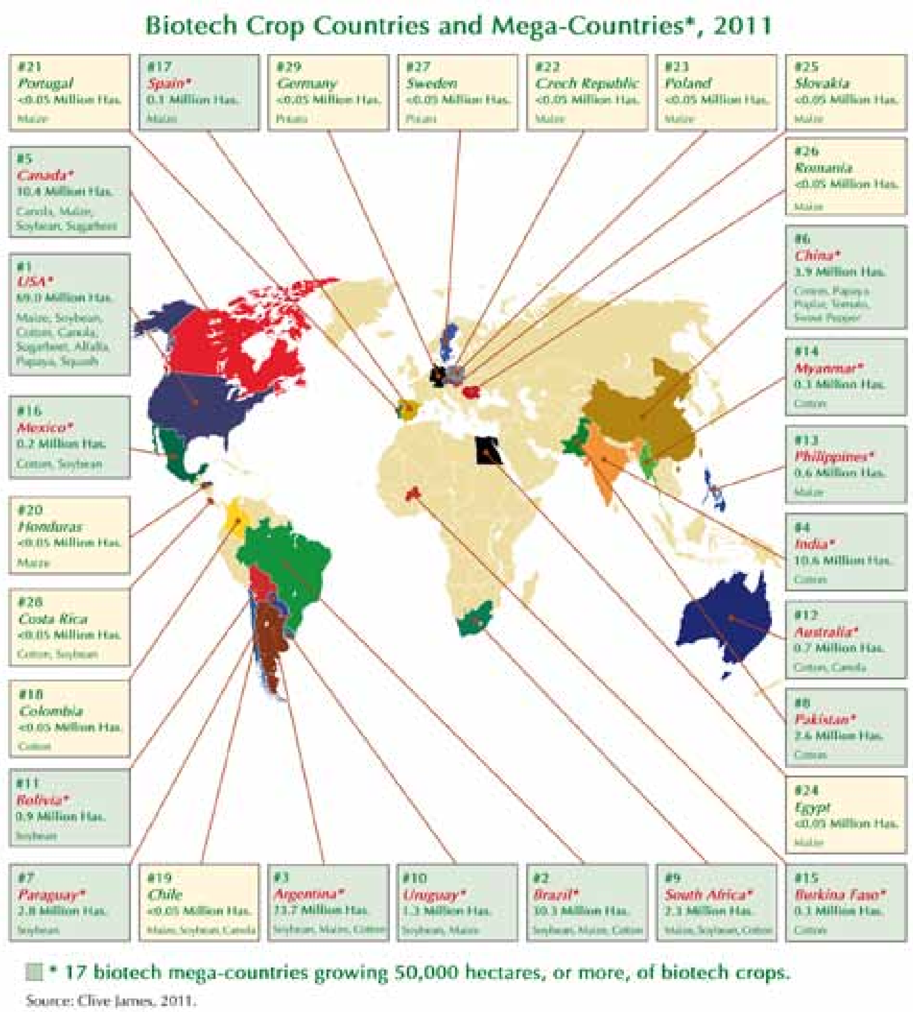

Figure 1 Global Map of Biotech Crop Countries and Mega-Countries in 2011

In China, seven million small farmers benefit from Bt cotton

In China, 7 million smallholder resource-poor farmers grew a record 3.9 million hectares of *Bt* cotton at the highest adoption rate to date of 71.5%. The government has reconfirmed the national importance of biotech crops, to be developed under strict biosafety standards. Biotech phytase maize and *Bt* rice, approved for biosafety in 2009, are undergoing routine field testing.

Maize has been accorded priority for commercialization to meet a rapidly growing demand for domestically produced biotech maize as an animal feed in response to a demand for more meat. The expected commercial approval of biotech Golden Rice in the Philippines in 2013/14 will be of significance to China, and also to Vietnam and Bangladesh which are evaluating the product with a view to deployment.

Mexico, successful with biotech cotton; trials biotech maize

In 2011, Mexico planted 161,500 hectares of biotech cotton and 14,000 hectares of biotech RR®soybean for a country total of 175,500 hectares, compared to 71,000 hectares in 2010. This 146% increase is an impressive performance by any standard. The aim is self-sufficiency in cotton during the next few years.

Following productive discussions between the private, social and public sectors to develop a "best practices regulatory system" that would facilitate predictable access to biotech cotton for farmers in Mexico, approval has been granted to commercialise up to ~340,000 hectares of a specific biotech cotton (Bollgard II and RR Flex) to be planted annually in specific northern states of Mexico.

The most significant recent development was the planting of the first biotech maize trials in the country in 2009, which continued into 2010 and 2011. Mexico grows over 7 million hectares of maize but imports about 10 million tonnes per annum at a foreign exchange cost of US$2.5 billion. This could be partially offset with higher yielding home-grown biotech maize hybrid cultivated in Mexico's northern states.

Mexico is estimated to have enhanced farm income from biotech cotton and soybean by US$121 million in the period 1996 to 2010 and the benefits for 2010 alone are US$19 million; the potential for the future is substantial (Brookes and Barfoot, 2012).

In Africa, three countries planting, another three conducting field trials

Africa made steady progress in 2011 in planting, regulatory and research activities on biotech crops. The three countries already commercializing biotech crops (South Africa, Burkina Faso and Egypt), together planted a record 2.5 million hectares. An additional three countries, Kenya, Nigeria, and Uganda, conducted field trials, while others like Malawi have already approved pending trials.

Trials focusing on Africa's pro-poor priority staple crops including maize, cassava, banana and sweet potato are making good progress. Examples include drought tolerant maize through the Water Efficient Maize for

Africa project, with ongoing second season trials in Kenya, South Africa and Uganda.

Argentina and Canada continue to post gains

Argentina ranked 3rd, and Canada ranked 5th, among countries adopting biotech crops. They retained their world rankings and both posted record hectarage of biotech crops at 23.7 million hectares and 10.4 million hectares, respectively. The largest gain in Argentina was biotech maize increasing by ~900,000 hectares, and in Canada herbicide tolerant canola increased by ~1.6 million hectares after Canada reported its largest ever canola crop.

Australia's cotton was 99.5% biotech

Following an unprecedented drought for three years followed by floods, Australia planted its largest ever hectarage of cotton of which 99.5% was biotech, equivalent to 597,000 hectares. In addition, Australia grew ~140,000 hectares of herbicide tolerant canola for a total of over ~700,000 hectares for the two biotech crops cotton and canola. There is also significant R&D effort in Australia on biotech wheat and sugarcane.

EU's Bt maize planting, up by 26% or 23,297 hectares from 2010

Six EU countries (Spain, Portugal, Czech Republic, Poland, Slovakia and Romania) planted a record 114,490 hectares of biotech *Bt* maize, a substantial 26% higher than 2010, with Spain growing 85% of the total in the EU with a record adoption rate of 28%.

An additional two countries, Sweden and Germany, planted a token 17 hectares of the new biotech quality starch potato named "Amflora" for seed production for a total of 114,507 hectares of biotech crops planted in the EU.

Bt maize hectarage increased in the three largest *Bt* maize countries: Spain, Portugal and Czech Republic, remained the same in Poland, and decreased in Romania and Slovakia. The marginal decreases in *Bt* maize there was associated with several factors, including disincentives for some farmers due to bureaucratic and onerous reporting of intended plantings of *Bt* maize.

Pending approval, 2014 should see the release of a new biotech potato named "Fortuna" resistant to late blight, the most important disease of potatoes. It is potentially an important product that can meet EU policy and environmental needs to make potato production more sustainable by reducing heavy fungicide applications and decreasing production losses estimated at up to US$1.5 billion annually in the EU alone, and US$7.5 billion worldwide.

Contribution of biotech crops to food security

From 1996 to 2010, biotech crops helped achieve food security by: increasing crop production and value by US$78 billion, providing a better environment and saving 443 million kg of (active ingredient) pesticides. In 2010 alone they helped reduce CO_2 emissions by 19 billion kg, equivalent to taking ~9 million cars off the road, conserve biodiversity by saving 91 million hectares of land and alleviate poverty by helping 15 million smallholder farmers who are some of the poorest people in the world (Brookes and Barfoot, 2012).

Increase in crop production from 1996 to 2010 is due mainly to the four major biotech crops whose distribution and adoption is discussed below:

- Adoption by crop-biotech soybean remains the dominant crop
  Biotech soybean continued to be the principal biotech crop in 2011, occupying 75.4 million hectares or 47% of global biotech area, followed by biotech maize (51.00 million hectares at 32%), biotech cotton (24.7 million hectares at 15%) and biotech canola (8.2 million hectares at 5%).
- Adoption by trait — herbicide tolerance remains the dominant trait
  From the beginning of commercialization in 1996 and up to 2011, herbicide tolerance has consistently been the dominant trait. In 2011, herbicide tolerance deployed in soybean, maize, canola, cotton, sugarbeet and alfalfa, occupied 59% or 93.9 million hectares of the global biotech area of 160 million hectares.
- Stacked traits occupied ~25% of the global 160 million hectares
  In 2011, the stacked double and triple traits occupied a larger area (42.2 million hectares, or 26% of global biotech crop area) than insect resistant varieties (23.9 million hectares) at 15%. The stacked genes were the fastest growing trait group between 2010 and 2011 at 31% growth, compared with 5% for herbicide tolerance and ~10% for insect resistance. This reflects a clear farmer preference for stacked traits. Stacked traits are an increasingly important feature of biotech crops ~12 countries planted biotech crops with stacked traits in 2011, and nine of them were developing countries.

Global value of the biotech seed market

Global value of biotech seeds alone was US$13.2 billion in 2011, with the end product of commercial grain from biotech maize, soybean grain and cotton valued at ~US$160 billion or more per year. A 2011 study estimated that the cost of discovery, development and authorization of a new biotech crop/trait is ~US$135 million.

In 2011, the global market value of biotech crops, estimated by Cropnosis, which provides market research in the crop protection and biotechnology sectors, was US$13.2 billion — up from US$11.7 billion in 2010. This represents 22% of the US$59.6 billion global crop protection market in 2011, and 36% of the US$37 billion commercial seed market. The estimated global farm gate revenues of the end product, the biotech grain and other harvested products, is much greater than the value of the biotech seed alone (US$13.2 billion). Extrapolating from 2008 data, biotech crop harvested products would be valued at approximately US$160 billion globally in 2010, and projected to increase at up to 10–15% annually (Cropnosis, 2011. Personal Communication).

Benefits of biotech crops and their contribution to sustainability

Biotech crops are contributing to sustainability in the following five ways:

- Increasing productivity and economic benefits sustainably at the farmer level
  Economic gains at the farm level of ~US$78 billion were generated globally by biotech crops during the fifteen year period 1996 to 2010, of which 40% were due to reduced production costs (less ploughing, fewer pesticide sprays and less labour) and 60% due to substantial yield gains. The corresponding figures for 2010 alone were 76% of the total gain due to increased yield and 24% due to lower cost of production (Brookes and Barfoot, 2012).
- Conserving biodiversity
  Biotech crops are a land-saving technology, capable of higher productivity on the current 1.5 billion hectares of arable land, and thereby can help preclude deforestation and protect biodiversity in forests and in other biodiversity sanctuaries.
  Approximately 13 million hectares of biodiversity rich tropical forests are lost in developing countries annually. If the 276 million tonnes of additional food,

feed and fibre produced by biotech crops during the period 1996 to 2010 had not been produced by biotech crops, an additional 91 million hectares of conventional crops would have been required to produce the same tonnage (Brookes and Barfoot, 2012).

Some of the additional 91 million hectares would probably have required fragile marginal lands, not suitable for crop production, to be ploughed. Or it may have seen tropical forests, rich in biodiversity, felled to make way for slash and burn agriculture in developing countries, thereby destroying biodiversity.

- Contributing to the alleviation of poverty and hunger

  To date, biotech cotton in developing countries such as China, India, Pakistan, Myanmar, Bolivia, Burkina Faso and South Africa have already made a significant contribution to the income of ~15 million smallholder resource-poor farmers in 2011. This can be enhanced significantly in the coming few years principally through biotech cotton, maize and rice.

- Reducing agriculture's environmental footprint

  Conventional agriculture has significantly impacted the environment and biotechnology can be used to reduce its environmental footprint.

  So far, progress includes: a significant reduction in pesticides; saving on fossil fuels; decreasing CO_2 emissions through decreased ploughing; and conserving soil and moisture by optimizing the practice of no till through application of herbicide tolerance.

  The accumulative reduction in pesticides for the period 1996 to 2010 was estimated at 443 million kg of active ingredient (a.i.), a saving of 9.1% in pesticides. This is equivalent to a 17.9% reduction in the associated environmental impact of pesticide use on these crops, as measured by the Environmental Impact Quotient (EIQ) — a composite measure based on the various factors contributing to the net environmental impact of an individual active ingredient. The corresponding data for 2010 alone was a reduction of 43.2 million kg a.i. (equivalent to a saving of 11.1% in pesticides) and a reduction of 26.1% in EIQ (Brookes and Barfoot, 2012).

- Increasing efficiency of water usage

  Seventy percent of fresh water is currently used by agriculture globally, and this is obviously not sustainable in the future as the population increases by nearly 50% to over 9 billion by 2050. The first biotech maize hybrids with a degree of drought tolerance are expected to be commercialised by 2013 in the USA, and the first tropical drought tolerant biotech maize is expected by 2017 for sub-Saharan Africa. Drought tolerance is expected to have a major impact on more sustainable cropping systems worldwide, particularly in developing countries, where drought is more prevalent and more severe than industrial countries.

- Helping mitigate climate change and reducing greenhouse gases
  Biotech crops can contribute to a reduction of greenhouse gases and help mitigate climate change in two principal ways.
  First, there are permanent savings in carbon dioxide (CO_2) emissions through reduced use of fossil-based fuels, associated with fewer insecticide and herbicide sprays. In 2010, this was an estimated saving of 1.7 billion kg of CO_2 equivalent to reducing the number of cars on the roads by 0.8 million.
  Secondly, additional savings from conservation tillage for biotech food, feed and fibre crops, led to an additional soil carbon sequestration equivalent to 17.6 billion kg of CO_2 in 2010. This is similar to removing 7.9 million cars off the road. Thus in 2010, the combined permanent and additional savings through sequestration was equivalent to a saving of 19 billion kg of CO_2 or removing 9 million cars from the road (Brookes and Barfoot, 2012).
  Droughts, floods, and temperature changes are predicted to become more prevalent and more severe as we face the new challenges associated with climate change. Hence, there will be a need for faster crop improvement programmes to develop varieties and hybrids that are well adapted to more rapid changes in climatic conditions. Several biotech crop tools, including tissue culture, diagnostics, genomics, molecular marker-assisted selection (MAS) and biotech crops can be used collectively to 'speed the breed' and help mitigate the effects of climate change.

Collectively, the above five thrusts have already demonstrated the capacity of biotech crops to contribute to sustainability in a significant manner and help mitigate the formidable challenges associated with climate change and global warming. The potential for the future remains enormous. Biotech crops can increase productivity and income significantly and serve as an engine of rural economic growth that can contribute to the alleviation of poverty for the world's small and resource-poor farmers.

Status of approved events for biotech crops

A total of 29 countries planted commercialised biotech crops in 2010. An additional 31 countries have granted regulatory approvals for biotech crops for import for food and feed use and for release into the environment since

1996. Turkey started approving biotech crops for import into the country in 2011. A total of 1,045 approvals have been granted for 196 events for 25 crops.

Thus, biotech crops are accepted for import for food and feed use and for release into the environment in 60 countries, including major food importing countries like Japan, which does not plant biotech crops. Of the 60 countries that have granted approvals for biotech crops, USA tops the list followed by Japan, Canada, Mexico, South Korea, Australia, the Philippines, New Zealand, the European Union, and Taiwan.

Future Outlook

The adoption of biotech crops in the four-year period 2012 to 2015 will depend on three factors:

- The timely implementation of appropriate, responsible and cost/time-effective regulatory systems
- Strong political will and enabling financial and material support
- A continuing wave of improved biotech crops that will meet the priorities of industrial countries and developing countries in Asia, Latin America and Africa.

There is an urgent need for appropriate, science-based and cost- and time-effective regulatory systems that are responsible, rigorous but not onerous, for small and poor developing countries. Lack of appropriate regulation is the major constraint that denies poor countries timely access to biotech crops which can contribute, but are not a panacea, to urgent food security needs. They can help in countries such as those in the Horn of Africa, where up to 10 million were at risk from famine triggered by drought in 2011, and exacerbated by many other factors.

The outlook for biotech crops in the remaining four years of the second decade of commercialization, 2012 to 2015, is assessed as cautiously optimistic. The year 2010 was a highlight. The increase in hectarage of biotech crops was the second highest in history and substantial progress was made on all fronts.

The growth in 2011 represents a phase of consolidation of gains to date, which is expected to continue in 2012, with a new country possibly becoming the 30th country to plant biotech crops globally. The consolidation of gains in 2011 and 2012 is projected to be followed by a more active period during which up to 10 countries may adopt biotech crops for the first time, bringing the total number of biotech crop countries globally to about 40 by 2015.

These new biotech countries are likely to include three more Asian countries, up to seven in sub-Saharan Africa (subject to regulatory approval) and possibly some additional countries in Latin/Central America and Western/Eastern Europe. Western Europe is a particularly difficult region to predict because the issues are not related to science and technology considerations but are of a political nature and influenced by ideological views of activist groups.

A biotech potato resistant to late blight discussed earlier offers an attractive and appropriate opportunity for selected potato-growing countries in the EU to join the growing number of countries benefiting from biotech crops globally.

In contrast to the first generation biotech crops that realized a significant increase in yield and production by protecting crops from losses caused by pests, weeds, and diseases, the second generation biotech crops will offer farmers additional new incentives for also improving quality of products. For example, quality traits, such as enhanced Vitamin A in rice, soybean free of trans-fat and reduced saturated fat and omega-3 rich soybean will become more prevalent, providing a much richer mix of consumer-friendly traits for deployment in conjunction with a growing number of input traits.

Five years ago in North America, a decision was made to delay the introduction of biotech herbicide tolerant wheat, but this decision has been revisited. Many countries and companies are now fast-tracking the development of a range of biotech traits in wheat including drought tolerance, disease resistance and grain quality. The first biotech wheat is expected to be ready for commercialization around 2017.

In closing, future prospects up to 2015 and beyond look encouraging. We can expect an increase of up to 10 new developing countries planting biotech crops, led by Asia and Latin America, and there is cautious optimism that Africa will be well-represented. The first biotech based drought tolerant maize is planned for release in North America in 2013 and in Africa by 2017. Golden Rice is set to be released in the Philippines in 2013/2014. *Bt* rice has an enormous potential to benefit up to 1 billion poor people in rice households in Asia alone.

Biotech crops, whilst not a panacea, have the potential to make a substantial contribution to the 2015 Millennium Development Goal of cutting poverty in half, by optimizing crop productivity. This can be expedited by public-private sector partnerships, such as the WEMA project, supported in poor developing countries by the new generation of philanthropic entities, such as the Gates and Buffet foundations.

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4

PLUGGING THE WORLD OF TOMORROW INTO GREEN ENERGY

23

DESERTEC — Clean Power from Deserts

Hani El Nokraschy

Deserts are found all over the world. Within 6 hours, they receive more energy from the Sun than that used by humanity throughout a whole year. With technologies available today, it is possible to harvest enough energy from wind and solar radiation, convert it to electricity and transmit it by means of high voltage direct current (HVDC) to urban districts within 3,000 km of these deserts. This could supply about 90% of humanity with clean, sustainable and "on demand" electricity.

A series of three studies, MED-CSP, TRANS-CSP and AQUA-CSP, commissioned by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, and conducted by the German Aerospace Center (DLR) in cooperation with several institutions from Middle East and North Africa (MENA), demonstrate the economic feasibility of this concept as applied to the EU-MENA region.

Available technologies

The studies showed that Concentrating Solar Power (CSP) with thermal storage for 10-14 hours and a backup emergency boiler could supply sufficient electricity for the peoples of MENA and an additional portion that can be transmitted to EU by means of HVDC lines around and through the Mediterranean.

Concentrating the sunrays is only possible for direct sunrays, as diffused sunrays or light cannot be concentrated. Direct sunrays are abundant in the desert regions nearly all year long. This makes them the ideal place to install thousands of mirrors concentrating the direct sunrays on a point or line focus, depending on the technology adopted. In both cases, a portion

Figure 1 The deserts of the world. The red square is the area needed to supply the whole world population with electricity (Source: DESERTEC Foundation)

of the collected heat is stored at a temperature of 400 to 550°C in a storage media to use during the night.

Concentrating solar thermal power plants have some technical advantages over photovoltaics (PV). Here, sunlight is concentrated to create heat, which may be used directly to generate steam and drive a turbine, or it may be stored cheaply and efficiently. Steam can then be generated at night from stored heat, allowing CSP plants to generate power during the dark hours of night or when the sky is cloudy. Gas or biofuel may be used as a stop-gap source of heat when there is not enough sun during long cloudy spells. This means that CSP plants can reliably deliver power on demand whenever it is required.

This ability to respond flexibly to peaks or troughs in demand is invaluable in maintaining the stability of power grids. Without that kind of facility, variable sources of power such as wind farms and photovoltaics may need to be backed up by supplies from conventional power plants (coal-fired, gas-fired and nuclear power plants), from pumped storage power plants (which are not widely available), or from relatively inefficient and expensive power storage devices.

Solar-thermal power plants have been in use commercially for two decades in the deserts of California, US. The first plants have been operating in Kramer Junction in California since the mid-1980s and new plants have

Figure 2 Andasol 1 in Spain - a 50 MW CSP power station with thermal storage for 7 hours full load operation after sunset (Source: Solarmillenium)

come on stream recently in Spain and Nevada. With the right framework of laws and regulations, the development of CSP plants may be ramped up fairly fast. Also, HVDC transmission lines have been in commercial use for decades and manufacturing capacity may be expanded as required.

There are two important features of HVDC transmission lines that will help win their acceptance by the public. Firstly, HVDC transmission lines hardly produce any electrosmog, which is invisible electromagnetic radiation which some claim may have adverse health effects. Secondly, for a relatively small increase in cost compared with overhead lines, it is possible to lay HVDC transmission lines underground or underwater, thus minimising their visual impact and speeding up planning applications.

A solution to water scarcity

Clean and sustainable water supply is urgently needed in MENA due to the increase of population and limited water resources. Another portion of the harvested energy can be used — most economically from waste heat from the steam turbine exhaust — for seawater desalination.

Using the waste heat of the steam cycle will essentially reduce its efficiency and thus its electricity output, which may be disadvantageous

Figure 3 HVDC lines connecting the economic sites for harvesting renewable energies in EU and MENA. Estimated losses 3% for each 1000 km (Source: DESERTEC Foundation)

for the investor. However, in desert regions, water is urgently needed as the increase in population may give it an even higher priority over electricity.

Future cost estimation

The costs of using fossil fuels for electricity generation continue to climb while renewable energy sources are becoming cheaper. It is easy to predict that the current trends of depending on burning fossil fuel and nuclear power generation will turn out to be the most expensive option on the long run. Switching to renewable sources may look expensive at the beginning, but after an initial push that enables their establishment in the market – they will continue their evolution of cost reduction following their learning curves.

International co-operation

Currently, Germany is facing the challenge of the so called "Energiewende" – or the shift to renewable energy. This triggered many discussions regarding the increased costs of electricity and reliable supply, following the decision to shut down all nuclear power plants by 2022 followed by a series of phasing out old coal power stations. The DESERTEC concept

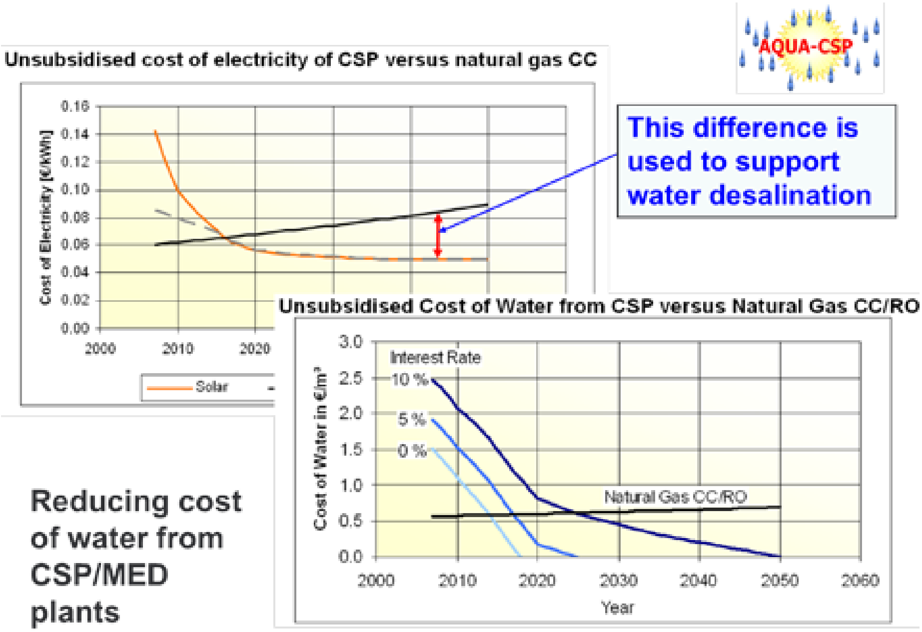

Figure 4 Seawater desalination using waste heat from CSP power plants. Cost of water production is subsidized by the profit from selling solar electricity at beneficial prices. (Source: DLR study AQUA-CSP)

offers a realistic solution to these topics and moreover gives the opportunity for developing MENA countries — a very dynamic region — which may result in prosperity and peace for both EU and MENA, if wisely managed.

One of the options is to direct each one of the HVDC lines from MENA to a nuclear power station site that is about to be shut down. This would allow the usage of the available infrastructure and avoid excessive reinforcement of the grid.

Scenario for co-operation between EU and MENA. About 20% of the CSP electricity from MENA can be supplied to the EU grid, covering 15% of the demand in EU to compensate fluctuations of wind and PV. (Source: DLR studies)

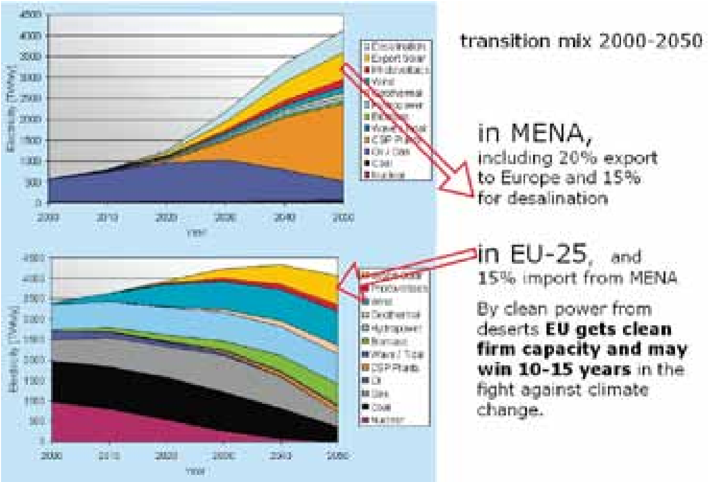

Figure 5 Scenario for co-operation between EU and MENA. About 20% of the CSP electricity from MENA can be supplied to the EU grid, covering 15% of the demand in EU to compensate fluctuations of wind and PV. (Source: DLR studies)

Conclusion

The DESERTEC concept to enable 10 billion people to live in a peaceful and sustainable way on our small planet with limited resources is summarized as follows:

- Responsibility when managing the remaining resources
  - Education for wise resource management
- All peoples of the earth shall have a realistic chance for development
  - Energy for development
- Collect energy from the deserts, as it is abundant and not used
  - The Sun provides in 6 hours the energy used by humanity in one year
- Transport the collected energy from the deserts over long distances to the users
  - Via HVDC, an available technology
- Produce potable water by desalination to satisfy food demand
  - Clean electricity and use of waste heat for desalination

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24

Tackling Waste Electrical and Electronic Equipment

João de Saint Brisson Paes De Carvalho

Since the 1930's, the electrical and electronic industry has created a huge market for all sorts of devices and equipment. With the progress of the technology, the obsolescence is gaining momentum and, today, the problem of gathering, treating and giving final destination to that scrap has acquired massive proportions.

Some countries have adopted effective policies that prevent the pollution caused by the inadequate disposal of Waste Electrical and Electronic Equipment (WEEE) and have organized re-processing systems to capture the value of that scrap.

We intend to present a short description of the suggested model to be adopted in the Metropolitan Area of Rio de Janeiro in Brazil.

Introduction

The recent volume of WEEE generation in the world has been evolving at a rapid pace.

Obtaining credit to finance consumption is easier than ever before. In most developed and developing countries, the combination of falling prices, high wages and rapid incorporation into industry and services of huge contingents of workforce meant that the consumer goods markets — durable and non-durabl — expanded significantly.

Typically, the heart of electronic equipment is comprised of a printed circuit board mounted with electronic components increasingly sophisticated and powerful, but, unfortunately, with an increasingly shorter lifespan. The speed of technological advances, aided by excellent marketing campaigns that emphasise the need for product replacement by newer more advanced models with often lower prices than the "antiquities" that we are using, cause rapid obsolescence.

Thus, the end of the useful life of these devices generates more and more garbage on a shorter time span. Despite all the campaigns of reuse, recycling and upgrading of equipment, these huge volumes of electronic devices will be dropped sooner or later by total technological obsolescence.

The improper discard of waste electrical and electronic equipment (WEEE) creates two problems. The first is the loss of materials that can be reused by recycling and remanufacturing, affecting the sustainability of the industrial process and the consumption pattern adopted by mankind. The second problem is the increased load of heavy metals, plastics and other materials of slow absorption that find their way into the environment.

Solutions for processing and reuse are being sought by governments and businesses. In the case of governments, programmes are being developed and implemented in almost all developed and developing countries. Unfortunately, many of these programmes are still in the pre-operating phase, including in Brazil.

Sustainability and sustainable development

The impact of rampant consumption and production of electronic equipment is far above the level of sustainability required these days for any activity, from an environmental as well as an economic point of view.

The term "sustainability" became widespread after 1987, when the Brundtland report of the World Commission on Environment and Development, commissioned by the UN, defined sustainable development as the kind of development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Of course, this is not the case today in the electronics industry trends.

Among the many indexes, the "Ecological Footprint" measures the power, in solar energy, required for the production of raw materials needed to manufacture the product and for the disposal of its by-products and wastes and translates it into a corresponding physical area. By combining these factors it generates an index called SPI (Sustainable Process Index) (Krotscheck, Naradoslawsky, 1995).

The comparison of the required area to keep the pattern of consumption of different regions shows the discrepancy in the use of resources. In 2007, the planet's population needed, by SPI, 2.2ha/per capita. However, there was only 1.8ha of biocapacity to manufacture products and absorb the wastes of production. The table below shows the average values for the ecological footprint of different countries:

Table 1 Ecological footprint (State of the Planet, New Scientist, January 2007)

Europe (EU25 and Switzerland)	4.7 ha
China	1.6 ha
Brazil	2.1 ha
India	0.7 ha
Great Britain	5.6 ha
USA	9.7 ha

Considering the demand growth noted in several categories of electronics, the ecological footprint grew enormously, demonstrating the urgency of a structured and economically viable method for recycling this equipment and its components.

The electrical and electronic waste

The average composition of electronic waste includes materials with broad market and with significant economic value due to the large amounts of equipment which are discarded annually.

The following table shows the main materials found in the WEEE:

Table 2 What is found in a million tonne of WEEE? — Cimelia Corp

Iron	35 to 40%
Copper	17%
Lead	2 to 3%
Aluminium	7%
Zinc	4 to 5%
Gold	0.2 to 0.3 Kg
Silver	0.3 to 1.0 Kg
Platinum	0.03 to 0.07 Kg
Fibres/Plastics	15%
Paper/Cardboard	5%
Non-recyclables	3 to 5%

On one hand, there is a value to be retrieved. But on the other, retrieving them is a difficult task due to the large number of materials that make up this garbage.

The expectation of exhaustion of many minerals used in electronic circuits is discussed in an article in Super Interessante based on data from the United States Geological Survey, Yale University and Lithium Supply and Markets 2009. The expectation of reserves depletion (in years), at the estimated consumption from the beginning of this decade and at projected rates, and the percentages of the volume currently recycled is shown below:

Table 3 The expectation of reserves depletion based on estimated consumption patterns

MATERIAL Use in	CONSUMPT. (kg per capita)	RESERVES Actual Consumption	RESERVES Projected Consumption	RECYCLING (in %)
LEAD Batteries	410	42	8	72
SILVER PCI's	1,6	29	9	16
ANTIMONIUM Remote Contr.	7	36	13	N/D
GOLD Microchips	0,048	45	36	43
NICKEL Cell phones	0,058	90	57	35
INDIUM TVs/LCDs	0,032	13	4	0
COPPER Cables	630	61	20	31
TIN Joysticks	15	40	17	26
LITHIUM Batteries	N/D	113	46	N/D

It is important to note that the mining of metals and other materials and the subsequent refining for industrial use consume large amounts of energy. It is an additional major cause of pollution and environmental degradation. In many regions, the energy required for these processes is produced by combustion of coal, oil and gas.

Contamination of the environment

As seen above, the WEEE is composed of about 1,000 materials such as metals, rare earths, glass, plastics and paper. By itself, this already represents a major issue for remanufacturing or recycling.

Among these materials there are toxic substances like arsenic, lead, cadmium, chromium, mercury, selenium and flame retardants in plastics (which when incinerated produces dioxins).

Today, the streets and the dumps are littered with remains of equipment that were destroyed by "scrap dealers" who seek the immediate expensive metals. Unfortunately, the process used by them is precarious, dangerous and wasteful, yielding low income.

To make matters worse, this "processing" puts the people involved and the soil in danger of contamination by heavy metals. This is a problem that affects Brazil and most countries around the world.

China

Negeria

Latin America

Possible solutions: Reuse, remanufacture and recycle

The question of sustainability and pollution caused by the disposal or treatment of WEEE leads to a crucial discussion about the reuse of this waste. The current knowledge advocates that the method of treating waste generally passes through the 3 R's, a hierarchy determined by less aggression to the environment:

- REDUCE our propensity to consumption, use the products longer, be immune to fashion trends and therefore delay the generation of waste;
- REUSE, in order to give a second life to products either by maintenance to renew and extend its useful life or even reuse parts in new products with the same or a new purpose;
- RECYCLE, reprocess the materials and partially save the energy used in its manufacture.

The second R, REUSE, is the process that best leverages the investment of materials, labour and energy of a product. But it needs to overcome many problems.

First, it is necessary to reduce the cost of dismantling by reducing labour costs. This applies to products containing high value materials. It would be impossible to carry out such an operation profitably with products of low value.

Second, the large scale adoption depends on having standardised designs for many parts, which would potentially harm technology progress and competition.

Third, we must understand the global economic movement — electronics are manufactured and sold in many markets, each with its own technical standards and consumer preferences.

Fourth, the sale to the consumer of remanufactured products must be accompanied by a guarantee of minimum life — which is a difficult thing to calculate and ensure due to the use of components with partly worn life.

Thus, while reuse should be a goal to be pursued, practically, its large scale adoption faces many difficulties.

The recycling of materials, whatever the rate of reuse, will be the main route to tackle the problem of the WEEE. Sooner or later, all equipment will end up as scrap.

Recycling allows reuse of minerals and other raw materials and saves much of the electricity used in the production of virgin materials. This reduces pollution caused by mining and power generation, saves water, creates a thriving industry and reduces costs for the manufacturer and the consumer.

This data is corroborated in several studies. The British Material Recycling Association (BMRA) shows the reduction in the use of original raw material and energy used:

Table 4 Metal and energy savings of recycling (http://www.recyclemetals.org/about_metal_recycling)

Recycling Scorecard	New metals made using recycled metals	Energy saving
Aluminium	39%	95%
Copper	32%	85%
Lead	74%	60%
Steel	42%	62-74%
Zinc	20%	60%

Obviously, recycling is not problem-free. The main problem is the difficulty of economic separation and purification of the different materials.

Reverse logistics

Most countries have adopted the principles of the European Community's (EC) WEEE Directive. Brazil has enacted a similar law that makes the manufacturer and/or importer the main party responsible for the end-of-life of electrical and electronic equipment (EEE), with the obligation to setup the collection with the retailers and waste systems.

The ultimate goal is to reconcile the interests of economic and social agents, business processes and environmental management. This is done by promoting the reuse of materials, reducing the generation of solid waste, pollution and environmental damage and stimulating the production and consumption of products derived from recycled and recyclable materials. Consumers have the responsibility to return used EEE at collection points.

In all countries, collection and recycling costs are borne by producers and/or importers and are passed on to consumers, included in the purchase prices of EEE.

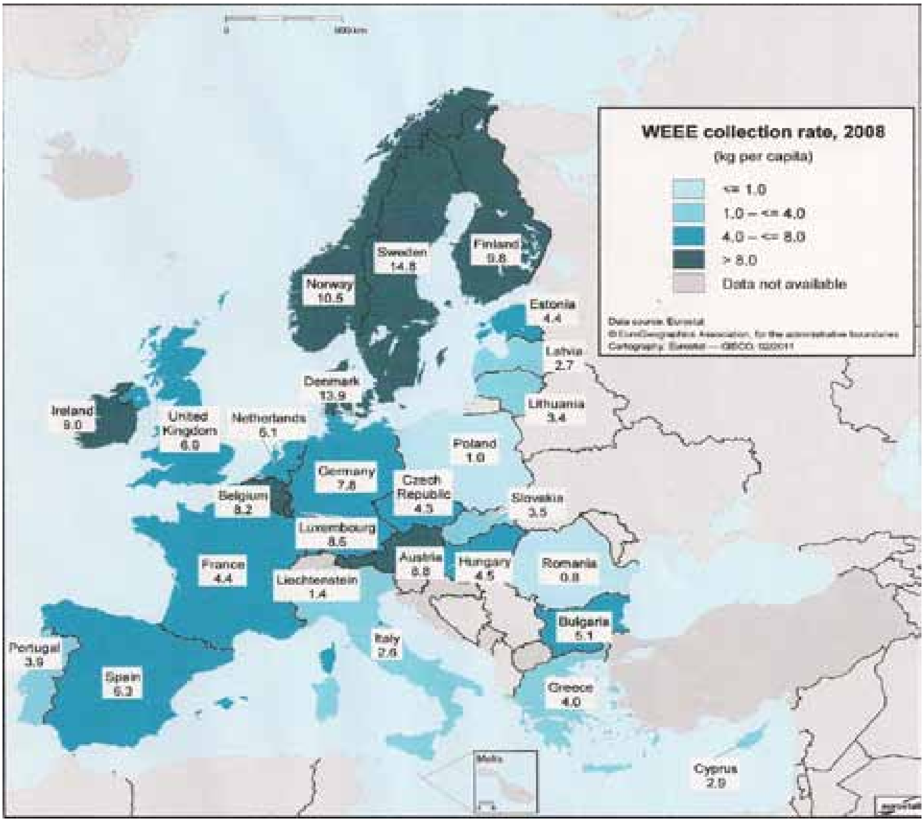

Figure 1 Map of WEEE collection in Europe.
(http://epp.eurostat.ec.europa.eu/portal/page/portal/waste/data/wastestreams/WEEE)

The results obtained by EC are quite good, as shown in the following map, taking into account that in 2008, manufacturers and importers sold approximately 5.1 Mt in EEE products, or 9.8 kg/citizen in average.

As an example, in 2001, Sweden launched a not-for-profit public-private system called El-Kretsen, controlled by 20 business associations and town halls. In 2008 it created another organization, the EAF, which collects the WEEE from shops. The scheme works as follows:

The physical flows are presented in continuous line and financial flows in dithered lines. Based on this scheme, consumers pay to producers which in turn finance the collection, treatment and recycling.

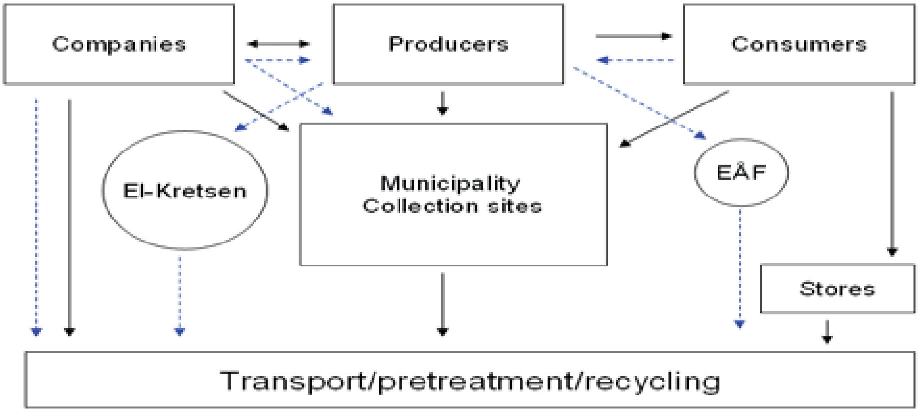

Figure 2 Operation scheme of WEEE collection in Sweden

The items that affect the cost of the reverse logistics process are:

- Distances and the local geography
- Population density
- Volume of WEEE
- Product type
- Cost of labour
- Standards of recycling and treatment
- Consumer behaviour
- Accumulated experience

The Rio de Janeiro case

The metropolitan region of Rio de Janeiro (RJMR), a conurbation of 19 municipalities, covers an area of 5,645 km^2 and had an estimated population of 11.9 million in 2008. RJMR's GDP was estimated at US$118 billion in 2008, resulting in a per capita income of US$32,000.

A 2007 census found that 99.95% of approximately 5 million households in the State of Rio de Janeiro had access to electricity; 98.41% had refrigerators; 98.42% televisions; 94.23% radios; 61.81% washing machines; 34.66% computers; and 88.22% phones.

To that inventory of EEE, we should add the equipment of the strong industrial, communication, commercial and services sectors.

Figure 3 Map of RJMR (white border)

According to estimates of the Royal Society for the Encouragement of Arts, Manufactures and Commerce (RSA) in the United Kingdom, through their WEEE MAN environmental awareness initiative, a Briton, on average, creates 16 kg/year of WEEE, directly and indirectly.

If we adjust that amount by the ratio of per capita income as published by the World Bank, a Brazilian citizen will generate about 3 kg/year of WEEE. Since the inhabitants of RJMR generate a per capita GDP of approximately 1.34 times more than the average Brazilian, WEEE generated by a citizen of the State of Rio de Janeiro should be about 4 kg/year.

Considering the population of 11.5 million, we will have an estimated production of WEEE of about 46,000 tonnes/year, of which approximately 72% are recoverable metals.

At an estimated processing rate of 80%, the value of those metals is about US$70 million, considering that the precious metals are not recovered in Brazil. If that recovery was made, the value would reach about US$600 million.

The RJMR Project

For analysis purposes we compared a totally private (TOPRI) and a totally public (TOPUB) setups.

The basic design is relatively simple, but it is not similar in both cases. The TOPRI model will need to install collection centres (CC) in several municipalities, neighbourhoods or regions depending on the volume of WEEE or population, while the TOPUB setup already has a domestic collection system established and will take the WEEE directly to its centres of accumulation:

1. Considering the development, by TOPRI, of CCs (one per 40 m^3/week of WEEE or 30,000 inhabitants, manned by 3 employees) in places where the population, small industries and commerce would deliver their WEEE; and considering domestic collection in the TOPUB project since the urban cleaning services already does it in most areas;
2. Establishing a processing centre (CP) where the WEEE received from the CC and/or from domestic collection and from large industries and trade will be disassembled and the materials distributed to industrial recyclers or disposal in suitable location;
3. Transport from the CC (TOPRI) or directly from domestic collection (TOPUB) to the CP.

Below we present a worksheet with the estimated costs for RJMR, considering labour, transportation costs, rentals, facilities, administration and other expenses:

Table 5 Calculation of cost for TOPRI and TOPUB

ESTIMATED COSTS		**USD 1,000**	
		TOPRI	**TOPUB**
Transport (TOPRI) Collection (TOPUB)		11,600	14,500
Management of CC:	Rentals/expenses (1)	1,000	0
	Labour costs	10,200	0
SUB-TOTAL LOGISTICS		22,800	14,500
Processing at CP	Labour ($ 0.083/kg)	3,600	3,600
	Rentals (2)	200	200
	Direct Expenses (3)	800	800
	Indirect Expenses (4)	600	600
SUBTOTAL DESMANTLING		5,200	5,200
TOTAL COST		**28,000**	**19,700**

(1) Estimated at US$250 per Collection Centre; (2) 3,000 m² at US$8/month; (3) Estimated at US$12.50 per worker per month; (4) Estimated at US$100,000 per month.

Discussion, conclusion and recommendations

Based on the above estimate, the TOPRI setup is costlier than the TOPUB solution, with the collection being the cost factor of differentiation. Incidentally, the cost of collection corresponds to approximately three quarters of the total cost of WEEE collection and processing in the two alternatives (81% in TOPRI and 74% in TOPUB). This shows that the logistics will be the main factor of possible economic gains.

In this study we took a simplistic vision of gathering 100% of the region's WEEE. We know that this total will never be reached because even in Europe, where policies have already been in place for a long time, the goal is to achieve an average of 65% of the weight of the EEE placed in the market.

An important aspect is that the cost of collection and processing is less than the value of the WEEE, estimated at US$70 million, and provides a sustainable solution in the long term, from the economic point of view, regardless of which option is adopted.

Obviously, the WEEE must not be previously scavenged by the junk collectors who will take the most valuable metals, such as copper (37% of value) and PCI (51% of value), and leave low value junk for the system.

The calculation of the break-even point shows that the RJMR system will balance at a collection rate of 52% of the WEEE generated, which will take a reasonable time to reach. This will make the system costly for the consumer and the manufacturer/importer for a long time.

However, most municipalities of RJMR do not offer a profitable volume of WEEE. That fact does not allow the execution by more than one company or consortium, since the surplus obtained in a few municipalities will have to be directed to cover the deficit in the majority.

As a recommendation for policy, a shared solution between the public sector and the private sector will be more beneficial to society as a whole, allowing the implementation of the law and getting better results in a shorter period.

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