Biotechnologies of the Future

How a focused science and technology strategy could lead to the creation of millions of jobs while dramatically recovering quality of life in co-evolution with nature

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Background

When the movie Frankenstein first came to the screen, the dangers of runaway science became obvious to the public at large. However, Frankenstein was nothing more than a fantasy. He never existed, and never will. Dolly, on the other hand, does exist, and (un)fortunately this first cloned sheep has the look of a real animal. Therefore, she does not evoke reactions of horror from the public at large. As evidenced by the creation of clones like Dolly, biotechnologies are popular and, although debate continues, only a few dislike her and only a minority vilify her. In reality, the opportunities afforded by biotech are vast and the stakes are great. New industries are about to emerge, fortunes are about to be made, patents registered, and monopolies created. Our lives and lifestyle are being shaped in a way we never imagined possible. Humanity is at a crossroads.

A lot of money is in search of the industries of the future. After the demise of the dotcoms and the disappointment with the telecoms, there is a desire among investment bankers to find the next magic. Some call it "life sciences", others "biosciences". The aim for many is clear: this is a chance to make money. The dream of others is that biotech will eradicate poverty from the world. Some are pretending to render a service to the world while in reality they only care about money[1] and themselves. Interestingly, both are feasible, if the right ethical choices are made. However, fundamental questions should be asked, such as: "can humanity be smarter than 3.8 billion years of evolution"? Is it advisable to change the course of development, creating something that could never otherwise have existed? If

we do so, it could fundamentally change the concept of life. Do we know what we are proposing?"

The present status of biotechnologies has been described as promising. They have been projected as a panacea for many illnesses, especially Alzheimer's and Parkinson's. Some believe that biotechnologies, genetics, and especially stem cell research will offer salvation for those suffering from incurable diseases. Would you object to this groundbreaking research if you were affected? At the mundane level, biotechnology proponents present genetic manipulation as a socially and environmentally acceptable solution for problems like pest control, bacterial infestations, and fungal attacks. Pest resistant crops cause less pollution since they require fewer pesticides. Drought resistant crops consume less energy and water. The benefits are obvious, aren't they?

Often we forget that the problems we face, such as incurable illnesses, pests, and droughts, result from our inability to understand how our production and consumption systems really work. Even the green revolution caused many problems, which have been described in detail elsewhere[2]. It does not demonstrate good governance to first create problems and then develop solutions to the symptoms of the problems without addressing the root causes. If biotechnologies only address the symptoms, then they will go the same route as the dotcoms and the telecoms: broken promises and ultimately large-scale bankruptcies. If, on the other hand, biotechnologies can address the root causes of the broad array of challenges the world faces, then they will likely become the most important industry, replacing the automobile and petroleum industries within a generation.

In light of the above issues, we need to reassess which biotechnologies to endorse and which ones to avoid. We will attempt to set guidelines within which we let our creative minds search for solutions to the most pressing problems our societies are facing. It is within this context that we can then define a role for the best of the biotechnologies. This article will demonstrate that hundreds of new business sectors can emerge in a fraction of the usual time provided biotechnologies are designed as part of a system that is nurtured by a bioculture. Business of the future will emerge and be embraced when its priorities are to respond to the basic needs of people for water, food, health care, housing, energy and jobs *in co-evolution* with nature, using what nature provides. In this framework a new business model will emerge that will provide a tremendous impetus to the development of a

production and consumption model that is fit for the future, one that will be even more than sustainable. The only caveat is that these biotech industries will look fundamentally different from the ones imagined today. Let us explore how.

The wrong turn has been taken without noticing

The Chinese proverb made it clear: "if you give a man a fish, he has food for a day. If you teach him how to fish … he will over-fish!" In the face of rising demand, dwindling ocean fish stocks, and the reduction of river species, there is a need for new fish catch and fish production strategies. As the Worldwatch Institute reports, annual world consumption approached 100 million tons over a decade ago[3] and has declined since. Although the Chinese have successfully practiced fish farming for centuries as part of an integrated biosystem, biotechnologies offered a "new, scientific solution" to the dwindling stocks. The scientific solutions start from the hypothesis that there is a shortage of fish and a scarcity of food. This is the typical mindset of the economist, who exists to study the best allocation of resources in a world suffering from apparent scarcity. It is obvious that the technologies that would be adopted in this framework are fundamentally different than those that would be favored were one to believe that there is no scarcity at all, but rather a world of abundance that has gone unnoticed. If we better understood how biosystems work, how nutrients are generated, and how fish could be farmed, then we would take a very different approach to science and technology.

Under the framework of scarcity, genetic modification of fish is understandable. Let us consider the fish served at many homes. Who would imagine that the white fish stick, coated with breadcrumbs and fried, is the product of biotechnologies? If you could ask this *Tilapia mozambica* if it has any clue where it came from, the poor fish could never imagine that it originated in Southern Africa. Its last stop for modification and breeding was the Philippines. The objective of this scientifically based production system is to allocate scarce resources and feed the world. However, the manipulation of this species is only the beginning of a food chain that can hardly claim to offer quality to the customer.

Most modern fish farming relies on hormonal treatment of fish. To increase productivity, the fish are treated with male hormones so that all females are ideally converted to males or at least neutered[4]. Since we do not check the sex of the fish on our table, most of us are unaware that modern

fish farming is actually the biggest sex change program ever undertaken in history. The logic is simple: the production of eggs is considered a loss of energy and a decrease in the amount of meat available for human consumption. Hormonal treatment raises productivity by 8-15% depending on the type of fish. In addition, the purpose of fish farming in ponds is not to reproduce fish, but rather to generate fish meat quickly. Therefore, although females would seem essential in any type of animal farming, they are actually superfluous.

Trout, salmon, tilapia, and the majority of cultured fish have undergone hormonal treatment and are male only. Even many salmon caught in the wild are escaped farm fish. Only one salmon out of every 200 consumed in Norway was born and grew up in the wild[5]. Not one animal rights organization has raised its voice and criticized this practice. There has been no detailed media coverage of this issue. The implications of this biotechnology are twofold. First, fish has become cheap and abundant, with salmon (once an expensive delicacy) rivaling the price of chicken (also once a delicacy). Second, women should be warned that, since farmed fish are treated with male hormones, moustaches could one day become common among women whose diet includes cultured fish[6]. While scientists would claim that this is an exaggeration, it cannot be disputed that eating a lot of fish could considerably increase the level of male hormones in the body.

This type of monoculture fish farming is also very capital intensive and requires a continuous flow of artificial additives. A typical fish pond is a closed container only 80-90 cm deep and the excessive concentration of one type of fish increases the likelihood of disease. This necessitates the use of antibiotics.

The use of antibiotics in cattle feed is widespread in both Europe and North America. They have also been aggressively introduced into the Third World as part of the drive towards self-sufficiency in food in the developing world. Entrepreneurs in the South are encouraged to adopt the same fish farming techniques as those prevailing in Europe. The country with the largest biodiversity in fish, Colombia, imports genetically manipulated fish fry, along with hormones and antibiotics, at high cost under the pretext that it will offer food security to the farmer's family. Is this an advance in science and technology in an effort to "feed the world"? Or is it a covert action to make the third world dependent on patented chemicals and fish and on feed which is producer controlled? In addition, the end product only serves a few (consumers of fish sticks) and totally neglects both cultural

heritage as well as biodiversity. We need to ask, what well-informed individual would willingly eat genetically manipulated fish which have been treated with hormones to the point of causing a sex change and subjected to excessive antibiotics, which may decrease the efficiency of the consumers' immune system?

Genetic Modifications

Genetic modifications are not novel. The technique was not even invented by human beings. Bacteria have practiced it for over 3 billion years. Two bacteria can simply swap and share genes, change their looks and create new features in a matter of seconds[7]. It is as if a person with blond hair could simply touch a person with an African complexion and acquire dark skin. It is that simple with bacteria. They are able to mutate quickly in response to changing conditions. Since humans are not able to reformulate our antimicrobials quickly enough to keep pace, we have difficultyi finding ways to kill off "germs" chemically. [8].

The fast changing world of bacteria has produced a lot of confusion on one hand, but on the other hand, it has offered the first inroads into biotechnologies under the label of enzymology. Enzymes, mainly produced from bacteria, are critical components of industrial production these days. The Danish multinational Novo Nordisk is likely the leader in the field. No one has modified more natural living species than this low-key Danish group that operates under a very "sustainable" banner. Novo Nordisk makes the enzymes (genetically modified and, of course, with both the product and the process patented) that make your laundry wash whiter than white. The same company makes enzymes for competitors but these are slightly modified so that both are proprietary. Novo Nordisk makes the enzymes that make deep frozen dough produce bread that looks, smells, and tastes like freshly baked, even if it has been in the freezer for weeks. The key is an enzyme that will make the crust of the bread so crunchy that you believe it indeed is fresh. It is all based on modified natural material. The propagation of enzymes is so effective that a process very similar to home yogurt fermentation is now one of the most important biotech processes in the world.

Rice for the Blind[9]

The biotech industry discovered early on that it faced an uphill battle to patent life. The truth is that most of the patented life materials are not really inventions; nature invented them long ago. They are merely discoveries that are adapted to industrial needs, i.e. high volume production

of highly standardized products with low margins, sold worldwide under the same brand. When the focus is on generating better profits from standardized products, then one is operating in the well-known core business, core competence, core market framework. In this environment, process technologies that make a marginal difference in production have a pervasive effect on the overall picture. That is the influence of the "economies of scale" concept where the search is for ever lower marginal costs. It is within this context that genetic modifications play a potentially critical role. The drawback is that the patenting of these process improvements, often based on genetic modifications, had a hard time gaining acceptance. In order to overcome resistance, genetic manipulation has been promoted as the solution to the suffering of human beings. Who could be against that?

It is amazing that scientists agree to such a distortion of the truth. Pesticides become necessary since farming practices such as monocultures and irrigation cause pests to flourish. Change the farming system and pests will be reduced. Chinese farmers even reserve a small percentage of their land to grow what the dominant pests prefer to eat, in order to save the rest of the land from infestation. These dominant pests then help keep all others away. Irrigation is the result of the need to farm crops in ecosystems to which they are not adapted. Therefore, instead of genetically manipulating a few global crops to be resistant to changes in climate and environment, we should farm what naturally comes from each region. Why the insistence on having crops which grow in any climate and any soil?[10] It can only be considered productive in the context of the quest for standardized food, predictable products, and ever lower marginal costs and prices. There is also an insatiable need to enhance performance in the eyes of the consumer, adding all goodies in one cocktail, using the genes of one species in combination with other species. This causes diverse problems from food quality to ethics. How will the Jewish and Muslim communities feel about vegetables enhanced with pig genes?

The most convincing effort to justify genetic manipulation by pretending to solve social and health problems to date has been made by Swiss researchers. Since some 50 million people in Asia run the risk of blindness due to a shortage of Vitamin A and beta-carotene, scientists got the idea to add coding for beta-carotene to the genes of rice, resulting in the carrot/rice hybrid "golden rice". No natural rice has a reddish tint, but the marketing exploited the tradition that golden rice, rice seasoned with saffron, is served on very special occasions in Asia such as a marriage or birth.

Golden rice is the symbol of happiness. Marketed by exploiting tradition, this hybrid rice is considered the symbol of scientific progress. This is a misrepresentation of the facts.

Five Kingdoms of Nature

The amount of beta-carotene that can be introduced into a person's diet through this hybrid golden rice is minimal, though scientists claim it is sufficient to prevent blindness. The main purpose of this research was neither to promote rice farming, nor to fundamentally reduce the incidence of blindness. It was considered by many, including the author, as a ploy to secure broader acceptance, under the umbrella of the United Nations, of genetically modified crops. The logic that one species, in this case rice, should produce multiple benefits is simply wrong. In nature, one species is never expected to provide all that is needed. All species in nature can be ingeniously divided into Five Kingdoms[11] according to specific roles and responsibilities. This allows a better understanding of how combinations of the five permit us to respond to the pressing needs of many through the creation of a world of sufficiency and, one day, abundance. We have five kingdoms. Why does "modern" biotech pretend that one species from one kingdom can do it all?

Whereas the injection of a beta-carotene gene could be considered a scientific breakthrough, it is actually misguided effort when the real purpose is to secure social development through sustainable agriculture while reducing the risk of blindness. An alternative has been demonstrated in Santa Vittoria do Palmar, in Southern Brazil along the Uruguayan border, in one million hectares of rice fields. The water used to irrigate rice is used to farm spirulina algae, a great source of beta-carotene. Why do we consider inventing "golden rice" a valuable breakthrough when spirulina algae can produce per annum per hectare over 100 times more beta-carotene than the genetically manipulated rice? Nature has a tremendous solution for blindness; the only problem is that we did not see it, even with our eyes wide open[12].

This blindness to solutions that nature provides generously is the result of our lack of understanding of how nature really works. It is the result of an obsession with the core business strategy: core competencies responding to the needs of a core market. Obviously, we will not see what is beyond our competence, since that would involve going beyond our core business. Nature never operates in such an isolated fashion. In every

ecosystem or microclimate, the necessary nutrients are available to support members of the five kingdoms. This is the result of an ingenious design: whatever is waste for one species is a nutrient for a species of another kingdom. Whatever is not useful for one, can be useful for another. And these systems of species belonging to the different kingdoms are remarkably efficient in cascading flows of matter and energy. All members cluster together as close neighbors and distant friends, even in the desert. They are likewise efficient in the elimination of toxins and viruses. Indeed, whenever a toxin or virus effects one species, it can be eliminated by a species belonging to another kingdom. Therefore, when matter passes through the five kingdoms, illnesses cannot survive and are expelled from the system.

Algae (e.g. *Spirulina platensis*), rich in Vitamin E and beta-carotene, are present in the water used to irrigate rice. The only limitations to its propagation are in some cases a lack of CO_2, or in other cases an excess of wind, which makes it difficult for these algae to grow. Human ingenuity can bring simple and quick solutions. The mere planting of bamboo creates a wind break (as is done in Brazil), and the pumping of CO_2 (as is done in Ecuador) from an energy generation center can take care of the former problem. The result is the cheap and abundant production of spirulina algae. This is innovation, based on a high level understanding of science, using simple technologies that quickly make a great difference. Does this not make a lot more sense than genetically manipulating rice? The advantages of this approach do not need to be the subject of a long consultation process. It is far preferable to generate nutrients locally with what people already have, generate jobs, and build up self-confidence amongst the people to address pressing problems, instead of relying on a foreign gene which should not have been there in the first place. This justifies going beyond the core business and competence axiom. The research and development agenda pursued is very pragmatic, results oriented, and achieves both economic and social objectives while being sustainable.

Solutions from the World of Four Seasons

The problems engendered by our focus on the core business, core competence, core market logic are compounded by our overall lack of understanding of how nature works. This core business approach leads to a lack of sensitivity to different climates and ecosystems. It does not take a biologist or a chemist to realize that the biodiversity and biochemistry of Northern Europe do not make sense for the tropics. Unfortunately, the

insensitivity of our business community is often shocking. Let us assess this issue in relation to forestry and the production of paper

The logic of making paper

For the raw material for papermaking,, the main option promoted around the world is genetically manipulated trees like Eucalyptus and Pine. It is difficult to assign a Latin name to these species since they have been genetically modified to such an extent that honestly no name can be given. The practice of planting millions of hectares of non-native trees in a world of abundant biodiversity is surprising. The land with the greatest diversity of trees in the world finds itself in the position of having embarked on a large reforestation program, but with non-native species. This could only result from a corporate decision making process determined by core business strategies, which are blind to the diversity of potential fiber sources for paper making available in Brazil. In addition to debating the economic and business aspects of this issue, we should also consider the children living in the Brazilian *favelas*. They would be justified in wondering why the Atlantic Rainforest was 93% destroyed to grow cheap sugar cane, and why no regret is expressed over that error in the past. The imposition of non-native species in an effort to supply cheap paper to the world (the core business) could be considered a criminal act. It is difficult to argue with this logic based on simple observation of history and the priorities of the industrialized world.

Indeed how can you explain to a generation of young Brazilians that in the name of progress millions of hectares of Atlantic Rainforest were logged in the 1950s to clear the way for sugar cane? The reason was simple, Europe and America wanted access to cheap sweeteners. Many people genuinely believed that this offer to invest represented economic development opportunities for Brazil. The offer to develop this new business was even stronger right after declaration of the 1962 boycott of Cuba. The goal was to develop a more friendly replacement for the largest supplier of sugar to the USA. The plans were executed with military precision: the Atlantic Rainforest was felled and cleared, the mills constructed, the sugar cane planted. Forty years later, the Brazilian sugarcane industry is in crisis. The reason is simple; sugar from cane has lost its appeal to the consumer and has been widely substituted by synthetic sugars. Once the rainforest thrived around the States of Alagoas and Pernambuco, then sugar was presented as the crop of the future, and now this is the poorest region of Brazil! This development model based on the core business of sugar as an international commodity clearly failed.

The drop in the world market price for sugar is the result of a change in consumer preference and is due to "globalization", and, as the argument goes, there is no one to blame. As the logic continues, those who are not able to react fast enough to the changes in the market, i.e. the shift from cane sugar to artificial sweeteners, will lose market share, and those who are farsighted and see the changes emerge will gain market share. This logic is false. The technologies and patents which permit the exploitation of new types of artificial sweeteners are controlled by Swiss and American corporations. They will not likely fall into the hands of Brazilian sugar mill owners, and will certainly never be accessible to the thousands of workers.

Brazil has to import these novel sweeteners at approximately 100 times the cost of sugar cane per unit of sweetness. This reality brings hardship to the workers, and a loss of faith in the future for the next generation and we need to ask: why is the sugar business in crisis in the first place? The crisis only occurs when the core business strategy makes one blind to any opportunity outside the sugar business. However, if one is prepared to look outside the box, there are numerous attractive options for regions stricken by the collapse in demand for sugar. If one is prepared to look beyond sweeteners, then a very different science and technology strategy emerges, one not involving genetic manipulation or the use of non-native species.

One thing which becomes apparent as soon as one leaves the core business logic behind is that sugar only represents 17% of the cane; the rest is fiber that could serve to make paper. The conversion of sugarcane mills to paper mills makes sense from a productivity point of view. After sugar has been extracted, the waste called bagasse includes 80% fibers that have been produced in less than 8 months. Why is this fiber not used for paper? The use of a cheap, abundant, local material would be a remarkable improvement over softwood pines trees, which, even when genetically manipulated, only generate 20% fibers after 7 years. It does not take a Master of Business Administration to figure out that this level of productivity dwarfs any other fiber making effort in the tropics[13].

Still, even when the data on productivity is glaringly in favor of using bagasse for papermaking, neither the paper nor the pulp industries are interested in this option. The sugar industry considers this alternative an interesting sidetrack, but it is not part of their core business. Without the

commitment of these companies and the desire to implement these changes, it is impossible to follow these new insights from idea to reality. Why is this logic not attractive to these companies? Actually, one can easily understand why the market leaders in the paper and pulp industries, based in Canada, Sweden, or the USA, are adamant that bagasse provides no future. Have you ever seen sugarcane growing in Scandinavia or North America? Of course not! The craft and chemical processing technologies have been exclusively designed over the years to function well with trees they know, trees that grow in their Northern Hemisphere. Therefore, instead of adapting the production process to the extraction of cellulose from a different source, they decided to retain the alkali sulfate process. This extraction system is based on technologies such as chemical burning: the lignin and hemicellulose are chemically burnt and the residue, which is called black liquor, is incinerated to recover energy. These process technologies only work with the biomass for which they were developed. Should the world therefore adopt genetically modified trees from Scandinavia and Australia?

This makes sense from the point of view of these northern corporations. It does not make sense from a tropical point of view. Why introduce non-native species just because the local biodiversity does not fit process technologies designed for species from the north? This does not even make sense from the point of view of productivity. Indeed, when you can quadruple output, why stick to such low levels of productivity? The tropical system could provide bamboo or sugarcane that has a yield four to five times that of genetically modified trees. Why is the tropical option not chosen and why do we not simply change the process so that the most productive source of fibers becomes the new market standard? The reason is that a shift in raw materials would require a shift in process technologies which would immediately result in a loss of efficiency for the multinational corporations at their existing plants. Their portfolio of patents would become obsolete. When the market for pulp and paper is plagued by low prices and over-capacity, no one welcomes a shift in technology.

In addition, if the tropical fiber succeeded on the market, and new process technologies came to dominate, then the existing stock of “4 seasons” trees would be downgraded in book value on the balance sheets of these traditional corporations. This reserve of forests represents one of the important assets of these public corporations. If new resources became the standard, then the old long-term investments would drop in value. The fourfold improvement in yield would lead to a loss in book value of similar

magnitude. At the time when market prices are already at an all time low, the introduction of tremendously productive systems would depress market prices even further, thus pushing many of these traditional corporations to the brink of bankruptcy. There is more bad news. The existing portfolio of patents, which have evolved towards a closed-loop production system that minimizes the emission of toxins such as dioxin, would be downgraded in value as well. Under these circumstances, it would be impossible to license these technologies to the Third World, thus endangering the funding for additional research into improving the existing process technologies. The entire traditional paper making system will find itself on the verge of collapse if these alternative tropical fiber sources became the market standard. It is clear that no one, especially institutional investors, wants this to happen to the paper and pulp industry. Therefore, it seems justified to plant non-native, inefficient species in the tropics.

The change from one system to another would be difficult since the investments needed for both plant construction and forest farming are vast, thus locking in business practices and technology options. Just wait until the tropics wake up! The reaction of the people against the millions of hectares of non-native and genetically modified trees cannot be blamed on Muslim fundamentalism or leftwing extremism. It is a mishandling of culture, tradition, and nature that could lead to an angry response. Who gets the blame when the locals put these forests on fire? We are all too often deaf to the arguments of the other, refusing to listen, and thus never even realize the logic of their point of view. However, the time has come to stop pretending that we in the North are democratic and have the problems of the developing world as our priority. This must transcend words and be visible in actions.

In conclusion, much of biotechnology has involved transferring what works in the North to the South and expecting it to work there. From fish farming to tree farming, it is surprising how little focus there has been on the design of biotechnologies that take what works locally and make it work better, in the desert, the tropics, the Andean highlands, or the coastal zones of the Antarctic. If we consider science and technology as the means of better responding to the needs of people for food, water, health care, shelter, energy and jobs, then there is an urgent need to redefine what we consider biotech, and what we are funding. This should be a first principle of biotechnology***: only build on what you have locally available in biodiversity***.

The ZERI Foundation is attempting to design a production and consumption system that addresses these goals and tries to imagine biotechnologies as unique tools to reach these objectives. The main difference between what has been widely described as the promises of modern biotech and the vision on biotechnologies presented in this article is that the tools ZERI scientists discover mainly make the best use of existing techniques nature has already invented millions of years ago. Humanity pretends to invent, and then wants ownership of this invention through patenting and intellectual property rights. The time has come to stop pretending that we are inventing and accept that we are merely discovering. Columbus did not invent America, he merely discovered it. It had been around for millions of years. At least Columbus did not attempt to patent his discovery.

Two families of biotechnologies

The research effort ZERI promotes and supports focuses on two clusters of technologies: (1) how to integrate and, (2) how to separate. Production of most goods involves extraction of key ingredients from source material and their recombination into a useful product. After wool is sheered off the sheep, we separate the lanolin from the fiber. To dye the fiber with indigo, we extract the color pigment from the plant, use urea to split one molecule from the indigo, and apply the intense blue dye to the wool. The wool is knit into a sweater, labels are attached, and it is packaged and sold. The techniques of integration and separation have resulted in a product which we can use for years to come.

Our production engineers have devoted decades of research and development to the search for the most useful combinations of raw materials for the manufacture of products. The major challenge that they are facing now is the task of finding out how to take the final products apart after the end of their useful lives so that they can be regenerated into the building blocks of the next production cycle. This is what we would call “ecofacturing” or “ecomade”, which refers to products which are generated in co-evolution with nature and which after use are regenerated into the elements needed for another cycle of production. Engineers have surprisingly paid attention to only one cycle: integrate until the product is sold. They have completely neglected the second cycle: regenerate until you have valuable ingredients for the next cycle. The logic for doing both is simple: before the apple can be subject to the law of gravity, it must defy the law of gravity[14]. Before you can put things together, you must have the

building blocks readily available. Nature is a master of both sets of technologies. It knows how to integrate and how to separate, from raw materials to the apple, and from the apple to the raw materials of the next cycle. The combination of both technologies creates systems which can address all the major challenges outlined above: water, food, health care, housing, energy and jobs. Some concrete examples will clarify this approach[15].

The rice farms in Southern Brazil are an example of an integrated farming system. The water from the rice farming operation can be used for farming spirulina algae. The kingdom of algae thus complements the kingdom of plants. If you are a rice farmer you can also be a spirulina farmer. Perhaps rice is sold below cost, but if you farm rice, then you have water, and then you can farm algae which can be sold at a higher price than the rice. The spirulina is also an excellent source of beta-carotene. The waste rice straw is ideal for farming mushrooms, which are edible by human beings. The kingdom of fungi follows the kingdom of plants. Next, the waste mushroom substrate can be used as an additive to cattle feed. The cattle produce manure that can be processed in a digester thanks to bacteria, and this generates biogas. These cycles never stop. The slurry from the digester is ideal for further mineralizing organic matter, as well as eliminating any residual harmful bacteria. This nutrient dense alkaline water can then flow into a fish pond to augment the fish feed! This is an integrated biosystem that generates more than any genetically modified organism (GMO) could ever achieve. This is the way nature works at its best. What do you expect after billions of years of evolution?[16]

If we bring this logic and this dynamic interplay to the Atlantic Rainforest, then this region will have a chance to recover from the dramatic logging of the past 5 decades. Now that the sugar mills are in crisis, the landowners are prepared to reforest the hilltops, which have the lowest rates of sugar cane productivity. Some 30 species from the remaining Atlantic rain forest are propagated in a nursery and reintroduced in the thick soil. The reason for the openness of the landowners is not generosity or love for the forest. The region is suffering from a drought and the hypothesis that reforestation from the top of the hills downwards will recreate the hydrological balance is being tested. The hope is that this could even regenerate some wells that will benefit the mills and the people living in town and valleys. Their livelihood depends on the availability of water.

However, this regeneration of biodiversity on the hill tops links the sugar hills with the remaining pockets of the Atlantic Rainforest. Taking farmland out of production is not always popular, unless it is guaranteed to generate new jobs. A few months after reforestation efforts have started one can already harvest thin pieces of rapidly growing bamboo. This small diameter bamboo, a grass which quickly regrows after harvesting, is converted to clothes hangers which are packaged in a cardboard made from bagasse which would otherwise simply be used as fuel. The hanger designed by Lucio Ventania received the National EcoDesign Prize of Brazil in the sustainability category. The regeneration of the forest goes hand in hand with the development of new economic activities, which generate jobs fast. Already 80 people are employed in this novel factory, made possible by an effort to restore the Atlantic Rain Forest[17].

Integrated biosystems for coffee, rice, and shrimp

The value of this integrated approach has been proven repeatedly. The farming of coffee leads to the production of coffee beans, which end up in a cup of coffee. In the process some 99.8% of the coffee plant is wasted! No wonder the coffee farmers are suffering from a crisis. Rather than a decline in world market demand or a growth in supply, the major problem is a consumption and production system that only values 0.2%[18]. The solution is not the substitution of coffee with something else; the solution is to establish an integrated biosystem which will give value to the 99.8% of the biomass that was considered waste. The waste from the coffee plantation can be used to grow mushrooms, and the waste from the mushrooms help feed cattle. Nature and its five kingdoms are creative but nature is also dramatically predictable. Once the systems are known, then we can just be inspired by that same logic.

The logic of the past was perhaps to grow organic sugar and organic coffee. This once again imposes the interests and priorities of the Northern European consumer onto the process. It was the Western desire not to have pesticides and synthetic fertilizer that made us establish international organizations, located in the North, which for a hefty fee will certify that the product does not include any of these chemicals. It is interesting that we have agreed to certify products for what they do not have, while we seem to reserve little or no attention for what these commodities do have. However, even organic coffee sold through a fair trade organization will barely fetch a 20% higher price. That is still not enough to get the farmers from the Third World out of trouble. It is therefore important not to stay within the logic of

the existing production, distribution and sales system. We have to invent a new process that leads to higher levels of productivity, and more generous compensation for the farmers. This is perfectly possible when we understand the logic of the five kingdoms of nature and their design principles.

The logic of integrated biosystems is not only applicable to agricultural systems like coffee or rice farming. ZERI has designed integrated systems for numerous crisis situations in the most diverse circumstances, in the North and the South. At first sight, the globalization of commodities leads to a social and economic disintegration. This is unavoidable when one only concentrates on core businesses. It is only after the design of an integrated biosystem that solutions become obvious, building on the core crop without ever having to drop it. Imagine if one were to propose to the Colombian coffee farmer or the Brazilian rice farmer that the fastest way out of their crisis were to first drop farming coffee or drop growing rice. Instead, the approach that ZERI proposes builds on what one has, integrating the efficiencies naturally endowed to the five kingdoms of nature. It is particularly effective when we address crises in the Third World.

The farming of shrimp is another case in point. The design of "modern" shrimp farms depends on the application of high protein feed, which consists mainly of waste from slaughterhouses mixed with the waste of shrimp themselves. This is a diet that the shrimp never imagined. These crustaceans prefer living off algae. Abundant algae depends on the presence of mangroves. The problem is that mangroves are typically eradicated to make space for shrimp farm basins. This interplay of crustaceans, plants and algae is a very dynamic one and if one of the team is eliminated, then the others also disappear[19]. Feeding shrimp with their own waste dramatically increases the risk of viruses (mancha blanca), which can destroy shrimp farms overnight. The answer to this problem is neither genetically modifying shrimp, nor the use of antibiotics, but rather the restoration of the mangroves. This will lead to the reemergence of algae and allow for the introduction of a biosystem which will generate abundance, instead of illness and scarcity.

About forest fires and sweaters

The concept of the integrated biosystem is applicable beyond agriculture and fish farming. There are even broader industrial applications, such as the production of a sweater. Sweaters are made from yarn, spun from wool, from sheep that can overgraze the land. Drought, compounded by

forest fires, can jeopardize an entire sheep herding enterprise. The solution is simple: an integrated system in which the small wood in the forest is harvested and converted with fungi into feed for sheep, thus reducing the risk of forest fires, overgrazing, and the expenses for the herder. The land, now less stressed from grazing, is then used to produce plants, insects, and even, in the future, mushrooms, from which natural dyes can be extracted. In this way the integrated biosystem design builds up a symbiosis between the forest, the grazing animals, the fungi, and even insects and soil bacteria. The end result is a product that is sold on the market: a sweater that is much more than a sweater[20].

This integrated system emulates nature, but can also, thanks to human ingenuity, do better than nature. The American mushroom expert Paul Stamets has patented the blending of mushroom spores with vegetable oil used as chainsaw lubricant, so that when one is clearing the forest, one is also planting mushrooms[21]. This is creativity at its best and demonstrates that if one is keen on improving the situation using what nature has provided, then there are fantastic opportunities up for grabs.

Integrating mountains and valleys

Even reforestation projects can be redesigned on the basis of integrated biosystems. It is no secret that in order to plant a tree there is a need for good soil. But if the soil is poor, due to erosion or acidification, the health of the forest is impaired. However, whenever we believe soil is poor, we really have a lack of insight into the dynamics of nature. The maintenance of the five kingdoms of nature, intact and healthy, depends on the dynamic interrelationship between the ecosystem and the Earth's upper crust layer, which is rich in the minerals and nutrients without which nothing could survive.

Over a century ago, scientists described how one could regenerate topsoil through the application of crushed stones[22]. While this use of dust from granite and basalt seems far-fetched to many who have not been exposed to the practice, the logic is compellingly easy. After all, valleys are rich in nutrients for farming thanks to millions of years of erosion which has deposited the rich mix of minerals from the mountains onto the farmland. Instead of waiting another couple million years, the topsoil can be recreated thanks to the efficient application of rubble left over from road and tunnel construction. The Austrian forester Viktor Schauberger built on previous research that is commonly known as "remineralizing the earth"[23].

Some 50 years of intensive monoculture farming and the excessive use of synthetic fertilizers has led to a massive loss of topsoil. The reduction of topsoil, combined with the introduction of non-native species mainly for ornamental purposes, has reduced the water retention capacity of the soil. This results in floods, as have occurred in Northern Italy and China. Whereas deforestation has often been rightfully blamed for the inability of the land to retain water, it is the loss of topsoil that causes an imbalance in the hydrological cycle. Rainfall, river flow volume, snowfall, and the ability of the soil to retain water are all interrelated[24]. With the loss of topsoil goes the loss of minerals critical to the long-term survival of most species.

It is in this context that one has to consider the opportunities to use rocks and rubble from construction sites to recover lost ground. When the Italian and French governments decided to construct a 57 km long tunnel connecting Lyon with Turin, the local population broadly protested it. If this engineering project, leading to the longest tunnel in the world, had been considered merely construction, then a unique opportunity would have been lost. It is like the sweater in New Mexico, which should never be considered a mere sweater. At first the engineers were planning to ship the rubble 150-200 km away at a major cost, since they were after all only building a tunnel. The new vision formulated by the Science University of Turin was to segregate all the rocks by quality and grade and replenish the top soil of, first, the Piedmont Valley, and then the Po Valley. It was estimated that the millions of tons of granite and basalt would be sufficient to add up to 1 meter of top soil to the Po, which has been one of the richest agricultural regions of the world since Roman times[25].

Research into the content of the rocks from one of the tunnels disclosed a high content of silica. At first this was a surprise but then it became clear that this mineral was a residue of rice husks. 60% of the rice farmed in Europe is farmed in the Piedmont Valley. One of the characteristics of rice is the silica in its husks. Farmers know all too well that silica and germanium in rice husks potentially renders the land infertile. Therefore, the cooperative of rice farmers has invested in a central incinerator that burns some 60,000 tons of husks per year. The waste, rich in melted silica, is shipped to the steel industry or to landfills. Although centuries of farming, especially the past 50 years of intensive farming with synthetic fertilizers, has reduced the level of topsoil, the construction of the new service tunnel is offering a unique opportunity. The rubble from the

tunnel is enough to replenish one centimeter of silica-rich material on the rice farms, which will quickly convert to 4 cm of top soil. The impact is significant: over the 110,000 HA of land, this freshly created topsoil will retain some 5 million tons of water. A small but important step will have been taken to avert a repeat of some of the floods that have affected the region over the past decade. What was the other option to fight floods? It is clear that dams could have produced the same result in terms of water flow. However, dams would have further decreased the distribution of eroded alpine rocks onto the farmland. Over time the farmland would retain even less water, leading to more floods and demand for more dams. It would be a self-defeating proposal.

From Rock Dust to Fertile Land

The application of rock dust or granulated rocks to farmland launches a web of interactions between bacteria, micro-algae, and fungi. These organisms break down the minerals and make nutrients accessible to plants. The results can be observed quickly. Perhaps the most impressive role is played by fungi and lichens, a symbiosis between fungi and algae. They can penetrate any type of rock. Since their hyphae are just one to two cells thick, they find enough space in between the minerals of a stone. The fungi then absorb nutrients and channel critical elements like magnesium, the basis of chlorophyll, to the soil. This process works in the mountains and also along the coast as can be observed in the Archipelago of Stockholm[26].

It is interesting to note the massive soil erosion due to overgrazing and inadequate farming practices in New Mexico, USA. The result is that the land is devoid of its formerly rich topsoil. Even though there is little rainfall, the soil was full of nutrients. However, once it has been washed away, it is difficult for people to live off the land. The reversal of this trend requires basalt, a rock type in abundance in New Mexico. The Native Americans have illustrated them extensively with their artwork, but the Santa Fe landfill is now stuck with too much of it. In order to deepen the landfill, the landfill management needs to remove some 30 feet basalt, which is crushed on site and shipped off at 50 cents a ton. These thousands of tons could be blended with mycorrhizal fungi and spread around as a dust, in an effort to regenerate topsoil that has been lost over the past few decades. It could hardly be cheaper! It is another example how a problem for one is a solution for another. La Cienega, once the last stop before Santa Fe on the long trail from Denver, could be regenerated using waste rocks! Solutions are often so local that it is a surprise to all.

Reforestation provides drinking water

In addition to lichens, another relationship that deserves attention when one designs an integrated biosystem is that between fungi and plants. The reforestation program of Las Gaviotas clearly shows that in spite of the expert opinion of several scientists, the Llanos in Vichada, Columbia can regain soil fertility. To accomplish this, the region must be reconnected with the thriving biodiversity of the Amazon rainforest, just three hundred miles to the east across the Orinoco River. Currently, the soil pH is 4, too low for trees or other high vegetation to grow, except along the rivers. The low soil pH also fosters the growth of a soil bacterium that is the main cause of the intestinal diseases which affect 70% of the population[27].

Everyone recognizes that a massive alkalinization program for an area of 6 million HA is too expensive to even consider. But Paolo Lugari and the creative scientists from the Environmental Research Center Las Gaviotas demonstrated once more that poor soils only exist in poor minds. He embarked on the largest reforestation project in the world incorporating mycorrhizal fungi. If indeed the soil is too acid, then trees will not survive. However, the young pine trees *(Pinus carribea)* used in this project are well prepared for their release into this environment. In the nursery, the roots are trimmed to only 5-7 cm and the young tree tops are cut back so that the tree must survive harsh conditions when still very young. At the same time, the roots of these saplings are covered with mycorrhizal fungi that live in symbiosis with the trees, providing nutrients. These trees, planted in the savannah and subjected to hot and dry weather, survive at a 92% rate! This is unheard of in forestry. Purchasing the land, planting the trees, and maintaining the growth for a few years at a cost of US $1,000 per HA, is also unheard of.

Once the trees are established, the large volume of fallen needles quickly contributes to the creation of a humus cap, which jointly with the newly created shade, offers protection against the harsh climate for anything that wishes to grow. Thanks to the mycorrhizal fungi, the tree roots receive predigested nutrients from the soil in return for carbohydrates. Soon the soil pH increases, especially around the roots, soil bacteria thrive, and the birds and the bees do the rest. Within less than a decade some 250 species of plants and trees have colonized this formerly barren area. Some 95% of the species come from the Amazon Rainforest thus confirming that the recreation of the rainforest is not just a dream, it is a reality. Las Gaviotas

succeeded in reforesting some 30,000 acres, but there are 15 million acres to go (or 6 million HA)! It is probably one of the greatest opportunities for carbon sequestration and climate stabilization ever. In the mean time, the Las Gaviotas team designed an integrated system that generates drinking water for the local population. Now, after a decade of operation, the newly created ecosystem is so generous that water can be exported to please the water gourmets around the world.

However, Las Gaviotas would not represent innovation and leadership if it addressed the issue of reforestation and water production without also tackling the issue of plastic bottles, a pollutant everywhere in the world. At first, Las Gaviotas opted for a plastic bag made from polypropylene. This option worked well since polypropylene is a good quality plastic and one can sit with a 200 ml bag of water in one's back pocket without any danger of popping it. The most interesting fact is that after use, what remains is a small, empty bag that can be kept in the pocket and returned when a new bag is purchased. The bags are then easily recycled into pipes for transporting the water from the forest. And, as the forest expands and water consumption increases, the amount of plastics and pipes increases.

The packaging improved with the switch to a bottle, but it is not the typical bottle that is a total waste after use. The designers at Las Gaviotas came up with a square bottle. The real innovation is the addition of four big buttons on the outside, giving the bottle the look of a Lego building block. This 500 ml bottle not only snaps together to make efficient use of packing space. After use it turns into a toy, which makes it a sought after item. Children can now build huge structures using only empty bottles. When the game ends, they can simply tear down the structure and the bottles are ready for reuse in another castle.

From the Savannah to the foothills of the Rockies

The insights from this program permit a fresh assessment whenever problems emerge. Take the case of the massive insect attack on the piñon trees in New Mexico. Insects were blamed for the problem, but in all probability the root cause was the decrease in mycorrhizal fungi due to environmental pollution. This reduced the capacity of the tree to acquire nutrients from the soil and retain moisture, and thus reduced the production of turpentine, the natural protection for the pine tree against insects. The lesson learned is that, if insects attack, avoid applying chemicals or the whole ecosystem will be adversely impacted. The systems solution, which

aims to revitalize the biosystem, is a mix of basalt or granite, blended with mycorrhizal fungi, and sprayed on the trees before sunrise. Humidity peaks in the morning and this cocktail of life will quickly be integrated around the roots, before the heat of the day. Fungi can grow up to one kilometer of hyphae a day and quickly enter into partnerships with other microorganisms. Strengthening the existing biosystem, using what nature provides, is one of the best protections against forest fires[28]. This option represents a big difference from the choices before policy makers today: drop water containing fire retardants and spray insecticides.

Urban Settings for Integrated Biosystems

The cases so far described work best in the Third World, and especially in an agro-forestry setting. Integrated biosystems can also be designed to function in urban settings. The treatment of septage is a point in case. In the richest country in the world, the USA, about one third of the population is on septic tanks. The removal of septage, and the treatment of sewage, has typically been regarded as a low priority, unprofitable activity. It is a business no one wishes to be associated with. Perhaps we need to remember that in Buddhism it is not considered a very humble lifestyle when you pay others to take care of your waste. That is what the majority of people who have a septic tank do. Furthermore, we are not concerned about what happens to the waste after it is removed from our property.

If septic tank maintenance is neglected, toxins can leach into our drinking water. The City of New York pays residents who are willing to either connect to the sewer or have their tanks lined. The leaching has reached such dramatic proportions that it could endanger the water supply of Manhattan. Sealing tanks and building sewers and the traditional sedimentation and aeration treatment plants is a costly solution. If we apply the integrated biosystem to human waste we can imagine different solutions, natural solutions.

Thirty years ago, John Todd first designed the “Living Machine”, utilizing 400 varieties of aquatic plants, extensive growth of algae, and the deliberate propagation of bacteria. The interaction of all these species leads to the cleaning of water. At one point the City of South Burlington, Vermont, was treating up to 10% of its sewage through such natural processes. Unfortunately, the costs were considered prohibitive and the demonstration project funded by the US EPA was discontinued. Michael Ogden operates similar systems at a smaller scale in New Mexico, in

typically arid areas. He has successfully built and operated facilities in the Southern United States and in Mexico. The logic behind the living machine technology is solid, though there is a need to go beyond what we have seen unfold over the past 30 years. How would one design a small scale system to treat 2,500 gallons of sewage per day, while also generating additional benefits for drought stricken areas, such as soil restoration and the provision of additional irrigation water?

While considering the options, the challenge of toxic chemicals in the bathroom must also be faced. While the production of human waste is natural, it is treated as if it must be destroyed, and destroyed quickly. The continued use of drinking water to pee and defecate in is one of the most appalling anachronisms in history. How can we behave so arrogantly or stupidly, when drinking water is one of the most valuable and scarce resources on Earth? If we were only to use water, it would be tolerable since water, urine, and feces can be recovered as nutrients. However, the reality is that whatever ends up in the sewage or the septic tank is dirty, not because of the urea, but because of the chemicals that we add.

Treatment of septic waste is difficult. Indeed, septage that has been mixed with household chemicals has a very low biological activity. Therefore, successful treatment requires first bringing new life to this matter by exposing it to bacteria. After an anaerobic and aerobic treatment, and exposure to a reed bed enriched with nematodes and earthworms, the water comes out quite clean. Also, this process generates two major products apart from clean water at the end: earthworms and water hyacinths. The operation is more expensive that the simple “dump and forget” approach, though it can be made more competitive if the available biota from the local ecosystem are used effectively.

The New Mexico-based foundation Earthworks decided to undertake such a trial. This organization, directed by the dynamic Leslie Barclay, raised the funds to build a septage treatment center in which the water hyacinths will be used for the farming of mycorrhizal fungi. These fungi are in great shortage in the region due to airborne pollution. The massive production of these fungi, which are local and adapted to the ecosystem, will permit their application in major environmental disaster zones, such as eroded riverbeds and areas that have lost 70% of their piñon trees[29].

The fungi can be applied especially to the sandy riverbeds that are the best areas for asparagus farming. Wild asparagus is one of the greatest delicacies in the world. It only grows in dry sand, which drains rapidly but protects the roots from the sun during the day and maintains warmth during the cold nights. Wild asparagus could be a major export crop for New Mexico. In addition, since asparagus has an extensive underground network of roots, it could be the basis of a plan against the soil erosion which is threatening even housing in the area. This entails using the water hyacinth and other aquatic plants to propagate the fungi, which are applied to the sandy riverbeds. It then becomes possible to grow the wild asparagus, a quality product adapted to the region. While providing sewage treatment, the integrated biosystem has gone a long way towards solving some other problems.

But there is more. The earthworms are local, adjusted to the climate and the region, and their enzymatic mix has evolved to match the type of food they ingest daily. They multiply prolificly, but, in arid New Mexico, selling worms for fishing bait is not an exciting business opportunity. However, their enzymes could be extracted with the contifocusing technologies of Prof. Dr. Gerben de Boer of the Netherlands and Dr. Sova of Slovakia. This extraction technique would yield a good volume of enzymes ideal for use in the septage tank[30].

After emptying the septage, one could add a quart of diluted earthworm enzymes to the tank. As septage flows into the tank, it will then be continuously digested. This provides dynamic processing and overcomes the reduction in biological activity caused by exposure to materials such as antibiotics. Another advantage is that this preprocessing in the tanks reduces the retention period in the septage treatment center living machine from 3 weeks to perhaps only 1 week, increasing the throughput and productivity of the system by a factor of 3. The economics are so advantageous that, if the customer agrees to add a few enzymes every day (instead of using the toxic toilet cleaners), they can be offered a reduced fee for septage removal. It is a win-win-win situation in which many opportunities are created simply by understanding how integrated biosystems work.

Practitioners of integrated biosystems

Several scientists have championed the concept of integrated biosystems. Paolo Lugari imagined reforestation like no one before him, and farming, especially animal husbandry, will perhaps never be as integrated as

when designed by Prof. George Chan. Paolo never studied at university and was educated by his father. He is dedicated to the people who make the projects work. Although his center, Las Gaviotas, was the first to have a broadband Internet connection in Colombia in the late 1980s, he refuses to use the Internet today. When solutions were needed, he found his team looking at the Internet studying what had been done elsewhere. People were looking for cases from outside to apply inside. He concluded that this stopped all creative thinking in-house and ever since then his team has focused on what they can come up with using their imagination, observations, and pragmatic vision. This has unleashed a high level of innovation and leadership.

The second champion is undoubtedly Prof. George Chan, who graduated with a degree in sanitary engineering from Imperial College of London. He then spent 15 years with the US EPA before retiring and returning to his ancestral home in China to learn how the Chinese deal with wastewater. Prof. Chan learned that if conventional standards for wastewater purification are met using the five kingdoms of nature, there is an excess of nutrients at the end! In ponds designed for fish polyculture, Prof. Chan is able to grow floating hydroponic crops to ensure the take-up of these nutrients[31].

Imbalances, pests, and weeds

Whenever there is an imbalance in an ecosystem, the typical response of the Western specialists is to "kill" or "burn"[32]. However, the eradication of a pest is only treatment of the phenomena, it does not tackle the root causes. This is exemplified by the case of the water hyacinth *(Eichhornia crassipes*). This ornamental plant from Latin America is creating havoc in Africa and Asia, blocking waterways and killing off aquatic life by consuming all dissolved oxygen. Of course, the blame lies with the immigrants and colonizers who wanted the flowers to adorn their ponds. This beautiful flower is still sold commercially in Europe and Japan, though it poses little threat in northern climates since the winter season kills off the plant before it can reproduce. However, eradicating this aquatic plant in the tropics requires a different approach. Simply killing off this plant is not a solution. If one wishes to solve the problem of the water hyacinth, then one must tackle the fundamental issues of soil erosion and excessive use of non-water soluble fertilizers[33].

To reverse the problem of the water hyacinth, farming practices must change. Whereas the rich and muddy soil in the North needs regular plowing to introduce air and stimulate the growth of soil microorganisms, the situation in the South is often quite different. Rainfall is scarce, or the topsoil is not as thick. In this situation plowing leads to devastation of the fungal hyphae and the nematode and earthworm tunnel networks. The plowing of dry soil leads to soil erosion, and when heavy rains do come, it will result in massive erosion since the basic biota which hold it together are disrupted.

Soil erosion is not only caused by agricultural malpractice, but also by urbanization and the subsequent increased use of water, by deforestation that eliminates the living roots, and by overgrazing by livestock. One strategy could be to stop overgrazing, which helps the land recover but which undermines the livelihood of the sheep farmers. A positive option which would benefit all parties is to imagine how to improve grazing opportunities with what one has. The water hyacinth offers a possible solution. First, one could harvest the ornamental plant and inoculate it with mushrooms which will convert it to humus, full of microorganisms, rich in protein. The purpose is not to farm a mushroom with a fruiting body, but rather to revitalize the eroded soil with a wealth of bacteria, micro-algae and fungi.

Since it is so difficult to make people change their behavior, let us establish within the existing ecosystem a series of feedback loops. This is critical to any effort to mitigate the bad side effects of farming or urbanization and create a self-correcting system. Water hyacinths proliferate because of an imbalance, and once that imbalance has been corrected, water hyacinths will simply not grow anymore. The day that the water hyacinths are gone is the day that soil erosion has stopped. Hopefully this will not be because of the complete demise of farming or the over-development of cities.

It is amazing that the biological solutions proposed by experts to eradicate water hyacinths include the introduction of insects. Just imagine that in order to fight a non-native species (water hyacinth) the proposal is to import non-native insects (the weevil beetle from Australia). Amazingly, this exercise has been repeated throughout Africa and no one questions the logic of fighting non-native plants with non-native animals. This is considered a better solution than spraying 2,4-D growth hormones (used extensively in the Vietnam war and supplied by Monsanto) to eradicate the plants. However, since the seeds of the water hyacinth have a germination period of

more than 7 years, no insect or chemical will ever be able to offer a lasting solution. The only one gaining for sure is the salesperson of the chemicals, or the expert on the insects. Everyone else loses in this process[34].

Integrated pest control implies the design of an integrated biosystem, which potentially combines all kingdoms of nature in a dynamic system in which the waste of one organism is always food for another from another kingdom. The African water hyacinth is harvested, converted to beautiful furniture, and sold on the European market at a premium price. It is also used as a basis for making fertilizers. It is very rich in minerals and therefore could be reapplied on the soil from which the minerals were lost in the first place. Unilever is now contemplating applying this technique to enrich the soil of the largest tea plantation in the world in Kenya, where nearby Lake Victoria is infested with water hyacinths.

Mrs. Margaret Tagwira, in a groundbreaking research initiative undertaken in 1997 at Africa University in Mutare, Zimbabwe, demonstrated that water hyacinth is an amazing substrate for *Pleurotus spp*, better known as the oyster mushroom. After some simple preparation, developed by Mrs. Tagwira on the basis of her experience in Africa and China, the water hyacinth reached a biological efficiency of up to 240%. This implies that on 100 kg dry weight of substrate, 240 kg of fresh mushrooms were harvested. This is an impressive result which leads to the conclusion that water hyacinth is actually a blessing in disguise. It is up to human beings to recognize that this plant is not trying to destroy our livelihood, it is actually desperately attempting to correct the fundamental mistakes made by humans.

From burning to best practice

The recourse to “killing”, “destroying”, and “burning” is widespread but thanks to the growing awareness of climate change, there is political will in some nations to reduce the burning of waste as a means to reduce carbon emissions. European experts have thus designed best practices and whatever is considered a useful solution in the industrialized world is proposed to, or imposed upon, the developing countries. It has been proposed that the leaves and branches pruned from trees on banana and palm plantations be left on the soil to compost. Whereas in Europe the practice of leaving all organic waste on the soil as enrichment makes sense, this is nonsense in the tropics. It is another example of why solutions for a region characterized by four seasons do not work in the tropics.

The reason is simple. In a four season climate, the enzymatic activities of bacteria and fungi on plants are limited. In the tropics, the activity of biological scavengers is much greater, but so is the capacity of plants to fend them off. This is due to a broad range of anti-enzymatic biochemicals. One of these is called furfural. As the content of furfural is very high in leaves, reaching 17%, the mulch created on the ground by leaving all the leaves and branches in place actually reduces soil fertility by covering the ground with a blanket of anti-enzymes. This makes the recovery of nutrients through the interplay of bacteria, micro-algae, and fungi very difficult[35].

Good solutions in the North are nearly always bad solutions for the South, even with the best of intentions on both sides, unless they are adapted to the local conditions. The solution in this case would be to extract the furfural from the leaves and drop the leaf residue on the ground. The furfural can be sold on the world market at a competitive price, and the residue will enrich the soil. The extraction process in a cold climate would not be economical since the furfural content is too low in the plants that grow there. On the other hand, this is competitive in the tropics. If one pays attention to the specifics of the biodiversity in an area, new competitive advantages can be created.

Best Practice for Whom?

The concept of best practice is often based on a strange line of thought. Take the case of the plastic bags used to protect bananas from insects. As soon as a bunch of bananas matures, it is wrapped in a plastic bag (PVC, PE) to protect the fruits. Although these plastic bags are treated with insecticides, they are only in contact with the fruits. Workers and other living species around the plantation are only minimally exposed to them. The problem is that after use, these toxic plastic bags must be destroyed. The "modern" best practice foresees the collection of these bags and their subsequent destruction in a specially built incinerator located on the plantation. Does this make sense? The idea makes sense for the producers of the plastics and insecticides who avoid liability for dispersing toxins in the air and exposing workers. The incinerators are designed and approved for this purpose as part of an international certification program. However, there are alternatives which can build on the local biodiversity and generate local jobs and revenue, instead of sustaining jobs elsewhere[36].

The regions which are home to banana and palm oil plantations are also rich in the root plant known as cassava in Africa or yucca (*Manihot esculenta*) in Latin America. These root plants are very rich in starch with concentrations of up to 92%, producing up to 30 tons per hectare. The Italian company Novamont developed a technique to convert starch to biodegradable plastics. This can be used to create new markets and generate additional revenues for the local yucca farmers who are today trying to survive with a market price of only US $100/ton. In addition, it will obviate the need to import plastic pellets and make plastic bags which then must be destroyed. This will be financially beneficial to the banana and palm plantations also. Once yucca-based plastic bags can be produced locally, scientists can concentrate on the design of a technique to lace the yucca-based starch with extracts of lemongrass (*Cymbopogon citrates)*, known for centuries as an effective insect repellent. Lemongrass is widely used in the coffee growing regions of the world to fight soil erosion and the harvested grasses can be immediately mixed into the production material for these plastic bags at a concentration of 1%[37].

The technology and the raw materials are available. The question is, why do the Latin Americans remain so fascinated with the technologies of the North, which do not suit them at all, cost money, create dependencies, and cause an outflow of hard-earned money? Is there a cultural or psychological barrier? Even though the economics and the concept seem reasonable, these ideas need to be converted into business models that work to get local governments and the entrepreneurs to consider these alternatives seriously.

When a poor person looks at bamboo, it is associated with poverty. When a poor farmer looks at coffee, it is associated with crisis. The same goes for yucca. But when the farmer looks at PVC plastic bags laced with an imported insecticide that need to be destroyed in a specially designed oven, it is called progress? It all is a matter of perception. We see what we believe we see. However, as has been described, the solution for coffee is not more coffee, or genetically manipulated coffee; it is doing something with the massive waste streams generated by coffee. The future of bamboo is not its substitution by cement, but rather how to imagine the use of bamboo and the multiple technologies it embeds, even in combination with cement. Merely substituting for yucca does not solve the crisis in yucca; it is finding value added uses for yucca within the economic framework that is evolving in the same region. It is the focus on appropriate technologies, as a central part in

the development of a portfolio of both product and process technologies, that leads to a fundamental change in the overall production and consumption system[38].

Material Separation Technologies.

The bridge from understanding integrated biosystems to a complete system design, incorporating many products and processes which are inspired by nature, is a first (difficult) step in the right direction. However, more is needed. The missing link is the introduction of a set of technologies known as material separation technologies. The optimization of both integration and separation occurs when the best of nature is used for both production systems. The waste of one species from a specific kingdom is an input for another species which belongs to another kingdom. The same logic is applicable to industry. Indeed the whole notion that industry should apply the closed loop concept is fundamentally wrong. Indeed, waste from one should serve as an input for another. In nature, whatever was assembled into one product is over time disassembled into various components ready for reuse.

Companies operate in a competitive market characterized by over-supply and ever-changing consumer behavior. Therefore, the idea that they should take care of their own waste demonstrates a total lack of understanding of how natural systems function and also imposes restrictions on creative solutions for business. Imagine if a tree were in charge of collecting and treating its own leaves![39] The plants and trees are delighted to leave this waste to mushrooms, ants, and earthworms. Imagine if all the leaves were gathered into a centrally operated landfill! This would create a major problem in the environment due to excessive transportation and the obligation of other species to concentrate on this one site. No wonder it smells bad, no wonder there are so many traffic jams, no wonder so many people object to its construction and operation.

The reality is that natural and industrial systems need not only to integrate; after the life of a product there is a need to separate. The engineering schools around the world only focus on how to quickly put things together; they have no idea how to separate. The only well known and widely applied techniques to dispose of products which have come to the end of their useful life are landfilling and incineration. These processes generate air pollution and soil pollution. Although this may still remain

within the limits of the law that permits polluting less[40], the time has come to eliminate the concept of pollution.

Natural systems are masterful creators of the greatest products in the world, as has been well described in the book Biomimicry by Janine Benyus[41]. Millions of species belonging to the kingdoms of bacteria, protoctista, fungi, plants and even animals apply fabulous nanotechnologies of which humans cannot even dream. But natural systems can do something else humans have to learn urgently: they separate into useful components that which they previously created. That is why all research initiatives underpinning systems design must include these two sets of technologies: (1) integrated biosystems and (2) material separation technologies. The first one is more widely studied. The second one is rather innovative since we train engineers to look at how the apple falls down. We seldom reflect on the question of how the apple got up in the tree in the first place.

This lack of understanding of how to separate raw materials into distinct components has led to a most destructive process design. When bauxite is mined, the only interest is aluminum (max 3%). When coffee is farmed, the only interest is the soluble coffee (max 0.2%). When beer is brewed, the only interest is the starch (8%). Oddly, even protein (26%) is considered waste in a world where 2,500 people die each day from hunger. When trees are felled to make paper (20%) the rest is incinerated (80%). The list is indeed very long. How is it possible that this singular approach dominates our industrial way of thinking?

The only industry where this obsession and focus on one component only does not apply is petrochemical refining. There are some 100,000 different molecules that can be cracked out of the long chains of petroleum. Of course, petroleum is predictable and stable. It is easily subjected to precise pressure and temperature, with the right catalysts, to produce a predictable type and amount of molecules. However, when one can produce 100,000 derivatives from one long chain of molecules deposited by nature under the Earth's crust, imagine what can be produced from the millions of biota which flourish in our ecosystems.

The Biorefinery

The biorefinery concept is timely and novel. The idea was first floated over a century ago and has received fresh attention from Prof. Dr. Em. Carl-Göran Hedén, member of the Royal Academy of Sciences and former

director of the Karolinska Institute[42]. The biorefinery is a simple concept. Instead of isolating just one element from nature, separate all into valuable combinations. It sounds easy, but it has never been done.

One of the most obvious first applications would be the processing of wood. Why does the forestry industry plant non-native species and then only use a small fraction of the total biomass? If native species were planted, as is done at Las Gaviotas in the Vichada region of Columbia, then the first biorefinery could be based on pine needles. Prof. Dr. Janis Gravitis and his team at the Latvian Wood Chemistry Research Institute operate an extraction system that produces some 20 different biochemicals from needles including a much-desired, non-toxic, anti-rodent product.

The biorefinery concept has been further developed for the processing of trees. Why only extract cellulose, when the hemi-cellulose can be quickly converted to a sweetener that neither causes dental carries nor makes anyone gain weight?[43] How can we justify the destruction of hemi-cellulose for the sake of efficiency? Today, artificial, or non-sugar, sweeteners are 100 times more expensive than sugar from cane. The time has come to make these beneficial food additives available in abundance, creating not only a new competitive industry, but also eliminating a health hazard which is affecting nearly all children around the world.

The other component of wood is lignin, which has a high caloric value. This is often given as a reason for the incineration of all waste from pulp processing. However, lignin can replace toxic and costly epoxies now widely used as binding agents and glue for fiberboard. Why do we continue to insist on using a toxic option when the natural one is available in abundance, could reduce costs, and provide a healthy alternative? This kind of logic is even more compelling when a biorefinery will generate value for 90 to 95% of the tree. These are the types of material separation technologies we need to promote. The technical viability has been demonstrated, and is patented under steam explosion technologies. It requires only pressure (40 atmospheres) and temperature (min 170 degrees C), and a closed water circulation system to extract all water solubles (sugars). The addition of a minute amount of NaOH and H_2O_2 guarantees complete separation without the need for any residual incineration.[44]

Vitamin E should be cheap

The shortcomings of the present industrial processes, which focus only on one component, are further clarified with the situation on the market for Vitamin E. Nearly two centuries ago, when the Dutch and British traders started coconut plantations in Africa and Latin America, there was a need to dry the fruits prior to shipment to prevent them from rotting during transportation across the Indian Ocean. Coconuts were converted into copra, from which fatty acids were extracted in Europe to make soap. It was a profitable business, which led to the creation of a business empire.

The shipment of coconuts ended long ago. Today, all vegetable oils are processed in local mills. That makes sense; the fatty acids from palm and coconut are of interest, not the fibrous waste. However, while it was necessary in the late 1700s to dry the fruits prior to shipment and processing, this is unnecessary today. Yet all designs of processing plants sold by engineering companies from Europe and North America still provide for the conversion of fruits into copra. This does not make sense from an energy point of view. The engineers defend themselves with the argument that, were this not done, insects and micro-organisms would feast on the fruits and destroy the harvest of fatty acids the industry is after.

This makes some sense, but it is not an acceptable solution for these industries in the Third World for the future. The most valuable component in the nuts is not necessarily the fatty acids. These have to face competition with many new materials, such as alkyl-poly-glucoses (APG) extracted from sugars, or citrus alcohol extracted from the waste peels of oranges and lemons. The great value of the coconut is its wealth of Vitamin E, and the exceptional value of palm oil is in its high beta-carotene content. Why is the large majority of the Vitamin E used in the cosmetics industry synthetic? Why is natural Vitamin E so expensive? The reason is simple: the largest source of Vitamin E is simply sacrificed in an outdated process. All Vitamin E from palm and coconut is destroyed the moment the fruits arrive at the mill, when all fruits are subjected to a steaming process.

It is difficult to understand why this is happening[45] since the same process engineering companies which design extraction systems for fatty acids will sell their equipment for the cold pressing of olives in order to make Vitamin E rich virgin olive oil. This is a selling point for olive oil. But olives only have a fraction of the Vitamin E content of the palm and coconut. Why has no process been developed for first extracting the Vitamin E, and then the oil and fatty acids? The beta-carotene from palm oil is not

destroyed but it is subjected to an even more anachronistic process. Since it is a popular belief, and all Western marketing surveys confirm this, that vegetable oil should be "gold" as if it were from corn, synthetic color is added to the healthy palm oil. The beta-carotene is basically destroyed in the process, and masked by an artificial color to make it look great. People who can afford it pay a premium price to buy beta-carotene. Strangely enough, it is not extracted from palm oil. People who need beta-carotene are often the same ones cooking with "golden oil" while biochemists resort to inserting a carrot gene into rice in order to fight blindness. Who is in charge of the design of these processes? How will the children of today will judge this ignorance in the future?

Carrageenan and iodine deficiency disorders

Our ignorance about our bio-resources is sometimes devastating and the solutions imagined for some of the most pressing problems in the world are hard to take seriously. Take the case of carrageenan. This extract from seaweed is indispensable for microwave and deep frozen food. Without this biochemical, our taste buds would simply not appreciate the re-cooked food. But when we extract carrageenan from seaweed, the food industry's interest is limited to this irreplaceable supplement. The waste, which is typically disposed of, is rich in iodine. Up to 30% of the indigenous populations of highland regions of Africa, South East Asia and Latin America suffer from iodine deficiencies. The response is artificially produced iodine, mixed with artificially made salt, and shipped off to the affected regions under United Nations flags as aid![46]

While no one doubts the intentions of everyone involved, it would make more sense to establish seaweed-processing centers along the African coast instead of shipping this freshly harvested, dried, and baled seaweed to Europe. Rather than treat the seaweed the same way as coconuts were two centuries ago, it could be processed locally. First, the crude carrageenan could be extracted, and the residue, which is rich in iodine, could be added to sea salt. Anything remaining can also be used as fertilizer on farmland, a tradition in the UK and Iceland, but now increasingly attractive in dry regions since the residual seaweed absorbs up to 10 times its own weight in moisture in addition to replenishing the iodine in the soil. The waste seaweed could also serve as an amendment to substrate for mushrooms. The iodine will accumulate in the fruiting bodies and this critical trace mineral will be available to consumers of the mushrooms. These three options are very basic examples of how a simple material separation process could be

designed, in the field, in the tropics, by people who may not be educated but are intelligent. We see how a local development strategy based on local resources like seaweed, and the complete conversion of the biomass to value added products, provides jobs and fosters the development of competitive industries which respond to the needs of the people.

Integrated systems designs

Biological processes can be highly sophisticated. Complexity increases as more technologies are incorporated. The Latvian Wood Chemistry Research Institute has mastered this approach for the separation of leaves and wood. Las Gaviotas applies similar concepts when it processes pine resin. Originally, the focus was on colofonia, a biochemical used in the paint and paper industry. However, other components can be extracted and purified: essential oils, terpenoids, saponification agents. After careful assessment, Gaviotas engineers concluded that they could separate some 15 different biochemicals from this one resin with one integrated process. All these biochemicals have market value. Contrast this with the conventional approach: 15 different extraction processes for 15 products including pure hydrogen. This implies that there are 15 separate cultivation processes, 15 distinct capital investments, and 15 individual operations for products that could all be produced in one biorefinery. This is inefficient, costly and uncompetitive. Why do our engineers not receive training in integrated systems design and why is it so difficult to think and act in an integrated fashion?

Biological substitutes for asbestos

These technologies represent more than simple separation systems; they also represent opportunities for eliminating toxic chemicals that are the standard today. Take the case of asbestos. There are few industrialized nations still permitting the use of mineral asbestos fibers. The third world has been less successful in substituting for this potentially very harmful fiber. The reason is simple: the synthetic fiber that has replaced asbestos is 30-40% more expensive. Developing nations often depend on cheap roofing and tubing systems that include the abundant use of asbestos, either locally produced, as is the case of Brazil, India or China, or imported from Russia or Canada (Quebec).

The question has often been asked: why is there no recourse to natural fibers? The engineers have a simple answer: natural fibers have sugars that prevent the full crystallization of the cement board and therefore pose a

quality risk. This answer is correct when one only considers the present separation technology, i.e. washing crushed fibers with water until no sugars are left. The volumes of water consumed are vast. In order to obtain one ton of fibers one may have to use up to 140 tons of water to eliminate all sugars. This process is not viable in the majority of countries around the world. Does this justify the use of synthetic substitutes for mineral asbestos fibers and the rejection of natural fibers? Why do we refuse to consider any innovations based on the principles of sustainability? Is it because the manufacturers of the synthetic fibers earn enough money to control the market and gain the support of policy makers?

There is a simple biological separation technique that could quickly eliminate the importation of synthetic or mineral asbestos fibers. Every fiber-rich material like sugar cane or bamboo has specific fungi, molds, and related micro-organisms which are patiently waiting to capitalize on any crack in the ligno-cellulosic matrix structure of the stem. Once a crack appears, these microorganisms unleash a massive onslaught of sugar-digesting enzymes. These enzymes are fiber and microclimate specific and, once one knows the process and system, can be applied to any separation system of sugars from fibers. The only condition is that one knows how to make yogurt. It is that simple. Since my mother even knew how to make yogurt with flowers, it seems feasible to recreate the process at an industrial scale[47].

The impact of this concept is quite pervasive. There are 2,000 varieties of bamboo, each with their 20-30 plant and ecosystem specific fungi and microorganisms. Once one knows which fungus produces the best enzymes to break down sugars (hemicellulase), the microbiologist will be looking for the same type(s) all the time. This makes each process environmentally benign and adapted to the local system. During the past 400 million years, nature has figured out how to separate lignin from cellulose, or hemicellulose from lignin and cellulose. We can now use the best of these natural processes.

Consider the tremendous water savings. If one were to use the same crushers as for sugarcane, then the amount of water needed for one ton of fibers would be a mere 2 tons. That is a savings of a factor of 70 over the traditional washing approach. It will also be considerably cheaper. As soon as the crushed bamboo is submerged in a basin with “yogurt”, an onslaught of enzymes is unleashed. This process will continue as long as there are any

sugars left. The endproduct, cement, will now be guaranteed to solidify since no sugars will remain in the fibrous biomass. Even the wastewater is not polluted: it is enriched with half-digested sugars which can be used as a basis for animal feed. The process respects the cycle of the kingdoms of nature: from plants, via fungi, to half digested plant matter, to animals.

The cement industry can now offer a great innovation: carbon dioxide neutral cement board. Whereas asbestos was a mere 3% of the fibers in the board or pipes, the ratio is now 50/50 (what/what?). This offers a completely new perspective not only from a climate change point of view, but also from a color point of view. Cement board is unappealingly grey. This new board is green! Close your eyes and imagine a city with green roofs. Can you imagine how people feel living there?! The products are commercially available from ASK-Board, a Japanese company operating in Indonesia.

The Zinner Cycle[48]

Separation techniques based on biological processes are not widely studied, researched, or applied. The simple reason is that our engineers have been trained to use temperature, pressure, and chemicals as the key ingredients for production engineering. They rarely consider time or biochemistry. There is massive opportunity for innovation once we realize that natural processes can indeed make a major difference, especially when they are applied as a series of complementary technologies integrated into a complete system. We need to imagine a process which employs all 5 Kingdoms of Nature, where the complementary chemistry makes the production of nylon as efficient as the production of a spider web.

The first objection many engineers raise is that this is impossible, or only viable in the Third World. The second objection is that this technology portfolio only applies to biological processes, involving agriculture, forestry and the like. This is not the case at all. Take the example of the Tetra Pak aseptic packaging[49]. This is an outstanding example of how engineers are capable of producing the best packaging system, which can be collated quickly and reliably, but which causes a dramatic problem at the end of its brief useful life. No one knows how to separate the plastic, cardboard, and aluminum.

While bauxite contains 3% aluminum, Tetra Pak offers a staggering 11% aluminum of 99.8% purity. This could be an exceptional resource if it were possible to separate aluminum from the sheet of low-density, food

grade, polyethylene. Separated, both are worth a lot of money; together, they are pollutants. The manufacturer of Tetra Pak has spent considerable time and money attempting to develop a method of separation but even the best Swiss engineering could only devise a shredding-freezing-centrifuge process that separates up to 70% of the packaging. Even with this heavy expense in money and energy, and the need to transport all empty packs to a processing center, 30% is left for the landfill. Japanese engineers figured out how to use an ultra-sharp knife on empty Tetra Paks to cut off the paper for recycling, but this still leaves the rest for landfill. And a Finnish paper group has agreed to take in 60,000 tons of packaging from Tetra Pak Germany in order to relieve the pressure on the local landfills and recycling organizations. StoraEnso is only separating the cardboard to be recycled with other waste paper, the rest goes to landfill or incineration.

Inexperienced but clear-minded

It took a Colombian researcher no more than one year to solve the puzzle. Unlike Tetra Pak, which urges the users to rinse out the packaging, Dr. Gloria Isabel Niño noted that the residual milk or juice in the carton quickly starts to ferment. She noted that microorganisms were able to loosen the cardboard and plastic. The solution was right in front of her. The fermented milk and juice delivered the micro-organisms which were keen on working their way through the packaging and within minutes these creatures, invisible to the eye, had separated the cardboard, Low Density Polyethylene (LDPE), and aluminum, leaving four perfectly clean films for recycling.

The technique is not much different from the separation of hemi-cellulose from fibers in bamboo. Whenever a species in nature desires a particular nutrient, it will build up and wait patiently to get to it. The beauty in nature is that there is never a need to send a letter of invitation. Tetra Pak and the Swiss and Japanese labs never found this solution since they worked only with clean samples, thus eliminating the potential solution even before they could identify the core building blocks for it. The remaining possible solutions could therefore only be energy intensive, relying on mechanics, temperature and pressure.

Originally, the innovative solution required warm water to operate quickly. But it did not take Gloria Isabel Niño a lot of research to figure out how she could do the same in cold water. Can you imagine the solution? You have to look for a synergy in another kingdom of nature! Once the logic is clear, it is a compelling guideline for being creative. With this wonderful

basis of inspiration, the development of new industrial processes will be simpler than ever before. We are at the brink of a technological revolution, the creation of a biotechnology we could previously only dream of: combining at least three species from three different kingdoms of nature gives us solutions which work perfectly in each local situation. Just imagine the impact when there are four species belonging to four kingdoms involved. What about when there are five?

From packaging to CDs

The same logic was applied to the need to separate ink, resin, aluminum powder, and polycarbonates from CDs. There are millions of CDs produced annually, but worse, there are millions discarded every day. The problem is the same as with the Tetra Pak: a wonderful product, cheap and very competitive, but after its use, it is nothing but a nightmare. The aluminum powder is once more of superior quality. DVDs even contain some gold dust. Separately, polycarbonates and aluminum are great and valuable materials, but once stuck together and covered with ink and a resin, they are pollutants. If incinerated, they produce a cloud of toxins including dioxins and metal oxides. Today a new technology is available: within a few minutes the resin and the ink separate leaving two materials ready for reuse: a polycarbonate and aluminum. Why do the largest producers of polycarbonates pay their clients to ship the waste back?[50]

The polycarbonates in CDs are of outstanding quality. Instead of disposing of them as waste, an opportunity emerges to reuse these top quality resins for sunglasses, or as the safety film in car windows. The interesting dynamics of the market are that today, Tetra Pak and the CD producers have to pay up to 150 dollars per ton to dispose of the material, whereas those who know how to separate the core components can make 500 dollars per ton. This is an interesting perspective for the future. The first Tetra Pak separation plant opened in September, 2002 in Curitiba, Brazil. The second was inaugurated just a few weeks afterwards in Bogotá, Colombia. While these plants only process a fraction of the total volume, the business is local, generates jobs, and secures sustainable income. At first, the reaction was that this is not possible. However, Tetra Pak soon realized that this was a breakthrough and now contributes to the overall success of the program by providing the supply of waste material.

Non-bio processes

The need for separation is tremendous. The European Union has passed legislation obliging companies to assume responsibility for their goods at the end of their life. It is a tremendous challenge. The problem is that there is not one engineer trained at university to design complete disassembly. The car industry is considering some radical approaches, such as attaching small plastic bombs to critical points in a car, allowing the car to be micro-blasted apart. This is a leap forward in thinking, though not exactly a process inspired by the latest biotechnologies.

Non-biological solutions should not be discouraged, although they are mainstream and biological processes are often overlooked or considered impractical or inefficient. Probably all engineers should learn the Zinner Cycle again. Zinner was a German engineer who professed that in order to achieve any manufacturing target, an engineer should rely on the combination of time, temperature, pressure, and chemistry. Unfortunately, processes are usually designed to take place in a short time period at high temperature and pressure, with chemistry providing its usual magic. The result is pollution and not necessarily integration and separation.

There are exceptions to the rule that chemistry dominates innovations. The vacuum evaporation technology developed and operated by Ogihara[51], the Japanese automobile engineering group, is worth mentioning. The engineers noted that each metal has its own unique gasification point. Since these temperatures are very high, they designed a machine to operate under high vacuum where the unique gasification point is reached at a much lower temperature. Trials with telephone sets, computer boards, and even zinc coated car bodies were most encouraging. All metals separated nicely in their purest form. The only drawback is the expense in energy necessary to generate the high vacuum. The cost notwithstanding, this vacuum evaporation technique is one of the most efficient means to separate metals which were until today hopelessly mixed in just about anything that includes electronics.

Converting an old cement plant

The treatment of septage and sewage is a challenge, but the disposal of municipal solid waste is often an even more insurmountable challenge for cities. The traditional solutions are clearly unpopular: landfill or incineration. Landfills are an eyesore, and the transportation of thousands of tons of waste to a central location is problematic. The incineration option is only a partial solution. Many people object to having an incinerator close by

since there is a proven track record of the generation of dioxin, a carcinogen created by the incomplete incineration of certain plastics. In the end incineration merely reduces the total volume of waste, since approximately 7-12% remains after burning at high temperature. This is simply landfilled as toxic waste.

Cities are struggling to find solutions. Recycling was a first step. Re-use of materials was a second step. The redesign of packaging offers a next alternative. The redesign of diapers[52] is one of these urgent challenges. Diapers already represent some 6% of total landfill mass, a percentage that is increasing as the use by the elderly of big diapers becomes more common. Diapers are not recyclable, and even though the contents are perfectly compostable, the outside is made with plastics and chemicals that are impossible to deal with in a natural process. The acceptance by distribution chains such as Sainsbury, Tesco, and ASDA in the UK, of Mater-Bi, the Italian corn-starch-based biodegradable packaging opens a new possibility for diapers as well. Research and innovative design will be required; however, there is so much at stake and yet so little interest in creative solutions. Why?

Germany has long been considered a forward thinking country in waste management. The "polluter pays principle" would guide the reorganization of the waste stream. In concrete terms this means that the consumer pays. The attempt to impose the Green Dot program is therefore a very costly affair. The German consumers are paying an estimated 4 billion dollars a year to have their waste separated and then what?[53] If one takes a mechanical approach, one will want to force the citizens to separate at source, thus putting all responsibility on the consumers' shoulders. Activists in the Third World have rightly called the polluter pays principle the: "rich people pollute principle". Several countries have succeeded remarkably well in separating waste, though perfect discipline has not been demonstrated anywhere in the world. Once we recognize that perfect separation at the source is not possible, then we have to accept this reality and design waste separation systems accordingly.

The old cement kilns offer a surprising option. These long cement kilns provide an ideal environment to simultaneously propagate aerobic and anaerobic bacteria[54]. This is a surprise to many who have claimed that either there would be bacteria living off oxygen, and then the anaerobes would die, or there would be anaerobic bacteria, and the aerobic ones would not

survive. But in nature, exceptions always confirm the rule. The inner-side of the kiln is covered with a patented material where the anaerobes can hide, while the rest of the kiln is mostly aerobic. When all the waste material is compacted on the bottom there is hardly any air available, so the aerobes will move towards the areas where there is some oxygen left. These kilns rotateabout once per minute and this combined aerobic-anaerobic process permits a thorough separation of the mixed waste.

After three days, the digested waste is ready for separation. Now the bottles are devoid of labels, the ink has been removed from the cardboard, and mechanics can now take over. After some 17 different physical separations, from screens and centrifuges, to trembling tables and magnets, all is more or less separated into uniform materials. The bulk is compostable and some can be of sufficient quality to meet organic label standards; other parts will have suffered contamination from batteries and will require further processing. But new technologies allow further extraction of the "life ingredients" from this slightly contaminated compost so that it can be applied to organic farms wishing to enhance performance with a mix of micro-organisms[55].

The separated material is now ready for optimal recycling at lower cost. Several of the elements that were not recyclable are now available for the generation of new value added. A mix of glass, some green, some brown, some white, splintered and thus useless for the glass industry, can now be converted through a baking process to an abrasive which substitutes for the harsh chemicals used to remove paint from wood or zinc from steel. It is innovative approaches such as this that allow a solution where creativity was lacking. Indeed, blended glass was always considered only good for landfill. There was no technique to make new glass from it. But now, the glass mix is ideal for the production of abrasives in a large baking oven. The oven generates enough energy to cascade its excesses into a tortilla factory[56]. Once you are used to cascading processes to generate value, there simply is no end to it.

Earthworm enzyme separation

Another interesting case of biological separation is the isolation of active enzymes from earthworms. Earthworms were already discussed in the context of septage. They offer renewable, biological resources that do not require any genetic manipulation. The question is: how is it possible to separate these enzymes according to pH to make industrial use of them?

Different products require different solutions. Mixed glass still could generate value by substituting for toxic abrasives. Enzymes from earthworms can generate value if separated and used as specific ingredients for products such as toilet cleaners.

Chemical engineers search for one active ingredient, and continue to produce this standardized material. In nature, it is rare that only one component generates results. It is nearly always the interplay of several. An earthworm is an enzyme factory but, is it really worthwhile to extract only one type? The strategy for separation pursued in this case is not the isolation of one enzyme, but rather the separation of a cocktail of complementary enzymes. It is like human beings having dinner: we seldom agree to just eat meat, or only rice; we enjoy a mixture. Enzymes are the same.

A team of Dutch and Slovak researchers identified a way to separate enzymes according to pH using a simple technique. Enzymes tend to gravitate to their preferred pH levels when placed in a liquid environment with a pH gradient[57]. They will end up stratified and can be separated by pH. This new approach is very different from the typical isolation of one desired enzyme and the propagation of that enzyme via genetic manipulation.

Competition revisited

After a couple dozen examples, we sense that this is only the beginning of a new era of biotechnologies. The time has come to go beyond the mere design of a product or process; the time has come to integrate it all into a system. These systems of production and regeneration of raw materials include two main types of technologies: material separation and integrated biosystems. This new approach not only suggests numerous research themes for scientists and scholars, it is also a wake-up call for industry. Who will be best positioned for the competitive framework of the 21st century?

The time has come to take a new look at how companies are expected to design their business. When the environmental havoc they were creating became apparent, it was suggested that companies model their development after the second law of thermodynamics which states that everything moves from order to chaos. Since business is one of the main culprits in our speedy move towards chaos, corporations were asked to reduce or neutralize their negative impact. The fact that corporations realize their detrimental impact

is certainly to be applauded. However, it is insufficient because it accepts the ultimate result of the second law of thermodynamics: chaos is unavoidable[58].

The new concept emerging for industry is to be inspired by nature, which does not know the concept of waste and has evolved over the past 10+ billion years from the absolute chaos of the Big Bang to an amazingly well structured system of life which is in permanent co-evolution. If one observes the workings of nature, one could come to the conclusion that there is enough for all on earth. The theory of scarcity on which economics rests simply does not hold anymore. In nature, thanks to feedback loops, autopoesis[59], and the self-adjusting capacity that members of a system have, there is somehow enough for everyone, and therefore for the system as a whole. Industry would thus better attempt not to just reduce its waste and minimize its adverse impact, but to actively target the creation of more structure and value. This would add to economic growth without reducing the reserves of nature. Industry could even assist nature in maintaining its evolutionary path.

If, on top of the inspirational framework offered by nature, industry were open to guidance from the thousands of years of wisdom accumulated by indigenous cultures, a world of splendor would be possible. The integration of the fundamental know-how acquired through connectedness with nature and the local environment which previous generations needed to survive, then our design process helping us to imagine the world tomorrow, will include all of the above, and add beauty, passion, enthusiasm, consideration, modesty, simplicity and joy to it. That is indeed a world which starts looking like paradise. It is the one we wish to create.

About the Author

Gunter Pauli (b. 1956), trained as an economist with an MBA from INSEAD (Fontainebleau), has claimed that companies should sack all MBAs. He feels that people specialized in the core business strategy are ill prepared to lead the future biotechnology revolution. He is professor of industrial design at the Science University of Torino and is dedicated to education. He has written 36 fairy tales for children, of which 21 have been adapted to stimulate business to be creative, innovative and demonstrate leadership. He has published 14 books in 27 languages.

Footnotes

[1] See the critique of Vandana Shiva in …. and the work of David Korten "When Corporations Rule the World".

[2] See the United Nations Report on …..

[3] See Worldwatch Institute Vital Signs annual publications

[4] See the fairy tale written by the author "For man only"

[5] See the wild salmon fish museum in Norway <www…. …>

[6] The business of removing body hair, especially facial hairs has expanded dramatically over the years

[7] See the work of Lynn Margulis in her book The 5 Kingdoms of Nature, co-authored with Schwarz.

[8] See the Fairy Tale written by the author "The 5 Kingdoms of Nature"

[9] See the Fairy Tale written by the author "Rice for the Blind"

[10] This was the real definition of Charles Darwin whereby the survival of the fittest was not the strongest but the one most apt to adapt to change.

[11] Bacteria, protoctista, fungi, plants and animals according to Lynn Margulis e.a.

[12] See the ZERI Brasil project started in 1997

[13] See the Fairy Tale written by the author "Why can't I eat sugar?"

[14] See the ZERI Fairy Tale "Can apples fly?"

[15] See the work of Prof. George Chan who has collaborated with the ZERI Foundation since 1995 and who has implemented numerous projects in Fiji, Namibia, Brazil, Colombia, and USA.

[17] See the ZERI Brasil project in cooperation with SEBRAE

[18] See the ZERI project in Colombia in cooperation with the National Coffee Federation

[19] See the ZERI design for a project in Ecuador

[20] See the ZERI project in New Mexico, USA in cooperation with Tierra Wools Cooperative

[21] This technology has been patented by Paul Stamets www.fungiperfecti.com

[22] See the work of Julius Hensel who wrote the book "Bread made from Stones" which was first published in 1894

[23] See the ZERI Design of the project Basalt

[24] See the ZERI Fairy Tale written by the author "Basalt Grows Snow"

[25] See the ZERI design in cooperation with the students of the Science University of Torino (Italy)

[26] See picture presentation made by Prof. Gunter Pauli

[27] See the project of Las Gaviotas recognized by ZERI as a leading example of sustainable development

[28] See the ZERI design for New Mexico in response to an information request from the National Laboratory Los Alamos.

[29] See the ZERI project in New Mexico in coordination with Earthworks and Michael Ogden.

[30] See the technology of contifocusing as described in ZERI publications like the proceedings of the African Workshop in Tanzania in 1997.

[31] See the Fairy Tale written by the author "For men only"

[32] See the fairy tale written by the author "How to take it apart?" with the Elephant and the Chimpanzee.

[33] See the fairy tale written by the author on "Water hyacinth" with tilapia fish and the aquatic plant

[34] See the ZERI project directed by Margaret Tagwira in Mutare, Zimbabwe and the scientific article published in the Proceedings of the 1997 ZERI Africa Workshop.

[35] See the research work on furfural undertaken by the Latvian Wood Chemistry Research Institute

[36] See the debate on PLA (polylactic acids) made from genetically manipulated corn, which requires heavy irrigation and which is patented and Mater-Bi made from starch without chemical processing.

[37] See the pioneering work of Gloria Isabel Niño

[38] See the policy document on Science and Technology written by the author for the United Nations Development Program in 1998 "Science and Technology for Sustainable Development".

[39] See the fairy tale written by the author "The strongest tree" which has been translated into over 100 languages and can be seen on the web www.zeri.org

[40] See the fairy tale written by the author "Why can't I steal less?"

[41] See the book Biomimicry written by Janine Benyus

[42] See the feasibility study written by Prof. Dr. Carl-Göran Hedén in 1994 to substantiate the concept of ZERI to the board of the United Nations University. A summary of the report is available at www.zeri.org

[43] See the fairy tale written by the author "Why can't I eat sugar?" a dialogue between a tree and a sugarcane

[44] See the feasibility study on this research subject written by Dr. W. Candler of the World Bank in 1995 and available on the website <www.zeri.org>

[45] This was the main research topic of the ZERI Link program in Kamakura, Japan where high school girls studied the making of lipstick and designed their version.

[46] See the work done by Prof. Dr. Keto Mshigeni on the island of Zanzibar, Tanzania.

[47] See the work by the University of Manizales, Colombia directed by ……..and the tests undertaken by ASK-Board part of the Japanese cement group Taiheyo Cement.

[48] See the website on the Zinner Cycle <www. … . >

[49] See the work by Gloria Isabel Niño, the leading designer of biological separation systems, some of which have been successfully implemented in Brazil and Colombia.

[50] See report from CD-Systems the largest CD producer in Colombia, which has 2 tons of wasted CDs per month.

[51] See website www.ogihara.com

[52] See the pioneering design of diapers by NATY AB from Sweden. Diapers represent 6% of municipal solid waste, and this percentage is increasing due to the use by the elderly of large size diapers, and the introduction of diaper usage in hospitals as a means to decrease bed linen maintenance costs.

[53] See the article in Stern Magazine (Germany) 31 May 2000 comparing Green Dot program to ZERI's approach "Green Dot tells you what to do with waste. ZERI tells you how to never have waste".

[54] See fairy tale written by the author "Sauna for Bacteria".

[55] See technology developed and patented by Gloria Isabel Niño

[56] See the Earthstone project in Santa Fe, New Mexico, USA and the website www.earthstone.com

[57] See the patent registration by Dr. Gerben de Boer.

[58] This statement was first made by Ted Turner on the occasion of the Johannesburg Summit

[59] The concept of autopoesis was first introduced by the Chilean scientists Maturana and his student Varela. For more information on autopoesis please see website <www. …. . …>