Unity

II The finished picture

It is 2020. A man walks along a country road. Inside his body, a new kidney takes the place of the old one that failed. It was grown outside his body from his own cells over a biodegradable scaffolding and was not rejected after implantation. He walks past a field where a farmer tends his crop and feeds the non-edible waste into a small biorefinery unit that breaks it up into different parts, including fibers that are used by the paper industry to partly replace wood pulp. In the distance, ships pull into to the port of Rotterdam to deliver their biomass cargo to producers of biofuels, fine and bulk chemicals and materials. Shipments of palm oil have markedly dropped since edible oils were first extracted from algae.

Other parts of algae supply farms like this with fertilizer. The vegetables grown here have been carefully bred to not require any pesticides. The man stops to wave at the farmer before he reaches his destination. He then goes through a door with a DNA lock that recognizes him through the same technology that is used by forensic investigators. He sits at his lab bench and begins again the work to develop the enabling technologies that help make his modern world possible.

Ten years ago, these were just tantalizing possibilities. Who can say what tomorrow might bring?

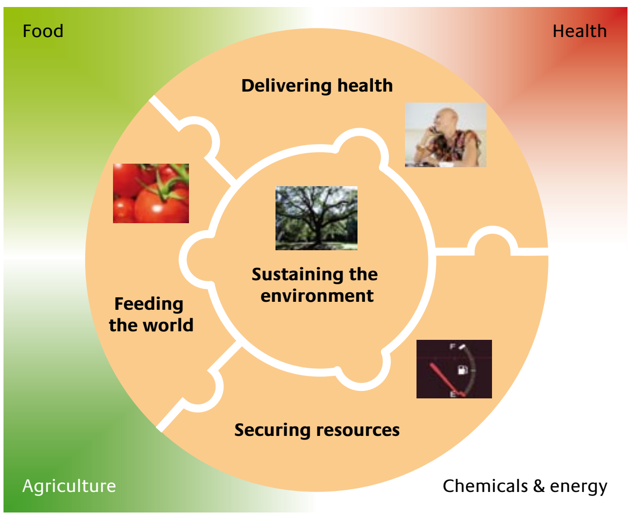

Figure 3: Socio-economic challenges and the life sciences field

If we return to this story in 2020, will it prove an accurate prediction? It may well. Though much work needs to be done, none of the examples given are beyond a reasonable extrapolation of the state of technology today. We will not solve the world's problems by 2020, but between now and then we can make significant progress on some of the most pressing issues. In this chapter, we will examine the main socio-economic challenges facing us in 2009 (Figure 3) and how the life sciences can help address them:

- **Delivering health** to an ageing population with an increasing prevalence of chronic diseases;
- **Feeding the world** and its growing population;
- **Securing resources** for growing energy, chemicals and materials needs; and
- **Sustaining the environment**.

These challenges cannot be solved in isolation. They impact each other. For example, using biomass as the base material for chemicals & energy impacts the environment, as well as the food supply. Comprehensive strategies to tackle these challenges require various disciplines, sectors and ministries to work together. The life sciences will play a major role in that collaboration.[10]

Let us paint a picture of 2020, of what the future could look like if the life sciences deliver on their promise. Mind you, it is an impression, not a prediction – and it is by no means comprehensive. However, it is not that far-fetched either, as the examples of ongoing PPP projects in the boxes throughout this chapter illustrate.

A. Delivering health

In 2020, almost 3.4 million Dutch men and women are over the age of 65, one-third more than in 2009.[11] Compounded by an increasingly unhealthy lifestyle (little exercise, bad food choices, increasing obesity) this has caused the prevalence of chronic diseases like cardiovascular diseases, cancer, diabetes and dementia to rise.[5] Increasing demand, higher expectations and a shrinking workforce have weighed heavily on our healthcare delivery system: costs were rising and personnel in short supply.

But by 2020, the rise in new chronic cases has slowed, patients enjoy a much improved quality of life and costs have been effectively contained. The life sciences have helped do this by enabling early diagnosis, personalized treatment, regenerative medicine, less but better testing, prevention and home care, and increased attention to diet and lifestyle choices.

The life sciences enabled us to see and understand processes in the body on a very small scale by observing biomarkers. From there we started to diagnose and treat (chronic) diseases in a very early stage, before symptoms showed and even before the onset of the disease. The focus has shifted to prevention guided by genetic predisposition. Diet and lifestyle are integral parts of both diagnosis and treatment. When a disease cannot be prevented, its early detection increases the chance of cure and/or reduces its impact on the patient's quality of life. For example, we now can look into white and red blood cells to see whether they are likely to clot, block the flow of blood and cause a stroke or heart attack. This we can then prevent or delay. We can also quickly differentiate between Alzheimer's and less severe causes of memory loss. Immediate treatment slows down the development of dementia in Alzheimer's patients considerably.

The life sciences have also increased the efficiency of treatment by making it personalized, specific to the exact disease and to the individual suffering from it. For example, by looking at the biological characteristics of both lung cancer and patient, we have learned which combination of therapies and dosage work best. Breast cancer treatment has been similarly personalized. More and more, medication delivery itself is targeted – i.e. delivered directly at the tumor site. By 2020, innovative, low-cost sequencing methods have flooded the market, and it has become quite common to have one's genome sequenced. Through systems biology, life scientists have taken large steps in relating genes to processes in the body and their outcomes. Enormous amounts of data and tissue, blood and urine samples from both patients and healthy individuals are collected and stored in data- and biobanks. Bioinformatics techniques have made it possible to process and correlate this information and to better understand predisposition, expression, risk, the effects of diet and lifestyle and prevention and treatment options, truly personalizing healthcare.

WORK IN PROGRESS

Understanding Alzheimer's disease

Age-related memory loss imposes an increasing burden on ageing Western societies. Memory loss is often regarded by patients as an indication that they may have Alzheimer's disease (AD), although in practice it is also a symptom of many far less serious conditions. An important challenge is to differentiate those patients who will and will not develop full-blown AD with dementia. One of the projects of the Center for Translational Molecular Medicine aims to develop new instruments with which to make an earlier and more reliable diagnosis of AD and create tools to evaluate novel medication. This will be achieved by identifying and quantifying biomarkers that indicate AD and developing technologies to make these visible.

Center for Translational Molecular Medicine, www.ctmm.nl

When early diagnosis and personalized treatment are not enough to prevent or stop disease progression, the life sciences offer a range of medical devices and tissue engineering techniques to heal or replace damaged tissue. Regenerative medicine developed, for example, an innovative biomaterial that when applied to damaged bones assists these bones in repairing themselves. And in 2020, the large-scale application of stem cells is not just a dream, but a growing reality. Stem cells have the ability to become any tissue and heal or replace damaged organs. Companies that use stem cell technologies have full and promising pipelines, and the first stem cell therapies have already reached the market.

WORK IN PROGRESS

Preventing kidney failure

Due to ageing, the worldwide incidence of kidney failure is expected to increase rapidly. Current replacement therapies are life saving but fall short of long-term efficacy. Therefore, the development of therapeutic strategies that prevent kidney failure at an early stage and promote functional kidney repair is crucial. The ambition of one of the projects of the BioMedical Materials program is to generate an implantable device that orchestrates the kidney microenvironment to promote the recovery of the kidney and prevent kidney failure.

BioMedical Materials program, www.bmm-program.nl

The life sciences have also impacted the development of health innovations themselves, reducing the need for animal testing and making clinical trials smaller, more accurate and cheaper. Cells have been developed in which the safety and efficacy of medication can be tested. Researchers have found ways to identify the exact subgroup for which a therapy is expected to yield the best results and focus clinical trials on them instead of on random samples of healthy people and patients. All of this helps keep medical innovation in 2020 effective, safe and affordable.

WORK IN PROGRESS

Improving drug dosage for children and elderly

Pharmacokinetics (PK) explores what the body does to the drug: the mechanisms of absorption and distribution, the rate at which drug action begins and the duration of the effect. Pharmacodynamics (PD) explores what a drug does to the body: the mechanism of drug action and the relationship between drug concentration and effect. By modeling the interrelationships between PK and PD based on preclinical and clinical data, predictions can be made on drug efficacy and safety in humans. This allows, among others, for more efficient clinical trial design and improved dosing schemes for patient groups like children and the elderly for which limited clinical data is available. Furthermore, the mechanism-based approach supports the study of drug effects on disease progression. In a project of the Top Institute Pharma, six big Pharma companies and four Dutch academic groups collaborate, yielding mathematical models that are based on existing data to predict among others drug dosage. In this way, an unprecedented knowledge base is created containing models that are based on very rich, multi-partner datasets.

Top Institute Pharma, www.tipharma.nl

Prevention and home care have done the same for healthcare delivery. By 2020, people have become used to (early) diagnostic tools and preventive techniques. Periodic checkups, kits for home care and attention to diet and lifestyle help keep people healthy and out of the hospital. Innovative medical devices that combine life sciences with ICT and nanotechnology allow patients to stay at home and undergo treatment and monitoring from a distance. Healthcare has thus become better, cheaper and more responsive to the needs of patients.

In keeping people healthy, the boundaries between the food and health sectors have blurred. Obesity is one of the main risk factors for chronic diseases and these can be prevented or delayed through lifestyle and diet choices. Our understanding of the relationship between food and health has vastly improved. We better understand our metabolism and what a food component, like a vitamin or sugar, does in our body. We can now predict what genes it will activate, what protein will be produced, what cascade a protein will start, and what consequences that will have for the body. Biomarkers allow us to observe these metabolic processes and signal potential issues. Science-based claims for the impact of food products on health can now be made, and the public can make informed decisions about what to eat and what not. If in 2009 we had the notion that omega-3 fatty acids might reduce the risk of heart disease, in 2020 we know exactly what they do and how and, consequently, when to take them.

WORK IN PROGRESS

Relating food and diabetes

Using a molecular and genetic research approach, new insights can be obtained into the role of food components like fatty acids in regulating organ function and human metabolism and disorders therein. Metabolic disorders are at the onset of major diseases. Insulin resistance syndrome, in which normal amounts of insulin are inadequate to produce a normal insulin response from fat, muscle and liver cells, greatly increases the risk of cardiovascular diseases. One of the projects of the Nutrigenomics consortium aims to understand the impact of fatty acids on gene regulation in the liver and identify biomarkers in the liver for insulin resistance syndrome.

Nutrigenomics consortium, www.nutrigenomicsconsortium.nl

Food companies have used the life sciences to introduce so-called "functional foods", products that improve health or lower health risks. Certain additives help maintain muscle function and mass in older people. Specific proteins reduce blood pressure and the incidence of cardiovascular diseases in groups at risk. Overeating is addressed by developing food products that satisfy at lower quantities. We have learned how to make healthier foods taste, look, smell and feel like their "bad" alternatives, or even better. Nanoscience and life sciences combine to improve texture. Food products are also used to influence the number and type of microorganisms in our digestive tract, to boost resistance or assist in nutrition uptake. These microorganisms outnumber body cells by a factor ten. Life sciences (particularly systems biology) have taught us much of how they function and function together, enabling new prebiotic and probiotic products. Often these (functional) foods are developed for and tailored to a certain population group, and some even expect this to lead to the food equivalent of personalized medicine. That may be a bridge too far, but even so the products on the market in 2020 are only a first step.

WORK IN PROGRESS

Increasing muscle mass and function with dietary strategies

Skeletal muscle mass and function decline with ageing. This is accompanied by reduced physical performance, loss of functional capacity and an increased risk of developing chronic diseases. Age-related loss of skeletal muscle mass has been attributed to a reduced response of the machinery that synthesizes muscle protein to protein ingestion and/or physical activity. One of the projects of the Top Institute Food and Nutrition investigates this reduced response and defines effective nutritional interventions to stimulate muscle protein synthesis and as such increase muscle mass and function in elderly.

Top Institute Food and Nutrition, www.tifn.nl

Our increased understanding of the relationship between food and health is helping us improve food safety in 2020.

WORK IN PROGRESS

Developing alternatives for antibiotic usage in livestock

This research program of Immuno Valley develops alternatives to antibiotic usage in livestock. One of the objectives of this program is to develop a vaccine against Staphylococcus aureus. This bacterium causes inflammation of the udder of dairy cattle and also threatens humans (MRSA). Two other objectives are phage therapy against Streptococcus suis infection in pigs and the application of peptides and herbal extracts that improve the natural defense system of chickens and pigs.

Immuno Valley, www.immunovalley.nl

Food is now preserved through tailored targeting of decay mechanisms rather than filling them with additives. An important aspect of food safety is microbiological safety with livestock. The majority of new human infectious diseases originate from animals. Infectious diseases are still a continuous health risk for humans and animals in 2020.

Early warning systems and sensitive diagnosis have reduced the threat by carefully monitoring epidemics throughout the world (e.g. influenza). Integration of genomic data of variants of microorganisms (viruses, bacteria and parasites) allow timely and effective vaccination of relevant populations of animals and humans. The “One Health” concept, where animal health is integrated into human healthcare planning, is up and running in 2020 (e.g. for Q-fever). Antibiotic resistance is still a threat but can be controlled by efficacious alternative treatments, for example in the fight against MRSA.

The life sciences play a major role in producing all of this safe and healthy food. Through advanced breeding techniques, like genetic modification or marker assisted breeding, livestock that produce healthier products, like unsaturated milk fat, have come within reach. Similar techniques are used to grow vegetables with higher concentrations of health-promoting ingredients. In 2020, we can really set microorganisms to work to control and enrich our food – and not just food, but these organisms produce pharmaceuticals as well. In production, the boundaries have also blurred between food, health and agriculture.

B. Feeding the world

In 2020, the world is shared by 7.7 billion people; this number is expected to rise to 9 billion by 2050.[4] At the start of the 21st century, food shortage was mainly a distribution issue; enough food could be produced for all but it was not easy to get it where it needed to go. Since then, population growth, the limited availability of arable land and dietary shifts in emerging countries (from vegetables to meat) have made production limitations a growing issue. Meat production places a much larger strain on our production capacity because animals need to be fed and cared for. The agricultural sector has therefore been looking for innovative solutions to increase food and feed supply.

We have seen a revolution in crop breeding strategies. This includes the reduction of production losses. More and more plants are being bred to be resistant against diseases, weeds and insects. The life sciences not only provide invaluable understanding of the exact disease mechanisms inside a crop, its natural defense mechanisms and the genes associated, but also biomarkers to monitor plant breeding and optimize the process. Phytophthora, or potato disease, has been all but exterminated. Some plants are even bred to secrete substances that repel harmful insects and preclude the need for pesticides.

In 2020, tougher crop strains have also been developed to survive harsh conditions like droughts, floods and high salt concentrations. With climate change and rising sea levels, such conditions have become more common. But thanks to the life sciences, yields on less fertile ground have increased and harvests have become more predictable and less vulnerable to weather fluctuations. For example, breeders can select lettuce types that are less sensitive to variations in the availability of water and nutrients and can grow under “low-input” conditions. Mushrooms have been bred with low sensitivity to bruising, allowing (cost) efficient mechanical harvesting methods. We have also managed to increase the efficiency of plant light uptake, making them grow faster and bigger. A tomato plant has been bred that can perform photosynthesis (turning carbon dioxide into carbohydrates using energy from light) 24 hours a day in greenhouses. Yields have increased significantly from these and other innovations, mitigating, if not eliminating, the problem of food scarcity.

Livestock produce a major proportion of the world’s food. The life sciences have also impacted animal stocks. By analyzing DNA, animals that are resistant to certain diseases can be selected for breeding. Animal health solutions enabled by the life sciences, such as vaccination, also reduce production losses and increase yields. Breeding strategies have enabled the development of highly productive livestock variants. Another life sciences strategy to secure food supply is to match cattle with feed. By studying their metabolism, we have increased the efficiency of food uptake in animals, achieving maximum nourishment with minimal feed. This not only increases the output per acre, but also reduces the acreage needed to grow plants for

WORK IN PROGRESS

Making potatoes disease resistant

The potato is the number one vegetable crop in the world. Like its close relative the tomato, it is one of the few food crops that can be grown virtually everywhere. The Netherlands is the global leader in the breeding of potato varieties. One of the aims of the Centre for BioSystems Genomics is to create resistance to the disease late blight. This disease costs several billion Euros in crop losses annually, despite several billion Euros which are spent on fungicidal sprays. Methods like market assistant selection and the classification and mapping of all resistance genes in potato are used to achieve necessary plant resistance to this disease.

Centre for BioSystems Genomics, www.cbsg.nl

WORK IN PROGRESS

Shedding light on tomatoes

For optimal growth, fruit vegetables like cucumber, tomato and sweet pepper need 4, 6 or 8 hours of darkness per day. Thus photosynthesis does not take place for 17, 25 or 33% per day. If these vegetables could be grown under continuous light, a substantial increase in production is expected. However, continuous light causes severe problems that lead to poor production or even the loss of the crop. This project aims to understand why the current tomato cultivars show deleterious effects in continuous light and develop markers for breeding lines with a significant increase in yield under continuous light conditions.

Technological Top Institute Green Genetics, www.groenegenetica.nl

WORK IN PROGRESS

Improving milk production

The aim of the Milk Genomics Initiative is to identify genes that contribute to natural genetic variation in milk-quality traits, in particular milk-fat and milk-protein composition. The program provides tools for improved breeding programs to exploit natural genetic variation in milk-quality traits and contributes to the knowledge base needed for innovative dairy products. The initiative combines expertise in the fields of dairy science, quantitative genetics, genomics and bioinformatics.

Milk Genomics Initiative, www.milkgenomics.nl

animal feed. On the demand side, our understanding of human metabolism enables us to improve the efficiency of nutrient uptake in humans and reduce the quantity of food a person needs. Life sciences research is also looking for alternatives to meat, such as algae; ways have even been found to grow some strains in the desert.

In the early 21st century, much was made of the competition between food and fuel for biomass and arable land. By 2020, a bio-based economy has emerged that uses all of the plant: the edible parts for food and the non-edible parts for chemicals, materials, fuels, heat and power.

C. Securing resources

This brings us to the third socio-economic challenge we saw in 2009. The demand for energy, chemicals and materials has steadily risen as the population grew and emerging countries became more prosperous. World energy demand increased by 20% between 2009 and 2020, driven mostly by emerging countries.[6] Because fossil fuels are finite, and because the majority of oil and gas comes from unstable regions, the search for alternative energy sources has picked up speed and the life sciences have taken a leading role.

In 2020 we are well on our way towards becoming a bio-based economy. In the bio-based economy, biomass, not oil, is the base material for energy, chemicals and materials. Life sciences techniques are employed to genetically optimize biomass production. One example is a higher productivity of food and non-food crops by increased efficiency of the photosynthesis. Another is biomass with higher content of oil or specific compounds to produce higher yields, or lower lignin content for easier processing. Chemical and biological processes are used to convert biomass into fractions that provide the building blocks for a range of bio-based products (food, feed, chemicals, materials) and energy (fuels, heat, power). The process is called biorefinery, by analogy to its petrochemical inspiration.

In 2020, the Netherlands has both larger and small-scale biorefineries that convert both imported (corn stover, sugar cane bagasse, wood chips, dedicated energy crops) and domestic biomass (grass, municipal and garden waste, agricultural and forestry residues). The edible and non-edible parts of the crop are separated, where applicable, and from the non-edible parts all high-value, but low volume fractions are extracted first. These can be vegetable oils, proteins, chemical intermediaries or even pharmaceutical ingredients. Next, cellulosic material is disconnected from the lignin, broken down into sugars by enzymes and fermented to make biofuels. Last, the remaining material (lignin, etc.) is gasified for heat and basic molecules.

Smaller biorefineries are located on farms where they use agricultural residues and on industrial sites where they use residue streams from, for example, paper or chemical factories. The larger biofuel installations can be found in the port of Rotterdam, which in 2020 is the largest hub for biomass and bio-based (intermediate) products in Europe, building on its petrochemical position and infrastructure. A large synthetic gas facility operates in Delfzijl. Several pilot facilities for conversion of algae and seaweed have been built. An open-innovation pilot plant for fermentation technologies was realized in the Delft-Rotterdam region in 2012. Today, in 2020, 25% of the value of European bio-based products now passes through the Netherlands. The goals formulated in 2007 by the Green Resources Platform and the Dutch government have been largely achieved (20% of energy from renewable resources including biomass) or are on track (30% of fossil resources replaced by biomass in 2030).[12,13]

The life sciences have been a driving force behind the transition to a bio-based economy, from the genetic optimization of biomass to conversion technologies that use specialized enzymes and tailored microorganisms to the

WORK IN PROGRESS

Converting waste into biofuels

In addition to its traditional industrial applications (e.g. production of bakers' yeast and yeast extracts, beer and wine fermentation), the yeast Saccharomyces cerevisiae is rapidly gaining popularity as a multi-purpose platform for metabolic engineering. One of the Kluyver Centre projects focuses on metabolic engineering of Saccharomyces cerevisiae for the production of ethanol and more advanced liquid fuels from lignocellulosics from agroresidues and forestry.

Kluyver Centre, www.kluyvercentre.nl

synthesis of bio-based products. Increasingly, living organisms are used as factories for industrial production of chemicals and materials, including food products and ingredients, and (bio)pharmaceuticals. The organisms, like yeast, are genetically tailored to their tasks. For example, so-called lactic-acid bacteria produce a range of ingredients such as flavor compounds, proteins and vitamins. But they also produce enzymes as input for other industrial production processes. Tailored cells multiply (parts of) flu viruses for use in vaccines. Also, plants are increasingly used not just as base material for further processing, as explained above, but also for direct production of end products.

Not just whole organisms, but also specific processes within organisms are increasingly used in production on an industrial scale. Enzymes, our natural catalysts, and the reactions that they catalyze have been studied in great detail. Enzymes have been found that can efficiently synthesize tailored peptides that have widespread use in the health sector. Others break up large molecules into useful building blocks. Often such enzymatic reactions are used in combination with chemical process steps. Many of the bio-based production processes require less energy than their synthetic counterparts. These biological production methods thus simultaneously secure future chemicals and materials supply and contribute to overcoming the energy challenge.

WORK IN PROGRESS

Setting enzymes to work

Production of end products often requires many chemical process steps. Instead of a cascade of process steps, it is also possible for these to take place at the same time. An example of this kind is tandem catalysis, where two reaction steps are combined. The Integration of Biosynthesis and Organic Synthesis program in one of its projects investigates a process where a biocatalysis step, performed by enzymes, takes place parallel to a polymerization step. The knowledge assembled in that project is expected to be used in the production of advanced dyes for MRI purposes (e.g. vein imagery in hospitals).

Integration of Biosynthesis and Organic Synthesis,
www.nwo.nl

The biological products developed in the bio-based economy increasingly replace synthetic ones. Polystyrene foam products in construction and packaging are being substituted by biofoams made from polylactic acid. Bioplastics are steadily replacing synthetic. These bio-based products provide us with new functionalities. They are biodegradable, for one. Novel biomaterials used to coat medical devices prevent the body from rejecting them when implanted. We have come to rely on many of these products in our everyday life. What is more, we have seen our economy thrive and our environment improve as we made the transition to a bio-based economy.

D. Sustaining the environment

The growing world population, its increasing prosperity and the attendant rise in demand for health, food, energy, chemicals and materials put a huge strain on the environment in 2020. Fortunately, the world has woken up to the challenge. Worldwide levels of CO_2 emissions have still increased by 16% since 2009, largely due to emerging nations, but Western countries at least have managed to curb their emissions of greenhouse gasses.[6] Energy savings and a move to renewable resources like sun, wind, but also biomass, have made this possible.

The bio-based economy has been key to this transition. CO_2 is a growth gas and the growth of new biomass binds greenhouse gasses emitted in the production of energy, chemicals and materials from biomass. This does not happen with oil or gas. Biological conversion processes using microorganisms or enzymes often require much less energy and produce less waste than their petroleum-based counterparts. Biological products are also typically biodegradable, reducing our waste problem.

WORK IN PROGRESS

Using genomics for sustainable animal breeding

The pan-European project Cutting Edge Genomics for Sustainable Animal Breeding, utilizes the latest techniques in genetic science to develop more economically and environmentally sustainable production systems for cattle, pigs and chickens. The aim is to provide a range of new breeding strategies to improve animal health and welfare, reduce chemical and energy inputs, minimize livestock waste and pollution and maximize food safety and quality. Genomic and epigenetic science will be used to generate new knowledge and apply it in practical breeding improvement strategies.

Cutting Edge Genomics for Sustainable Animal Breeding, www.sabre-eu.eu

WORK IN PROGRESS

Understanding ecosystems

The Ecogenomics Consortium discovers and characterizes new (un)culturable microorganisms in soil and water, with the aim to identify potential genetic markers using GEO and Phylochip technologies as a thermometer of soil health. The consortium also aims to unlock the vast genetic potential of microorganisms to discover and identify new microbial biofunctional compounds (antibiotics, biocatalysts, etc) using metagenomics approaches and HTP bio-screening. Finally, the consortium aims to explore the possibility of using whole genomic information of (in)vertebrates to develop eco-alternatives to animal-based safety assessment of chemicals. The Ecogenomics Consortium recently teamed up with B-Basic to enhance the development of biologically-based, ecologically balanced sustainable industrial chemistry (BE-Basic).

Ecogenomics Consortium, www.ecogenomics.nl

Of course biomass as an alternative to fossil resources is only beneficial to the environment if it is produced in a sustainable way. Sustainable agricultural production, for both food and non-food uses, has become an integral part of any strategy for safeguarding our environment. Cradle-to-cradle and lifecycle approaches have been applied on a large scale to land selection, the machinery used, the efficiency of harvesting procedures, the transportation of biomass to converters and bio-based products to end users, the use, recycling and bioremediation of these products, etc. Here again, the life sciences have played a critical role. Plant breeding has reduced the need for (synthetic) fertilizers and pesticides. Yield increases in both crop and meat production have made it possible to reduce the area used for food supply and have allowed fields to lay fallow and recover. Alternatives for meat, like algae, reduce pressure on the environment. Local pretreatment of biomass destined for biorefineries ensures that nutrients remain on the field and are returned to the soil. Greenhouse crops have been developed to grow under low energy conditions. The list goes on.

The life sciences have also provided us with a wealth of information on how to interact responsibly with our environment. We now better understand the complex ecosystems in which we live and the threats we pose to those ecosystems, like the risk of depleting the soil by "over-farming", the effects of (ground) water pollution on our ecosystem and our effects on biodiversity. We know how to monitor and manage these risks. Electrochemically active bacteria that produce a current depending on the amount of a certain toxin in water are used as biosensors and enable real-time responses to safeguard sustainability in our daily activities.

Starting in 2009

This could be our future. Of course, the life sciences will have to deliver on their promise to make this future a reality, but it is plausible all the same. Perhaps this future is not as far away as we think. A life sciences legend, Craig Venter, the man behind the commercial sequencing of the human genome, has claimed he will make all discussions of food versus fuel and climate changes obsolete. His company, he says, will in the near future combine the processes for feedstock growth and fuel processing by designing organisms that inhale CO_2 and excrete sugars.[14] Wouldn't you like to see that?

WORK IN PROGRESS

Finding alternatives to animal testing

One of the research lines of the Netherlands Toxicogenomics Centre focuses on alternatives to animal testing with regard to chemical carcinogenesis. At present, (putative) human carcinogens are identified via testing of compounds in two chronic two-year rodent bioassays, namely with rats and mice. These testing methods have severe ethical drawbacks in that they use numerous animals under stressful conditions, plus they have practical shortcomings and limited reliability. The aim is to identify a set of genomics effect markers that is able to test compounds for their carcinogenic potential and study the underlying molecular mechanisms of chemical carcinogenesis.

Netherlands Toxicogenomics Centre, www.toxicogenomics.nl

Quote from Rudy Rabbinge

"**The dominating science in the societies of the 21st century**

The life sciences as a common denominator for many impact-oriented scientific domains is rightly seen as the dominating science in the societies of the 21st century. The increased insight, the better understanding and the tremendous perspectives enable innovations in the medical sciences, the chemical sciences and food and agro sciences.

Demarcation lines between and within the natural sciences are fading away and enable the application and use of physical, chemical concepts and principles in biology at various spatiotemporal scales. That will contribute to sustainable development and food security as technological and scientific innovations flourish."

Rudy Rabbinge, Chairman of the Council for Earth and Life Sciences of the Royal Netherlands Academy of Arts and Sciences (RAL-KNAW)