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Food, Feed, Fibre, Fuel and Industrial Products of the Future: Challenges and Opportunities. Understanding the Strategic Potential of Plant Genetic Engineering

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Abstract

Plants and plant crops have always been, and will continue to be, of vital importance for humankind. They are an essential source of food, feed, raw materials, energy and pleasure. One of the main concerns in agriculture has always been to improve the quality of seed. Today, at the beginning of the 3rd Millennium, agriculture is confronted with a wide range of complex challenges. With diminishing availability of farming land, climatic changes and the threat of declining water resources, the task is to meet the growing demand for food, feed, fibre, fuel, industrial products and products based on 'functional' plants. Future-oriented, knowledge-based and added-value agriculture will have to become reality. This will mean reduced use and redisposition of resources - in other words, 'Do more with less!' Within this context, the possibilities offered by efficiency developments in conventional seed breeding, supported by gene technology and plant genomic research, will improve the prospects of being able to use our limited natural resources to best effect in the 21st Century. The appropriate use and timely development of these important aspects will ensure sustainable production of food, feed, fibre, fuel and industrial products in the future.

Key words: added-value agriculture – functional food / feed – functional genomics – industrial ecology – Integrated crop production – Integrated gene management – integrated natural resources management – modern biotechnology

Introduction

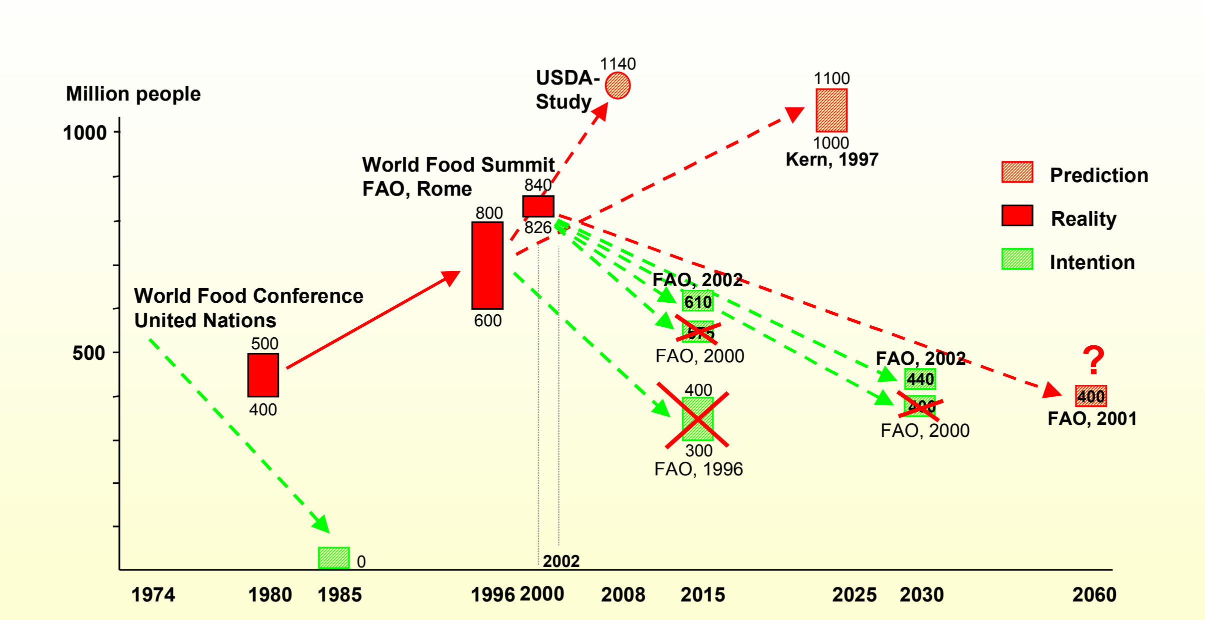
'Agri cultura .... Est scientia, quae sint in quoque agro serenda ac facienda, quo terra maximos perpetuo reddat fructus.' [Agriculture is a science, which teaches us what crops are to be planted in each kind of soll, and what operations are to be carried out, in order to that land may produce the highest yields in perpetuity.] This is a passage in 'Rerum Rusticarum', one of a number of Latin treatises written by Marcus Terentius Varro, a Roman landowner of the 1st Century BC (Kern and Germandi 2001).
'Agriculture is the foundation of culture, economic progress and the dignity of humankind' (L. Dajue, Institute of Botany, Chinese Academy of Sciences, Beijing, unpublished), and 'Without agriculture, there is no stability, without cereals, there is only chaos' (Deng Xiaoping, unpublished).
Agriculture has always been, and continues to be, one of the ways in which humankind has improved the basis of human existence on earth. Technologies were always an integral part of agriculture. Time and again, new technologies and developments have had a decisive impact on methods of cultivation, and our agriculture will continue in future to be based on innovations. For more than 10,000 years, human ingenuity has been developing agricultural technology: the wooden plough, the water wheel, drilling machines, improved seed, new crop plants, the harnessing of horses and fertilization with animal manure led to artificial fertilizers, hybrid seed, plant protection products, tractors and combine harvesters, and now to genetically modified plants and satellite-controlled cultivation and harvesting, all of which are helping to ensure that in the year 2002 we have sufficient food available for more than 6 billion people.
Plants have always served as a vital source of food, feed, raw materials, energy and pleasure. Human beings have been developing plants as a key resource for their own advantage for over 8,000 years, particularly by Isolation, crossing, artificial pollination and selection of plants - i.e. crop plants. Improvements in the quality of seeds were always of great interest. Seeds are the basic agricultural input for sustainable agriculture. Seeds are in fact the hub around which all other strategies for improved productivity revolve. Today, at the beginning of the 3rd Millennium, agriculture is confronted with a wide range of complex challenges - diminishing availability of farming land, the inefficiency of

fragmented small farms (Zhou 2001), climatic changes, future shortage of water resources and the need for timely development of necessary technologies.
'Meeting the needs of the present without compromising the ability of future generations to meet their own needs' is our guideline for sustainable development set down in the Brundtland Commission Report in 1987 (Brundtland 1987) and prioritized in the United Nations Agenda 21 (1992) Programme of Action (United Nations Agenda 21 1992) for Sustainable Development in Rio de Janeiro. During the Rio + 10 conference in Johannesburg, South Africa in 2002, the implementation of action programmes for sustainable development will be the most important task.
Sustainable development means continuous innovation, improvement and utilization of environmentally friendly technologies with the aim of reducing environmental impact and consumption of resources. Improving sustainable agriculture means redisposition and rearrangement of resources or, in other words: 'Do more with less!' For example, the addition of a further plant species which might be grown for food, feed and feedstocks for energy and industry would be of great benefit, as underlined by Jonathan Swift (1729): '...that whoever could make two ears of corn, or two blades of grass to grow upon a spot of ground where only one grew before, would deserve better of mankind, and do more essential service to his country, than the whole race of politicians put together.' Nowadays, we would add: '...conventionally by breeding, assisted breeding or modern biotechnology.'

Food of the Future

The really important questions to be answered are the following: 'How can we feed the future world population sustainably and in keeping with human dignity? (Kern 2001b), 'Who will be fed in the 21st Century?' (Wiebe et al. 2001), and 'What can and must be done - and by whom - to ensure that we react in time to changes?' (Kern 2002b).
In 1996, Heads of State and Government attending the World Food Summit in Rome pledged very optimistically to reduce the number of the world's hungry to half the present level by 2015. Only 4 years later, at the end of 2000, this 'unrealistic target' was abandoned, and instead it was hoped that there would be only 575 million hungry people in 2015, and 300-400 million in 2030. A U.S. Department of Agriculture (1998) study has now shown that as many as 1.14 billion people will be suffering hunger in 2008. If the political will is lacking, the most optimistic scenario is that 1 billion will be suffering hunger in 2025 *(Fig. 1)*.
Hunger in the world is partly – though by no means entirely - a problem of distribution. Future global food supplies cannot be ensured in the long term without the efficient use of existing agrotechnologies and the consistent development of appropriate new ones. The Director-General of the Food and Agriculture Organisation (FAO), J. Diouf, called on everyone concerned (Food and Agriculture

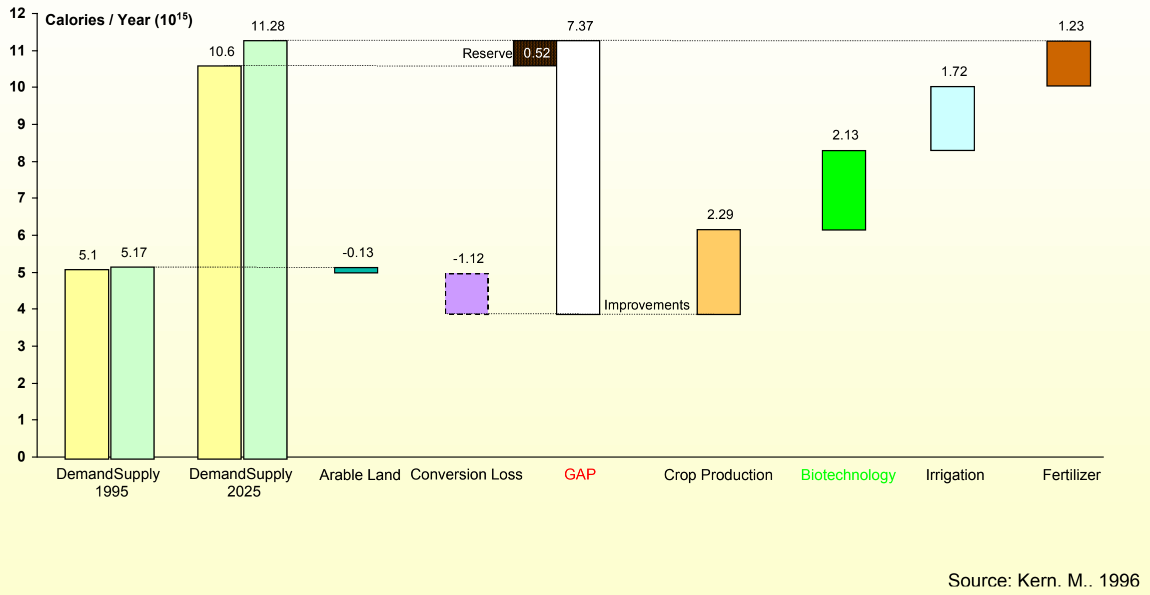
Fig. 1: Global Malnutrition: Predictions and Reality, 1974-2030



Source: Böckle et al. (1983), Weltbank (1993), FAO (1996), USDA (1998), Kern (1997/1999), FAO Report: 2015-2030 (2000), FAO: Committee on the World Food Security (2000), http://www.fao.org/sof/sofi/, 2001, 2003

Organisation 2001) to mobilize all resources - public, private, domestic and international - to increase the productive capacity of agriculture in order to alleviate extreme poverty and reduce malnutrition.
At present, the amount of food-stuffs produced throughout the world exceeds the amount actually consumed by only 0.26 % *(Fig. 2)*.

Fig. 2: Global Food Forecast, 1995 - 2025



Over the next 30 years we will have to produce throughout the world more foodstuffs than over the whole of the last 10 000 years (Kern 2002a). To ensure sufficient food supplies for the world population on a sustainable basis, yields must be increased, and a decisive role will be played here by full exploitation of all available techniques of plant production and modern biotechnology. We will have to make increasingly intelligent use of materials and resources, especially of biological resources.
The necessary increase must come from increases in agricultural productivity in favourable areas and in rainfed and marginal areas. Prospects for the 21st Century are opened up in this direction by effective improvements in agricultural seed development on the basis of gene technology and plant genome research.
Modern plant breeding, including genetic engineering, will help to achieve productivity gains, introduce resistance to pests and diseases, improve crop tolerance for abiotic stresses such as drought, temperature, frost, salinity and acidity, improve the nutritional value of some foods, and enhance the durability of products during storage and transport. In addition to other factors, for example biotic and abiotic factors such as radiation, salinity, chilling, freezing and heavy metals in soil, drought causes severe yield loss worldwide, and it will continue to be amongst the most damaging stresses in crop production (Kern 2002b).
Agricultural biotechnology is expected to contribute significantly to poverty reduction and food security in various regions of the world – especially in Asia, where 2.8 billion people live on less than $2 a day – through increased productivity, lower production costs and food prices, and improved nutrition.
Biotechnology is not a panacea to solve the world's hunger problem, nor will it be able to eradicate hunger - hunger has dozens of fathers', and most of them are manmade.
The positive contributions of agricultural biotechnology to poverty alleviation and improvements in food security for small, middle-sized and big farms have meanwhile been well described (Qaim 1999, National Academy of Sciences 2000, Persley and Lantin 2000, Amerasinghe 2001, Asian Development Bank 2001, James 2001, Wambugu and Kiome 2001, Pray et al. 2001, United Nations 2001, Krattinger 2002, Kern 2002c).
Studies in Mexico, and in Kenya and other African countries (Qaim 1999, Wambugu and Kiome 2001), showed that new technologies and products were easily adopted by farmers. The 'quality/technology is in the seed' and farmers do not need to alter their traditional farming practices to obtain tremendous benefits. Genetically modified insect-resistant cabbage, for example, is not cultivated any differently

from non-Insect-resistant cabbage. Insect-resistant cabbage is not devoured by cabbage moths and thus safeguards the harvest.
Furthermore, estimates of national economic advantages to farmers planting transgenic crops as well as the distribution of economic surplus amongst farmers, technology developers, seed suppliers and consumers are well documented by James (2001).

Functional Food of the Future

McKenna and Wheat (1999) described 'functional' foods as 'foods that provide health benefits beyond those of basic nutrition and have a measurable clinical effect'. At present, the request for functional food applies especially to highly industrialized countries, but will in future also apply to developing countries, since the median age of the population of about 26 years today will increase globally over the next 50 years to over 44 years (Schartz and Leyden, 'unpublished' with website http://www.wired.com/wired/5.07/longboom/ html). Global life expectancy has grown more in the last 50 years than over the previous 5000 years.
Several factors, including an ageing population, ever-increasing health care costs, and consumer demand for healthier food, have been significant driving forces in moving functional foods and nutriceuticals into the corporate mainstream. Interest in this area is growing very rapidly (Mazza and Oomah, 'unpublished with website). Consumers seek more goods that are not tied to simple survival. The role of food will change from the traditional 'survival and pleasure' to food as medicine. Antioxidants, such as carotenoids, vitamins A, E and C, flavonoids and glutathione, which are thought to play a role in the defense of the body against cardiovascular disease, cancer, arthritis and visual impairment, will be a hot topic for the functional food industry in future. Food now has many different names: nutriceuticals, functional food, dietary supplements, nutritional supplements, medical foods, fortified foods, foods for special dietary use, health foods, pharmafoods, cropceuticals and bioactive foods.
The European Commission (2000) Project Report on FAIR Agriculture and Fisheries (including agroindustry, food technologies, forestry, aquaculture, and rural development) specifically described the trends in functional food science and scientific concepts of functional foods in Europe. The definition of functional food put forward by The European Commission (2000) is as follows: 'A functional food can be a natural food, a food to which a component has been added, or a food from which a component has been removed by technological or biotechnological means. It can also be a food where the nature of one or more components has been modified, or a food in which the bioavailability of one or more components has been modified, or any combination of these possibilities. A functional food might be functional for all members of a population or for particular groups of the population, which might be defined, for example, by age or by genetic constitution'. The estimated global market for functional foods will increase from US $ 20 billion in 1998 to US $ 50-150 billion in 2010 *(Fig. 3)*.
Examples of functional foods of the future created by genetically engineered plants include: genetically engineered potatoes and bananas expressing therapeutic proteins and peptides, hepatitis B antigens, human epidermal growth factors and human calcitonin, vitamin A-enriched 'Golden rice', soybean producing ferritin, rapeseed expressing oil low in saturated fatty acids or hirudin, barley synthesizing an active ingredient which reduces cholesterol levels, tomatoes with high levels of vitamin E; rubber trees producing albumin; beet cotton plants producing healthier margarine and cooking oils.
Some plants are improved by eliminating toxic or unfavourable ingredients, for example tobacco free of nicotine; Bt-corn with reduced levels of mycotoxins, cassava without CN compounds; melon and aubergine without kernels or the plant *Lathyrus sativa* without toxins. An extraordinary technology roadmap for plant/crop-based new pharmaceuticals and nutriceuticals/functional food has been presented by the Rural Industries Research and Development Corporation, Australia (2000). A further overview of transgenic plants and functional foods is given by De Kathen (2001).

No Future for Misused Functional Plants!

No discussion of the possibilities of genetic modification of plants can afford to ignore the subject of plant misuse, bio-terrorism and crop biosecurity (Bushnell 2001).
Although agriculture is a matter of strategic importance in almost all countries of the world, it is hardly ever considered as a realistic target for terrorist action. Crop plants form one of the most valuable elements of the capital of humankind, as they feed the greater part of the world's population. For this reason it is vitally important over the long term to preserve crop biosecurity and safeguard it against possible acts of bio-terrorism. Viruses, plant pathogens or harmful insects and plants created by human agency in order to destroy plants or harvests for terrorist reasons must be outlawed and banned, and all developments of this kind must be blocked from the outset. For this purpose,

strategies will have to be devised to avoid the misuse of gene technology. Scientists and politicians alike are called on, to exclude all possible forms of misuse (Kern 2001b).

Fig. 3: New Generation of Functional Food in the USA, 1999

LOWERING BODY	**F**	**AT** *(health)*
G	**U**	**T MALADIES** *(affict 70 million American / year)*
GE	**N**	**DER-SPECIFIC AND AGE-RELATED NEEDS** *(medicine)*
EMOTIONAL	**C**	**OMMOTION** *(sleepiness, stress, digestive upsets)*
BREAS	**T**	**AND PROSTATE DISEASE** *(self-care)*
JO	**I**	**NT HEALTH** *(arthritis, aging)*
BLO	**O**	**D LIPIDS** *(lower cholesterol)*
HORMO	**N**	**ALS** *(40+ million women, menopausal symptoms)*
OPTIM	**A**	**L VISION** *(improve eyesight, Japan!)*
SKE	**L**	**ETAL STRENGTH** *(38 million osteoporosis)*
	F	**UN**
FAV	**O**	**R FLAVOR**
ENJ	**O**	**YABLE**
FAST FORWAR	**D**	**SERVICE**
	S	**IMPLE**

Source: modified after Sloan, A.E., 1999

Feed of the Future

Animal feed

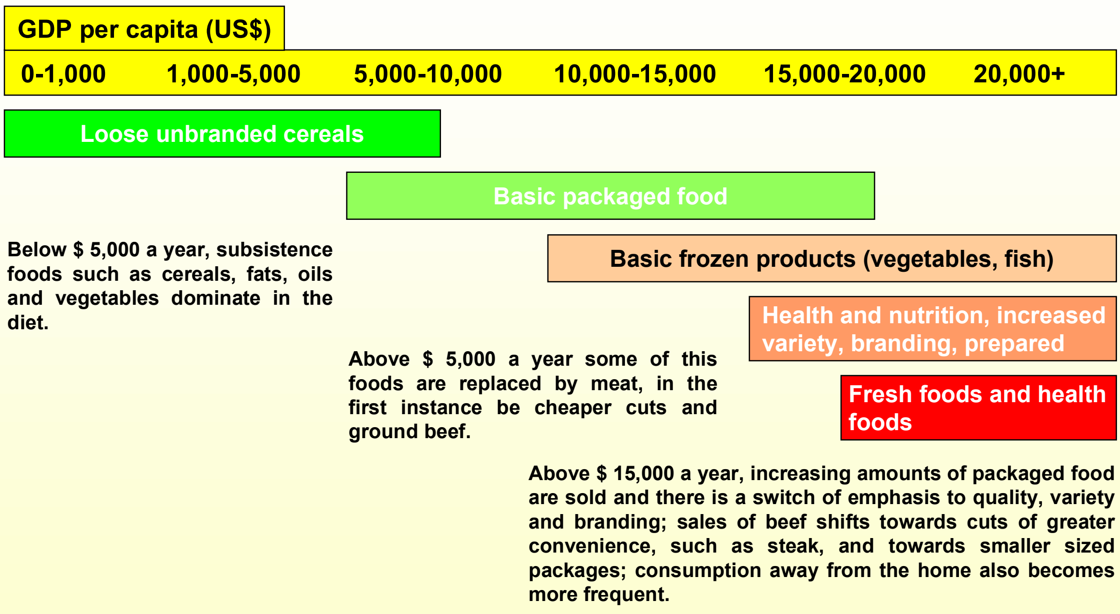
As incomes rise *(Fig. 4)*, especially for certain urban professional groups, people tend to move up the food chain, i.e. consume more livestock products *(Fig. 5)*, the production of which either requires more grain *(Fig. 6)* or absorbs waste land.
The FAO has estimated that in 2015 the world will need to produce 195 million tonnes of soybean to meet global demand. Its estimate for 2030 is 254 million tonnes. Considering that global soybean production in 2000 was about 158 million tonnes, this means that we will need to increase global soybean production by 61 % or 96 million tonnes in the next 30 years. That will not be easy, but will be done through larger plantings and higher yields. No doubt biotechnology will have to play a major part in that effort (Baize 2000).

Pet food

At the beginning of the 3rd Millennium, the growth of the human population is being accompanied by a growth in the numbers of cats and dogs worldwide. The global number of cats and dogs in 1998 was 245 million cats and 235 million dogs (Euromonitor Petfood Industry, London, unpublished). In Germany alone, where more than 6.8 million cats and 5.2 million dogs are fed, around 8-9 % of arable land in Germany is used for cat and dog food alone. Depending on income, the quality of pet food changes significantly *(Fig. 7)*.

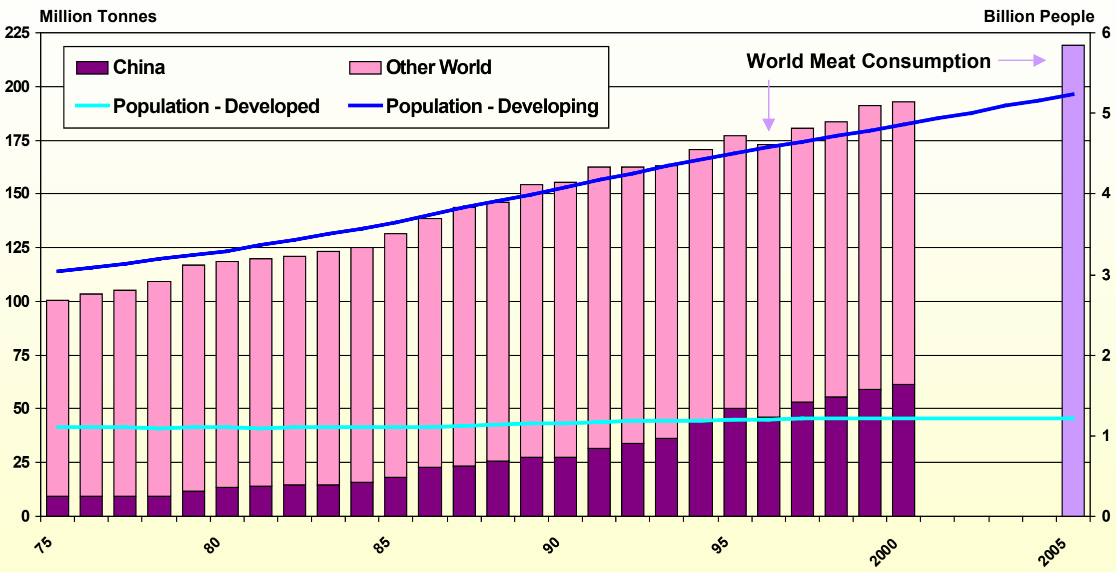
This is a trend or fact not only in industrialized countries such as the USA, the Netherlands, France or Germany, similar trends are foreseeable for China, Thailand, South Africa, Brazil and several other countries, Significant increasing amounts of cereals, fish, and meat will be used for pet food. Global pet food sales will increase from $US 27.5 billion in 1998 to more than $US 40 billion in 2010 (Promar International 'unpublished' with website).

Fig. 4: Trigger Levels of GDP per Capita for Different Types of Food



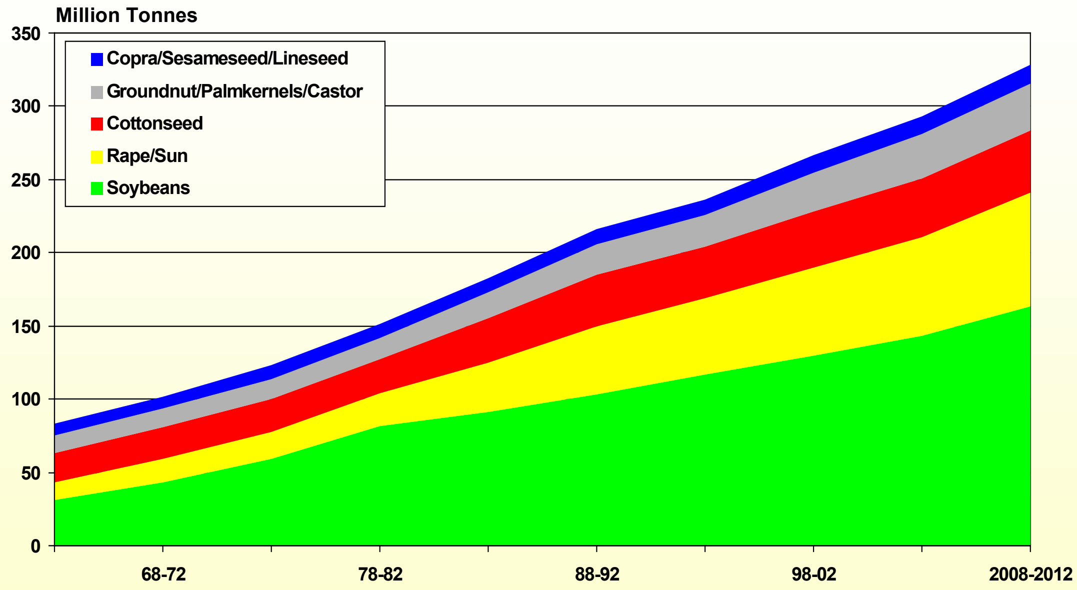
Source: Steenkamp, 1997 in: The World Beef Industry, 1998

Fig. 5: World Meat Consumption and Population



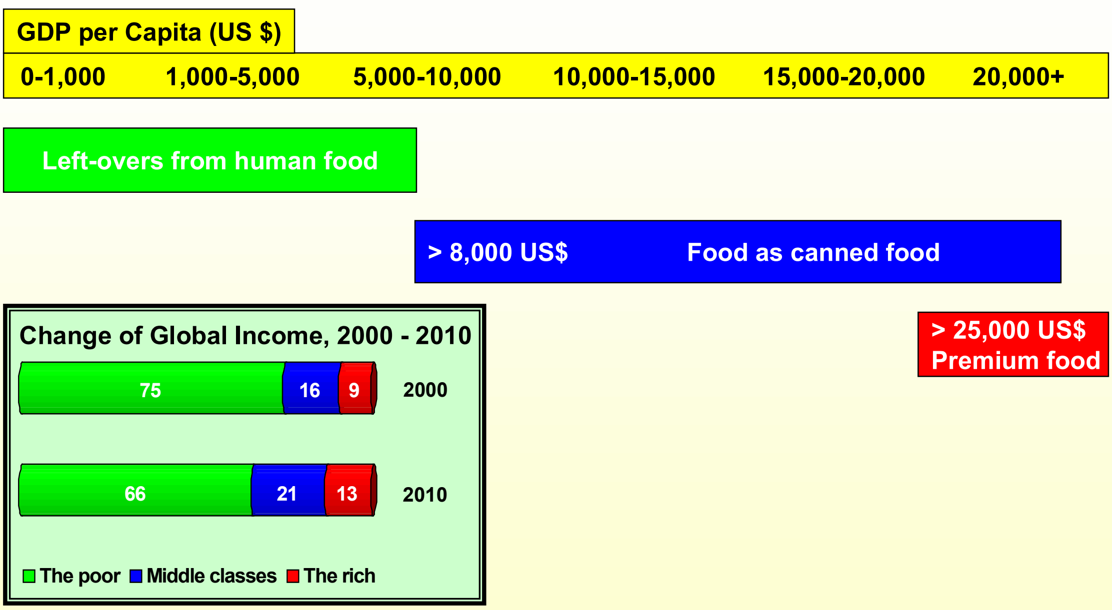
Source: USDA, IMC in: IMC Global, World Agriculture and Fertilizer Situation, 2001

Fig. 6: Oilseeds: World Output by Kind (5-year annual averages), 1960 - 2012



Source: Oil World 2012, ISTA GmbH (1994), ZMP-Bilanz (1997)

Fig. 7: Trigger Levels of GDP per Capita for Cat and Dog Food



Source: promar international, 2000

Functional Feed of the Future

Animals

Current targets in plant breeding designed for functional feed useful for animal production include: increased energy or protein content in corn, enhanced protein quality through increased lysin/methion content in corn, oilseeds and grain legumes, reduction of antinutritional factors, reduced grain moulds and mycotoxins, and low phytic acid in corn and rIce. In general plants are modified to produce ingredients/probiotics which create favourable gastrointestinal bacteria for more efficient feed conversion, reduced protein requirements, and decreased environmental impact, for example to reduce the nutrient load, especially of phosphorus and nitrogen, in manure.
Examples of research objectives are alleviation of the antinutritional problem of ß-glucanes and arabinoxylanes in cereal grains by development of novel barley cultivars that produce highly active and thermostable ß-glucanase and xylanase in the grains, and expression of novel proteins such as feed enzymes in developing barley grains.
As stated also in the International Livestock Research Institute (2000) strategy paper 'ILRI Strategy to 2010 -Making the Livestock Revolution Work for the Poor', one of the priorities is to enhance the quality of livestock feed using biotechnology.
At the present time, genetic modifications are being made to a number of plants, such as spinach, cow pea, maize, lucerne, tobacco and barley, in order to express suitable vaccines against rabies, foot and mouth disease, and diarrhoea of piglets and cattle. An excellent survey of activities in this area has been provided by De Kathen (2001).
In future, genetic engineering of plants will offer an opportunity to develop higher quality feed products in a shorter period of time.

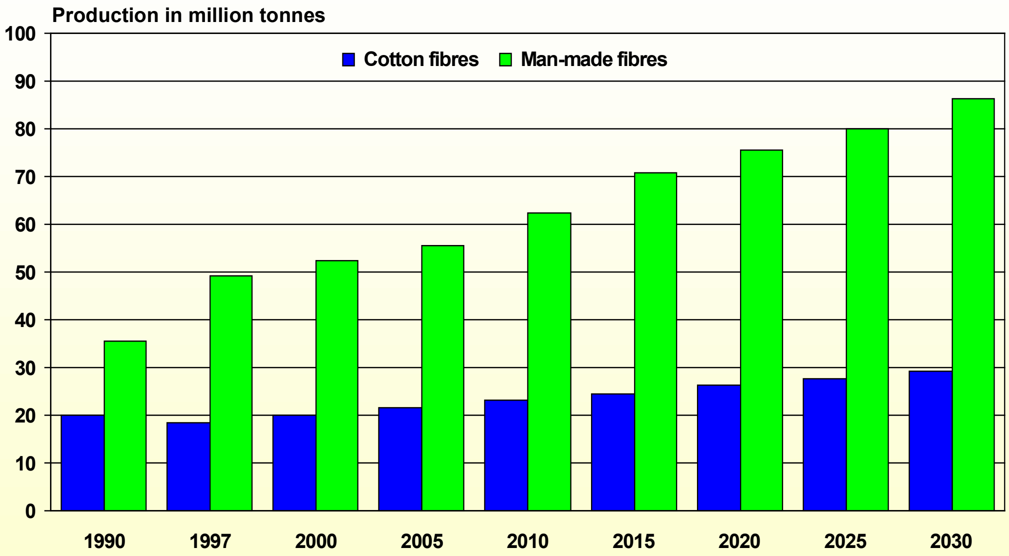
Pet food

Nowadays, new functional feed/food for pets is commercialized. Products are designed specifically for pups or fully grown dogs, small or large breeds, overweight dogs or old dogs, containing additives such as antioxidants (taurin and vitamin C), specific proteins, inulin, folic acid, biotin, vitamin E, omega-3 fatty acids and glucosamine for more efficient food utilization and healthy nutrition.
Functional or healthy pet foods and supplements are between 5 and 10 % of the pet specialty pet food market, or about US $ 200 million at wholesale. 'The whole-health pet nutrition thing is becoming a big part of the pet food system' (Farrell 'unpublished' with website). The consumer consciousness of healthy diets and awareness of foods with benefits beyond nutrition for dogs and cats are now apparent in the pet specialty food market at the beginning of the 21st Century.
Modern biotechnology will significantly target this profitable segment by designing optimized pet food. Special plants will be genetically modified.

Fibre of the Future

In 2025, more than 8 billion people will need clothes, a significant proportion of which will be made from cotton *(Fig. 8)*.
It has been predicted that there will be an increase in the demand for fibre (cellulosic, cotton, wool, manmade and others) from approximately 50 million tonnes year^{-1} today to 130 million tonnes year^{-1} by 2050 (Ditchfield 1999). Fibre flax or hemp production for textile manufacturing will only go to small niche markets. For hemp there is no big industry investing in fibre processing (Ruckenbauer 1999). Further information on the prospects for hemp and other natural fibres and on the possibilities of improving them further with the aid of biotechnology will be found in the comprehensive paper by Ditchfield (1999).
The global area of transgenic cotton in 2001 is estimated to be 6.8 million ha. The most significant increase was reported for China, which tripled its Bt-cotton area from 0.5 million ha in 2000 to 1.5 million ha in 2001. Approximately 3 million small farmers in China derived significant benefits by using Bt-cotton in 2000 (James 2001).
The goal for cotton is to improve cotton fibre performance and plant yield: longer, stronger and more uniform fibres are desired. Targets for biotechnological improvements in cotton are: selfdefoliation, tolerance of temperature extremes, gossypol-free seeds, resistance to aphids and pathogens, and increased photosynthetic efficiency, fibre length, and speed of plant breeding.

Fig. 8: Cotton and Manmade Fibres



Functional Fibre of the Future

Plant fibres are now competing with glass fibres. They have decisive advantages compared with synthetic fibres. One great advantage of using plant fibres instead of glass fibres is their optimized strength-to-weight ratio-, others are their better workability as a result of optimum fibre length and cell wall thickness, their high anisotrophic qualities, and their good ion exchange capacity in water purification systems. The natural products are readily biodegradable and are renewable. Taken all in all, this serves to improve the ecological balance. These factors are also arousing the interest of the motor and aircraft industries, which make a great deal of use of glass fibres for reinforcing structural elements (Kern 2001a).

Further innovations in cotton are underway in: markets for cotton non-wovens and competition non-wovens, especially hygiene, incontinence and medical non-wovens, carding, air-led web forming of natural, synthetic fibres and binder fibres, thermalbond, needle punch, sponlace and other technologies (unpublished; http://www.cotton.org/beltwide/Conference-Highlights.cfm).

The production of spider web silk in potatoes or tomatoes might possibly yield another sector of new, highly flexible and elastic fibres, though research here is only at a very early stage.

Functional genome projects are running to develop a comprehensive understanding of the genetic mechanisms that control fibre development and, consequently, regulate important fibre properties such as yield and quality.

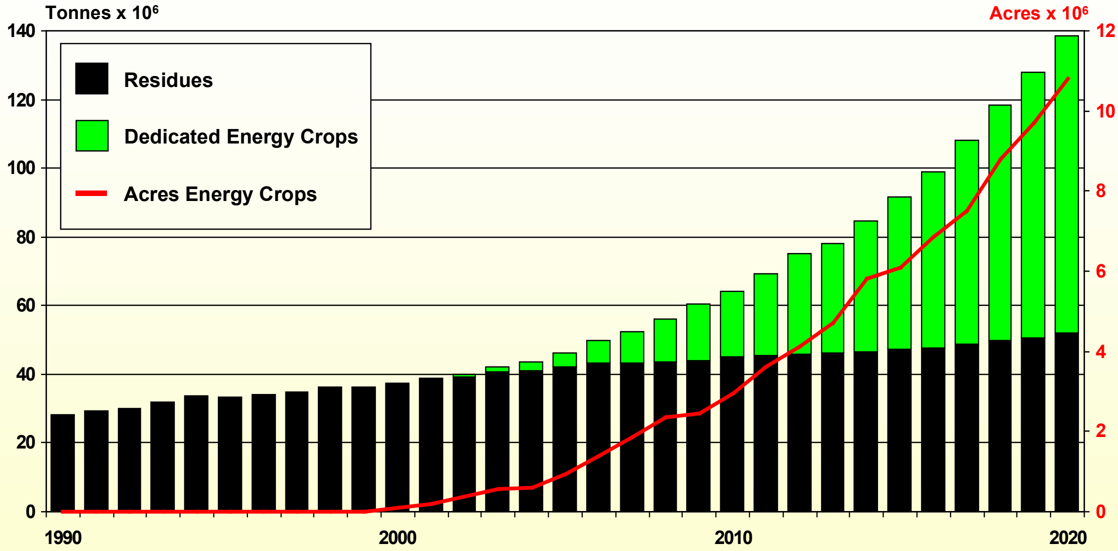
Fuel of the Future

'In the 21st Century we will have to solve three important problems: 1. the question of energy, 2. the question of energy, and 3. the question of energy' (Vahrenholdt 2002, Chairman of the Board of REpower Systems AG, Hamburg and a member of the Council for Sustainable Development in Germany 'unpublished' with website).

Energy is an essential element for the survival of humankind and vital for any economic growth. Plants, especially agricultural biomass crops, which can be considered will be one answer and a further essential key in renewable energy strategies of the future (El Bassam 2001). Currently, biomass contributes almost 15 % to the global primary energy consumption (El Bassam 1996). Biomass is used, mostly in developing countries, with much less efficiency than is technically possible and economically feasible. In industrial countries, biomass, mainly industrial and agricultural residues and municipal wastes, is presently used to produce thermal energy and to generate 'green electricity'.

Plants and crops, especially some energy plants, have highly efficient photosynthetic systems to collect solar energy and to convert it into chemical energy.
To date, more than 250 000 plants have been identified or described. About 75 000 are edible and about 7000 are cultivated and used as food. Twenty plant species are widely used, and in the future only five species, namely wheat, rice, soybean, corn and rape, will be more than 80 % of our food and feedstuff. Currently, in industrial countries, biomass residue sources account for 100 % of the fuel used for biomass power production or 'green electricity'. About 90 % of the residues are wood waste and the remainder are agricultural residues (U.S. Department of Energy, Office of Solar Thermal, Biomass Power, and Hydrogen Technologies 1996). The strategic plan 1996-2015 of the US Department of Energy projects by 2020 an increase of fuel consumption in the form of biomass by a factor of 3-4, of which more than 60 % will come from energy crops *(Fig. 9)*.

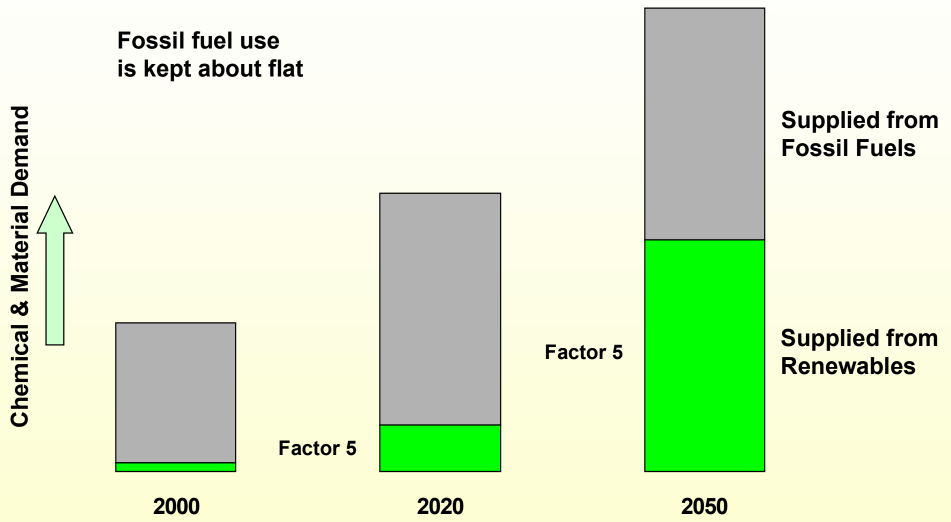
Fig. 9: Projected Biopower Growth; Fuel Consumption by Biomass Type



Source: US Department of Energy, Strategic Plan 1996 - 2015, 1996

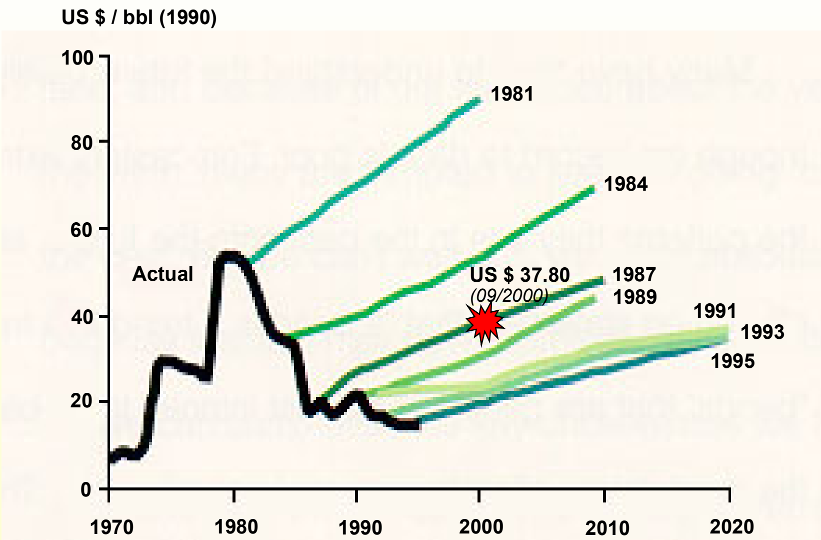
A new vision of plant/cropbased renewable resources for 2020 and 2050 is given in the technology roadmap of the Renewables Vision 2020, Executive Steering Group (1999) *(Fig. 10)*.
The vision of a 5-fold increase by 2020 is expected to set the stage for another 5-fold increase by 2050, and at that point renewable resource inputs will begin to match the use of fossil fuels to meet the projected growth in demand for consumer goods. Renewables will not compete with nonrenewables - this will not be a competitive replacement strategy. Both renewable resources and nonrenewable resources will be needed to meet demands in the 20-year time-frame. Nevertheless, the development and commercial use of renewable energy plants will always depend on the availability and price structure of petrochemicals *(Fig. 11)*.
How long it will take before they are developed and put into use will depend on economic, ecological and political factors, as well as on how urgent it becomes to open up alternative energy-providing resources.
To reach the full potential for biomass power development, a guaranteed stable feedstock of biomass fuel supply systems, as well as new and efficient technologies, such as gasifiers, gas turbines, fuel cells, and steam cycles, have to be developed. Furthermore, it will be essential to reduce the average delivered cost of energy crops by means such as improved crop yields and improved harvesting equipment.

Fig. 10: Material Made from Fossil Fuels and Plant / Crop-Based Renewable Resources, 2020 - 2050



Source: The Technology Roadmap for Plant/Crop-Based Renewable Resources 2020, 1999

Fig. 11: Crude Oil Price Forecasts



Source: International Energy Workshop, in: WBCSD Global Scenarios 2000 - 2050, 1997, MAZ, 21.09.00

More than 40 plants are described as potential energy crops (El Bassam 1996): for example, annual ryegrass, bamboo, black locust, cardoon, eucalyptus, miscanthus, topinambour and wheat.
To date, powerful conventional breeding programmes for energy crops are rudimentary or do not exist. Breeding targets for breakthroughs of energy crops (El Bassam 1998) are:

- increased photosynthetic efficiency,
- more efficient uptake of nutrients and water,
- development of low-Input cultivars, especially for developing countries,
- modification of the transport mechanism of assimilation within plants.

Functional Fuel of the Future

The development and introduction of biotechnology and gene technology could offer new chances to accelerate and support traditional plant breeding (El Bassam 1998), for example, new resistant cultivars of energy crops with special qualitative features for feed and foodstuff, and the development of various compounds relevant for conversion to electricity.
In 2000, Brown (Brown 'unpublished' with website) published a scientific breakthrough. Genetically modified rice which could boost yields by up to 35 % was developed jointly by Washington State University and agricultural researchers in Japan. Genetic material from malze was inserted into rice (C3 plant), boosting the rate of photosynthesis so that the plant was able to produce more sugar and higher grain yields. The transfer of such relevant energy systems will be a question of time and facilitate the breakthrough of energy crops in order to improve sustainable development for present and future generations.
Recent results of joint research by Aventis CropScience (unpublished) and the Institute of Biotechnology of the University of Cambridge in the UK have shown accelerated plant growth resulting from increased cell division. After an *Arabidopsis* gene had been introduced into a tobacco plant, it was possible to achieve rates of cell division twice as high as those of normal plants. This achievement opens up opportunities to speed up the growing season, resulting in several harvests a year and an overall increase in plant biomass production. However, agricultural biomass production must not compete with food production, but should increase diversity in some regions of the world and make feasible the beneficial use of often destructively exploited land resources. Caution will be necessary with respect to the removal of too much of the crop residues, which may effect soll fertility, and the use of good cropland for energy plantations. Thus, long-term planning will be essential in order to avoid effects on the population-food supply balance in the future (Best 1995).

Industrial Products of the Future

The potential of plants as industrial products is high for grains such as sugar, potatoes, whole crops, waste and woody materials in making ethanol and methanol and bioplastics, although commercial viability is often dependent on significant increases in oil prices, improved processing efficiency and/or generation of external, for example environmental, benefits. Only one example of a new functional industrial product will be given. In 2000, the Rural Industries Research and Development Corporation, Australia predicted that by 2010-2015 raw material costs of biopolymers produced from plants would be competitive with those made from oil. But this has already become reality in 2002. Meanwhile, in 2002, Biophan® (Trespaphan, Frankfurt, Germany), a film based on polylactic acid (a polymer made from corn), has been produced in France and commercialized worldwide. Biophan® is used, for example, to produce biodegradable films, shavers or shampoo bottles. It is completely compostable and biodegradable within 6 weeks and produces only water and carbon dioxide as degradation byproducts. Petroleum-based plastics do not decompose (Fass 2002). Polylactic acid will be useful for recyclable and biodegradable packaging, such as yoghurt cups and sweet wrappers. It has also been used for food service ware, lawn and food waste bags, coatings for paper and cardboard, and fibres for clothing, carpets, sheets, towels and wall coverings. The book 'Green Plastics' by Stevens (2002) extensively describes the perspectives of the emerging bioplastics technologies.
Industrial plants such as oilseed rape, mustard, false, flax, sunflower and spurge, from which vegetable oil is produced, are used in cosmetics, lubricants, hydraulic oils, mould oils, motor oils, solvents and detergents. Linseed is used for paints, lacquers and glazings, maize, the starch of wheat and wrinkled peas are used for paper, cardboard and packaging, potatoes are used for films and detergents, the sugar of sugar beet, sugar cane, topinambour and chicory is used for films, detergents, paper, cardboard, bioplastics and drugs, extracts of medical plants and spices are used for medicaments, ethereal oils and cosmetics, tomatoes are used to produce spider silk; fibres of hemp and cellulose are used for paper, isolating materials, yarn and cosmetics, cellulose fibres of wood are used for paper, cardboard, cigarette filters, furniture and toys.

Functional Industrial Products of the Future

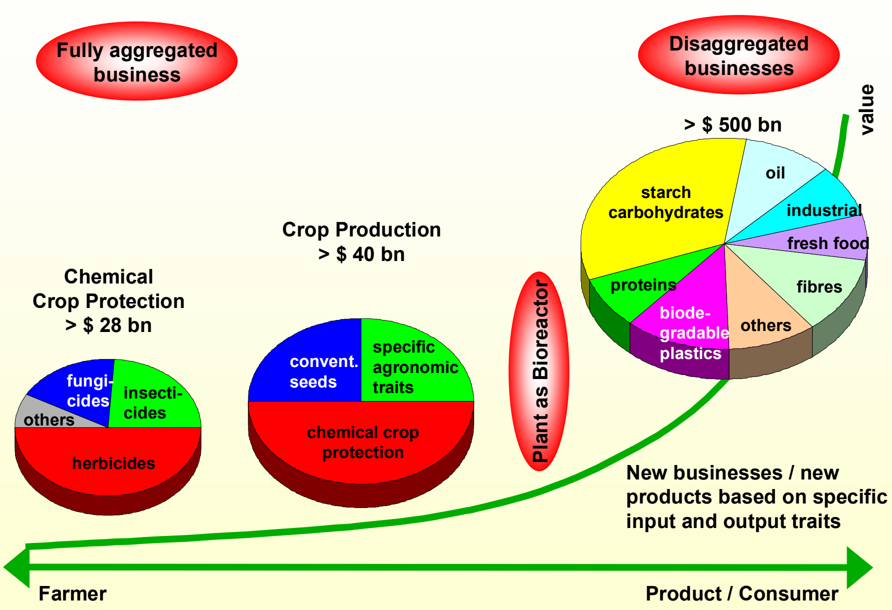
Advances in genetic engineering of plants and fermentation technologies hold the promise of reducing material costs in making industrial products that currently rely heavily on the use of petrochemical resources. Genetically engineered crops offer the prospect of a better environmental performance in industrial processes.

In the area of functional industrial products for plant science, the following challenges lie ahead: better understanding of gene regulation and control of plant metabolic pathways, better understanding of functional genomics to improve gene modification, the development of new screening systems, the improvement of biotechnological methods for gene stacking, organelle transformation and molecular evolution, better understanding of carbon flow at the molecular level, the search for mechanisms of gene switching, and the development of broad bioinformatics.

Added-Value Agriculture

In the future, the crop production market may develop further downstream. New products based on specific input and output traits of plants will create new values for agriculture *(Fig. 12)*.

Fig. 12: Tomorrow's World: The Crop Production Market may Develop Further Downstream



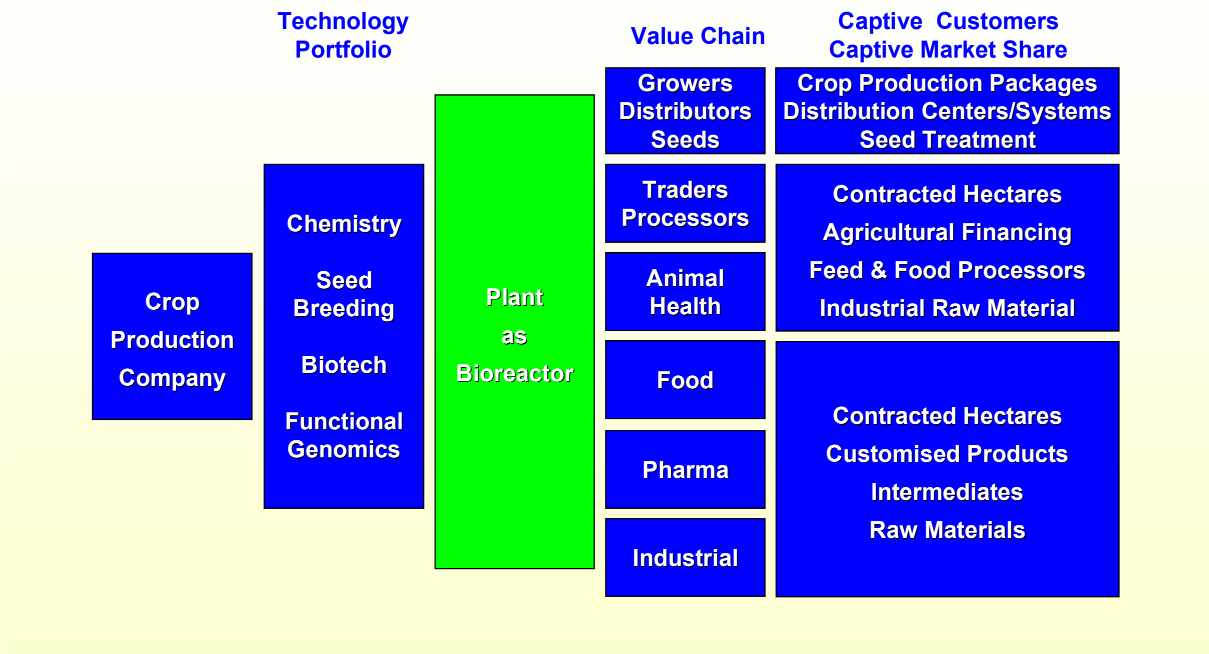
Starch, proteins, biodegradable plastics, oil, industrial products, fresh food, fibres, and other products produced from improved crops will be key yardsticks for sustainable development.

How can we improve the value creation chain in plant production? How can we realize added value agriculture? How can we develop a more efficient use of land, energy and material, or: how can we establish a superior 'industrial ecology'?

With all the challenges ahead in the fields of food, feed, fibre and fuel, there will be increasing variations in future agricultural production systems. The agriculture of the future will be increasingly multifunctional, heterogeneous, complex, multicomplex, knowledge-driven, technologydriven and adapted to available resources.

Thus, it will be important to encourage more fluid transitions amongst the various cultivation systems: rationalized agriculture, value-added agriculture, high-output agriculture, low external input farming, precision farming, prescription farming, site-specific farming, subsistence farming, organic farming, integrated farming, progressive farming, pioneering farming, knowledge intensive agriculture; synergies and symbioses will have to be studied, implemented and put into practice (Kern 2000c). More sophisticated technology will bring about a significant increase in the diversity of agricultural production systems *(Fig. 13)*.

Fig. 13: Agriculture 2025: Consequences for Future Players



The optimized and integrated use of all available technologies has to be implemented at farmer level. Extreme positions, such as organic farming focusing mainly on the environment only and high-cost intensive farming focusing on production, have their niches, but cannot satisfy from a global point of view (Kern 1998).

Quite apart from the high diversity of agriculture adapted to available resources, it must always be remembered that resources such as soll, climate, water, technical know-how and knowledge are distributed unequally throughout the world, and that progress in agricultural technology will be implemented very rapidly in some regions, but hardly, if at all, in severely handicapped regions.

The integration of the seed business into modern plant production and the agribusiness industry, and also the drastic changes brought about by e-commerce, will lead to marked changes in value creation in the agricultural business processes. It will no longer be new products alone that create value, but overall package solutions.

Specialized supply chains will spring up. Rural communities that hitch themselves to the new agriculture will benefit from the jobs that processing activity will bring, as well as the prospect of higher incomes for large local producers (Drabenstott 'unpublished' with website).

In 2001, the estimated global area of transgenic crops is 52.6 million ha, grown by 5.5 million farmers (James 2001). Worldwide, more than 90 transgenic plants have been registered (cotton, chicory, potato, pumpkin, corn, soybean, oilseed rape, papaya, tobacco, tomato and pepper). To date, more than 35 000 field trials have been carried out worldwide. Today, genetic modifications of more than 500 plant species are growing in laboratories, green houses or in the field throughout the world.

The possibilities offered by efficiency developments in conventional seed breeding, supported by gene technology and plant genomic research, will open up good prospects for the 21st Century. Genomic research is concerned with the mapping and sequencing of genes (structural genomic research) and the definition of their specific functions (functional genomic research). Genomic research, and in particular functional genomic research, will in future doubtless become a key area of agricultural gene technology. By 2011, a computer model 'virtual plant' that stimulates the common plant molecular functions will be used to understand plant physiology and select genetic modifications for favourable traits (Economic and Social Research Council 'unpublished' with website). Functional plant genomics will enable us to make qualitative modifications in crop plants more precisely, easily and rapidly, and thus also to adapt them more rapidly to changes in climate or increases in temperature.

The genetic code is a gigantic biological manuscript which we have only just started to investigate and decipher. One of its principal objectives is to determine the functions of genes *in silico, in vitro* and *in vivo*. This applies to plants from the First to the Fourth World.

More than 20 organisms have already been fully deciphered genetically. The genome of virtually all major crop plants will have been analysed within the next 5 to 10 years.
Functional genomic research will help us to understand how the genome determines the phenotype. Marker-assisted seed development will be a basic instrument for future seed improvements for food, feed, fibre, fuel and industrial products. Seed optimization will be increasingly adapted to future requirements by new strategies and tactics, which will be developed largely as an outcome of functional genomic research (Mahalakshmi and Ortiz 2001).

Conclusion

In conclusion, a good visual summary of the challenges addressed within this paper is given by the logo of the Second International Conference on Sustainable Agriculture for Food, Energy and Industry, to be held in Beijing, China, in September 2002 with the major conference topic: 'Developing sustainable agriculture, supplying more food, energy and industry for mankind's sustainable development' *(Fig. 14)*.

Fig. 14: Second International Conference on Sustainable Agriculture for Food, Energy and Industry, Beijing, China, 2002

The key task facing humankind is to use our limited natural resources reasonably, equitably and efficiently, ensuring sustainable development for human society (L. Dajue, Institute of Botany, Chinese Academy of Sciences, Beijing, unpublished). If we are to be prepared for foreseeable challenges and the broad variety of opportunities, we will have to develop a future-oriented, knowledge-based agriculture at the global, regional and local levels. Enhanced agricultural efficiency, i.e. added-value agriculture and prudent conservation of resources by modern biotechnology, will be one of the answers to the questions and challenges raised.
To be successful, we need courageous scientists, politically far-sighted decision makers, social transparency and public acceptance. In the end, we need to develop and to implement an ethical integrated management of genes following the vision: 'To understand the dialogue of genes and develop it further - to decipher, marvel at and understand nature's primary language, to add to it with a sense of responsibility and to make use of it in an ethically acceptable way (Kern 2002c).'

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