Plants for the future

The way there

STAKEHOLDERS PROPOSAL for a STRATEGIC RESEARCH AGENDA

PART I

SUMMARY

European Technology Platform
‘Plants for the Future’

Stakeholder Proposal for a Strategic Research Agenda 2025
Including Draft Action Plan 2010

Part I
Summary

9th August 2005

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Document layout

The Agenda is divided into three parts:

- Part one provides a brief and general overview of the **Plants for the Future** Technology Platform and its Strategic Research Agenda for a general readership, including policy-makers, non-specialist scientists, and interested members of the general public and other stakeholders. Part one contains a concise summary of the four challenges and how the Platform proposes to address them.
- Part two contains a detailed exposition of each of the four challenges. For each challenge, it covers an in-depth introduction to the issues pertaining to it, the goals the Platform plans to achieve, and deliverables and research activities for the next two decades. Owing to its length and technical nature, it is likely to be of primary interest to specialists in the particular field covered. However, all stakeholders are invited to read Part two or the sections of it that draw their attention.
- Part three compiles the proposed activities for the period 2006-2010 as the 'Draft Action Plan 2010'.
- [1] *Part two and part three can be downloaded from www.plantTP.com, or by contacting PlantTP@psb.Ugent.be*

1. Introduction

Towards a knowledge-based bio-economy

The EU is working hard to fulfil its ambition of being the world's most competitive knowledge-based economy. This conjures up images of silicon valleys and technology parks, of high-tech equipment and cutting-edge pharmaceuticals. But where do plants fits into the equation? Surely plants are to do with the countryside or the garden or the forest, not part of the avant-garde of technological progress.

Well, of course it is true that the cultivation of plants – agriculture – is one of the most ancient of human technologies. And the use of plants as medicines, foods, clothing and shelter predates agriculture. Humans have depended on plants since the inception of human civilisation and, indeed, virtually all modern human societies have based much of their progress on plants.

Thanks to agriculture, nomadic humans settled and laid down roots. Traditionally, plants have generated virtually all the important resources for humankind, not only food and feed, but also oils, fibres, energy, and wood for building houses and ships. The simple but essential thing that plants can do – and no other organisms can – is to take simple chemical building blocks from the air and the soil and make complex organic products using the sun as a source of free energy.

Humans have been intimately dependent on plants for millions of years. But we do not know very much about them. Agriculture is 15 000 years old but structured plant breeding is a 20th century art. Intensive agriculture and organic farming alike require improved plant varieties, but they depend heavily on their ability to alter the environments in which plants grow (by weeding, fertilising, the timing of planting, etc.). It is only at the beginning of the 21st Century that humans are starting to have any understanding of how and why plants respond to changing soil or climatic conditions, or the presence of pests and diseases. We are starting to understand the basis of drought and stress resistance. We know a little about plant development and growth. We have a good sense of how plant leaves move around to maximise the amount of solar energy they collect.

Plants have helped humanity blossom, and they will be every bit as essential in the future. A growing world population has to be fed, and increasing demand for high-quality, safe and affordable foods have to be met. Fossil resources – limited in availability and a major source of greenhouse gas emissions will need to be replaced with renewable resources. Sustainable economies will have to be based largely on renewable biological resources.

We already have a bio-economy[1]. Plants are the basis of European industries with an annual turnover of more than €1 trillion. Plants will have to play an even more important part in our economies in the future. There is no alternative, and not much time. But in order to rise to the challenges of a growing and ageing population, dwindling resources, and the environment, the new bio-economy will have to be knowledge-based.

Maintaining and strengthening our scientific and technological basis is of critical importance. Europe needs to become an incubator for top researchers and innovative companies, who are often tempted to develop their activities elsewhere. This is not the task of one organisation or of one country. It is only through the commitment of all stakeholders, working together in a coherent fashion at the European level, that we will be able to address these challenges.

Branching out into the future

It is with this in mind that the Plants for the Future Technology Platform was launched in 2004.

The Platform is open to the stakeholders supporting this vision paper, Member States and other interested partners. It was charged with drawing up a Strategic Research Agenda (SRA) that would signpost the way forward for the next 20 years and with developing a more detailed action plan for the 2006-2010 period. The Platform would like to thank the 290 people from 30 countries, that have been involved in the process of producing the stakeholder proposal for an SRA, including the Draft Action Plan 2006-2010. They represent different stakeholder groups – academia, industry, the agricultural and forestry sectors, as well as experts in educational, communications, legal and financial issues, governmental, consumer and environmental organisations. They contributed via direct participation in workshops, drafting groups or on-line consultations.

[1] *The term 'bio-economy' includes all industries and economic sectors that produce, manage and otherwise exploit biological resources (and related services, supply or consumer industries), such as agriculture, food, fisheries, forestry, etc.*

The courses of action outlined in this report are, of course, not set in stone. In fact, this stakeholder proposal for a strategic research agenda is moving on to its consultation phase – involving Member States and other stakeholders – which will last until the end of 2005. The final version of the Strategic Research Agenda 2006-2025 and the Draft Action Plan 2006-2010 will be available in mid-2006.

Wider web of collaboration

Plants for the Future will collaborate directly with other Technology Platforms: these may include Food for Life, Sustainable Chemistry, Forestry, Innovative Medicines, Farm Animal Breeding and Global Animal Health.

The Strategic Research Agenda and Action Plan will endeavour to address four main challenges:

- Challenge one: Healthy, safe and sufficient food and feed
- Challenge two: Sustainable agriculture, forestry and landscape
- Challenge three: Green products
- Challenge four: Competitiveness, consumer choice and governance

The following chapter gives a concise summary of each of the four challenges, including deliverables and proposed research activities to address these challenges.

2. Overview of the four Challenges

Challenge one: Healthy, safe and sufficient food and feed

Food demand is likely to rise significantly in the coming decades, both within Europe and globally. This will be fuelled by population growth, which is expected to reach 9 billion, from the current 6 billion, by 2050. In industrialised countries, more prosperity and a greying population will push up demand for high-quality and safe food. While many of the poorest countries will continue to struggle simply to put food on the tables of their burgeoning populations, improving living standards elsewhere in the developing world will enrich the diet of the average citizen, including more diverse food and an increased demand for meat, straining agricultural resources still further. Meat consumption is expected to increase by 7% annually over the next decade[2]. This would result in a doubling of today's feed production by 2015. We will either need to double the arable land needed for animal feed or significantly increase crop productivity.

Diets and lifestyle are cornerstones of human health. The combination of high-fat, energy-dense diets and sedentary behaviour increases the incidence of such chronic conditions as obesity, diabetes mellitus, cardiovascular disease, stroke, hypertension and some cancers. These 'rich world' diseases spread to developing countries as they industrialise. We have to encourage people to eat healthier diets, as well as to exercise more and lead healthier lives. We should also exploit the potential of food for preventing the onset of chronic diseases. Nutrition research can help identify the relationship between food and health and plant sciences can help develop specially tailored food products.

Accordingly, the specific goals that will be explored under this challenge are:
1. Develop and produce safe and high-quality food.
2. Create food products targeted at specific consumer groups and needs.
3. Produce safe, high quality, sufficient and sustainable feed.

♦ Goal one: Develop and produce safe and high-quality food

Although quality concerns consumers, the improvement of the quality of harvested plant products was not really an issue in the past. However, quality is essential and determined by different characteristics.

- Plant raw material for food and feed need to contain certain main components (carbohydrates, proteins and oils) in desirable amounts, as well as all the factors influencing its nutritional value. Nutrients, such as vitamins, specific classes of unsaturated fatty acids, antioxidants (for example, vitamin E) or mineral nutrients (such as iron or magnesium) are well recognised for having an impact on human health.

- Other factors influencing the quality of plant raw materials and, in turn, the quality of food are those determining the sensory and/or processing characteristics (for food manufacture). Flavour, texture and aroma are normally seen as essential characteristics and often said to be the most decisive factor in buying and enjoying food. Factors determining the shelf life of both fresh produce and processed food, or the stability of plant raw materials after harvest, are also important.

Deliverables and research activities include:

- **Five years:** Analysis of the regulatory pathways controlling the accumulation of storage compounds and specific metabolites in different crops. Identification of the steps to be modified for the improvement of composition. Identification of the molecular components of plants – in close co-operation with industry – that determine sensory characteristics and the shelf life of food, as well as post-harvest characteristics of plant raw materials. This should be followed by an analysis of the biochemical pathways leading to them as a basis for improvement.

- **Ten years:** Improvement of the quality of plants with regard to the key factors identified above. The scientific tools and technologies used for this purpose – be it molecular breeding, tilling and/or genetic engineering – will be selected and applied on a case-by-case basis depending on the crop species

- **Twenty years:** Produce crop varieties which satisfy the quality requirements of both consumers and the food industry

[2] *'Farm Animal Breeding' draft vision paper*

♦ Goal two:
Create food products targeted at specific consumer groups and needs

Food does more than meet our basic nutritional needs or appeal to our taste buds. It is also important for supporting our general health and well-being. A good example of this is plant-derived phytosterol which is an ingredient of margarine. It has been shown that regular consumption of this kind of margarine reduces blood cholesterol levels which lower the risk of coronary heart disease. For this reason, the Strategic Research Agenda also focuses on developing plant raw materials for healthier/functional foods.

Deliverables include:

- Plant raw materials for low-glycemic food, i.e. food containing carbohydrates which are metabolised slowly. This would be beneficial for diabetics.
- Plant raw materials for foods enriched with carotenoids – which are found in yellow and orange fruits and vegetables and in dark green, leafy vegetables – and/or polyunsaturated fatty acids. Age-related macular degeneration in the retina of the eye is the leading cause of severe visual impairment and blindness in the elderly. Carotenoids, such as zeaxanthin and lutein, may help prevent this. They can also help lower the risk of heart disease.
- Plant raw materials for food with cancer prevention characteristics. There is increasing evidence that certain plant components play a role in reducing the incidence of cancer which is on the rise as our population greys.

All these deliverables are based on small molecules or structural components out of plants.

Deliverables and research activities include:

- **Five years:** Identification and characterisation of the molecular structure of plant polymers, such as carbohydrates, as well as the characterisation of plant metabolites that reduce the incidence of cancer. This needs to employ an interdisciplinary approach bringing together plant scientists, doctors and nutritionists.

- **Ten years:** Elucidation and characterisation of the biosynthetic principles leading to the accumulation of carotenoids and polyunsaturated fatty acids.

- **Twenty to twenty-five years:** Market introduction of wheat, rapeseed or potato plants which satisfy the needs of specific consumer groups.

♦ Goal three:
Produce safe, high quality, sufficient and sustain-able feed

Over the past two decades, global meat production has increased rapidly. In the EU and other developed countries, the trend in animal husbandry is moving towards healthier, more convenient and varied meat and dairy products. To meet demand, the livestock sector is rapidly industrialising. At the same time, growing environmental concerns in the developed world are pushing agriculture towards more sustainable technologies.

Industrial feed consumption for livestock production in the EU-15 was largely stable in recent years and is expected to remain constant. The Union imports some 40 million tons of grain each year – 70% of these protein-rich compounds are used as feed. This situation is unlikely to change without significant plant and crop improvements, particularly for wheat and rapeseed. In addition to boosting production, safety is likely to remain a crucial issue when it comes to feed. In this context, the reduction of mycotoxins – caused by fungus – in cereals will play a prominent role. According to estimates of the Food and Agriculture

Organisation (FAO), the world loses $1 billion tons (approximately € 840 mil-lion) of foodstuffs due to mycotoxins per year. It is also important to have access to plant raw materials which contain few compounds that negatively influence the growth and health of animals or, in turn, humans.

Another major deliverable under this goal could be quality feed for quality food. The better we understand the feed requirements of cattle, swine and poultry on a molecular level, and the better we adapt feed to them, the higher meat quality will become.

Deliverables and research activities include:

- **Five years:** Develop biochemical tools and biological assays (high-throughput techniques) for precise quantification of mycotoxins in crop plants. Furthermore, the molecular mechanisms underlying the plant-pathogen interaction need to be deciphered. It is also necessary to assess the macro- and micronutrient characteristics we need in the plant raw material regarding feed uses, to characterise the cellular processes leading to the accumulation of these nutrients within the plant, as well as to elucidate the mechanisms plants use to accumulate such substances as heavy metals and xenobiotics. All this has to be done in close co-operation with agronomists and nutritionists to allow market-relevant assessment.

- **Ten years:** Based on the above, identify suitable germplasms in classical or novel crops meeting our demands. Furthermore, we need to isolate genes and quantitative trait loci (QTLs) relevant to introducing the desired feed quality traits into plants, and to use these genes and QTLs to develop appropriate crop plants using molecular breeding and/or genetic engineering.

- **Twenty years:** Delivery of crop plants to the European market.

Challenge two: Sustainable agriculture, forestry and landscape

The invention of agriculture sparked massive growth in the human population. Millennia have passed since uncultivated wildlife alone could satisfy the human race's food needs. The human population will continue to increase, perhaps reaching 9 billion by 2050. Some parts of the world still suffer from periodic famines. Today, around 800 million people (13% of the world's population) are malnourished. However, the unprecedented food abundance in many parts of the industrialised world makes many people, including Europeans, oblivious to the want elsewhere.

Over the next 20 years (2005 to 2025), the challenge is not only to satisfy growing demand – the first duty – but also to do it in a sustainable manner. Political and social will must lead the way. Europe's common agricultural policy – adopted to address agricultural self-sufficiency in the continent – show just what can be done when the political will is there: Europe's agricultural productivity has jumped two-fold within the last fifty years. However, the EU is still a net importer of agricultural raw material.

Comparable developments are expected in the forestry sector: the FAO predicts a 25% increase in wood demand between 1996 and 2010. This means further deforestation, which is associated with a loss of biodiversity and natural resources, appears to be on the cards. The increasing demand for forest products can be met by increasing the yields of conventional forests through tree improvement and better-managed forests.

This Technology Platform will result in new knowledge of plants that can help to address future needs. This knowledge will demonstrate what is possible in new energy-efficient farming practices and how the use of fertilisers and of phyto-chemical products can be modified. It will also help broaden the range of European crops, satisfy emerging needs for energy and renewable raw materials, and reduce energy-consuming transportation of food.

This sustainability challenge should focus on four goals:

1. Improve plant productivity and quality
2. Optimise agriculture to further reduce its environmental impact
3. Boost biodiversity
4. Enhance the aesthetical value and sustainability of the landscape

♦ Goal one: Improve plant productivity and quality

As a first priority, we need to strike a sound balance between boosting productivity and providing consumers with the products and quality they require from food and non-food industries. We believe part of the answer lies in plant genomics – understanding how all the inherited characteristics of a plant combine to imbue it with its intrinsic characteristics. The factors that influence the yields of agricultural crops as well as trees, for instance, should be important in supplying a growing world population with affordable and safe food and wood of adequate quality and quantity. Understanding how plants can produce the renewable fuels and raw materials that industry and consumers need would help lower dependence on fossil fuels and native forests. Plant genomics can also help manage natural resources and biodiversity optimally. And last, but not least, plant genomics can provide economic, social and territorial benefits for European citizens.

New plant genomics tools should allow us to identify and to improve the adaptability of existing crops and trees to different uses.

Already, for instance, there are wheat varieties that are adapted to the needs of the bread, biscuits or starch industries. Crops are increasingly being designed (by breeding) and grown (farming) to meet the food and feed industries' specific requirements. In addition to the nutritional value of food, crop products need 'functionality'.

Deliverables and research activities include:

- **Five years:** For each crop, including cereals, legumes, oil and fruit-producing species, as well as for tree species, the bottlenecks limiting productivity and affecting the stability of yields need to be identified using physiological and molecular approaches. Factors contributing to the quality of harvested products, including deleterious ones, should be identified.
- **Ten to twenty-five years:** On this basis, molecular breeding tools can be used to obtain elite cultivars cumulating in a high photosynthetic capacity, an optimised growth cycle and architecture, an improved tolerance to abiotic factors with emphasis on water-use efficiency and adaptation to low temperatures. Cultivars displaying stable yields under varying environmental conditions should also be obtained. Finally, new varieties of high quality and good taste can be obtained for major crops, as well as trees used as food and timber sources.

♦ Goal two: Optimise agriculture to further reduce its environmental impact

A second sustainability priority – perhaps the most important – is to reduce the environmental impact of agriculture. Developing milder crop protection methods will probably require both improvements in the management of phyto-chemical products and the development of self-protected plant varieties. Research can identify genes involved, for instance, in pest tolerance/resistance and this would allow plant breeders to select for such traits. Another important issue is the development of pathogen and pest resistances in forest tree species. This becomes increasingly important in light of ongoing climate change.

Water is likely to become scarcer. While the creation of new water resources and better irrigation management is essential, plant genomics can also help design 'water-efficient plants' by identifying sets of drought tolerance genes which are suitable for various climatic situations.

Optimising fertilisation is a related challenge. Plant genomics can improve the efficiency of nitrogen use in crops by characterising the relevant metabolic pathways and identifying the relevant genes.

Europe is the cradle of plant breeding and plant biotechnology, and has the potential to meet these challenges and create more sustainable cropping systems by combining genomic approaches with analytical techniques, molecular breeding and biodiversity studies

Deliverables and research activities include:

- **Five years:** A first priority is to develop accurate and inexpensive monitoring tools to identify, with a high degree of accuracy, when and where a specific agrochemical has to be delivered in the field. The goal will be to deliver the right molecule to the right crop at the right time using high-precision delivery tools. Monitoring tools should also be created to follow the cycle of the delivered molecule in the crop, the soil and atmosphere and to improve agricultural practices. Anticipating the new spread of diseases and pests cam also be improved through the development of monitoring tools allowing the farmer to perform an inexpensive and accurate diagnostic in due time. For many crops, high yields require high amounts of fertilizers and water. New farming practices preventing the leakage of nutrients/fertilisers by employing appropriate crop cycle management should be formulated.

- **Five to ten years:** Crop protection from pathogens and diseases is preferably achieved via the effective exploitation of genetic resistances. Major diseases and pests should be chosen for an in-depth identification of their virulence and spread using the molecular approaches of sequencing and functional genomics. Defence mechanisms operating in crops can be further characterised using molecular approaches. Beneficial biotic factors contributing to crop protection by preventing the proliferation of pests and diseases, as well as signal molecules involved in the recognition mechanisms, should be identified. The production of feed is one of the priorities of EU agricultural policy. This can be achieved by increasing grassland production, based on the development of new varieties of N-fixing crops which require less input for their management when appropriately mixed with other grasses.

- **Ten to twenty-five years:** On this basis, rational approaches to effecti-

ve disease and pest management can be developed, reducing the need for phytochemical protection and leading to improved farming practices. The creation of varieties cumulating various sources of genetic resistances via molecular breeding is likely to be a major goal of the programme. Based on the identification of bottlenecks in their metabolisation, varieties with improved water and nutrient utilisation efficiency should be obtained.

♦ Goal three: Boost biodiversity

The third sustainability priority should be to enhance and utilise plant biodiversity. Firstly, we need to characterise and maintain the biodiversity that exists in the field. We already have the tools to evaluate how different farming forest management practices affect biodiversity (ecological surveying, modelling, etc.). These can generate knowledge which would allow better biodiversity and landscape management in rural and suburban areas.

The impact of human activity on biodiversity in the forestry sector has been much smaller than in agriculture. However, the preferential use of certain, mainly coniferous, species, selected breeding material, the conversion of traditional utilisation (such as coppice) into more productive high forests, and the extended transfer of forest reproductive material all over Europe has altered forest biodiversity and genetic resources. Natural resource management and decision-making require tools to assess the trade-offs between different alternative choices.

Part of our existing biodiversity lies in the collections of plant varieties and related species in genebanks. These have served as the sources for many crop improvements. However, hundreds or thousands of stored seeds with potentially useful properties have never been explored. We now have the tools to look for the genetic biodiversity hidden in those collections.

Furthermore, the domestication of new plant varieties would greatly increase biodiversity within agriculture. The majority of crops grown in Europe originate from domestication processes that occurred thousands of years ago in specific areas, such as the Fertile Crescent (for wheat and barley). Crop improvement introduces diversity by bringing in the genes for specific traits from wild relatives of crop species. But with a greater understanding of a wider range of plants, breeders may also be able to bring wholly new crops to farmers. We may be entering a new phase in which the management of biodiversity in agriculture can lead to the creation of crops adapted to our needs.

Deliverables and research activities include:

- **Five years:** Farming practices need to be improved to reduce their negative impact on biodiversity. Monitoring and modelling tools should first be developed to compare accurately the impact of different practices on biodiversity in the field as well as in the forest. Core collections maximising the exploitable (and accessible) biodiversity available for major crops should be created and properly managed, based on the analysis of allelic diversity. Finally the identification of potentially interesting wild species, producing specific foods or feed of interest should be performed based on biodiversity studies. Due to long rotation periods, the management of tree biodiversity in forests requires specific approaches. Molecular tools can be used to study this biodiversity and the structure of tree populations in different parts of Europe.

- **Five to ten years:** The biodiversity of pathogens and pests has direct consequence on their spread and, therefore, on

their management. This biodiversity needs to be studied, using molecular tools, to identify mechanisms generating new virulent strains/pathotypes. This knowledge can be used to prevent their occurrence by using adapted agricultural practices.

- **Ten to twenty-five years:** Based on validated models of the relevant ecosystems, optimal practices can be identified and delivered. These approaches will include estimates of the impact of these practices on landscape biodiversity management. Core collections should be used to analyse the components of existing biodiversity, with emphasis on agronomically relevant traits and integrating performing alleles into breeding schemes. Wild species related to crops should also be used as new sources of biodiversity for the improvement of agronomic traits in these crops. These genetic resources can be exploited to create new varieties. The analysis of tree populations can help pinpoint the molecular basis of traits of importance (fibre quality, disease resistance, adaptation to climatic changes) and identify the corresponding exploitable genetic resources.

- **Twenty-five years:** Wild species can be transformed into the new crops of tomorrow through molecular breeding for domestication traits.

♦ Goal four: Enhance the aesthetical value and sustainability of the landscape

Another part of any sustainability objective should be the enhancement of the landscape. Land should no longer be viewed solely as a production silo, but rather as complex interconnecting networks and reservoirs of natural resources which can be used for human benefit without long-term damage to the biodiversity that underpins all agricultural and forestry production systems.

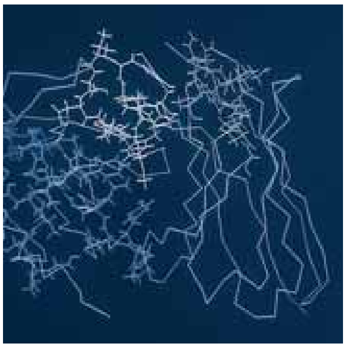
Plants have a tremendous capacity to compensate for environmental challenges. Through combining this ability with that of micro-organisms that rapidly evolve to use any compounds as nutrient sources, plants can be developed to extract and detoxify pollutants from their environments.

Deliverables and research activities include:

- Five years: Ornamental and indigenous plants are an important component of our everyday landscape. Their tremendous diversity needs to be preserved. An inventory of genetic diversity of ornamental and indigenous plants should be performed, taking into account their regional. specificities. New genes enabling the metabolising of a greater spectrum of environmental toxins

- Ten years: Their invasiveness in the environment and possible genetic exchanges with related wild species should be assessed.

- Twenty-five years: Improved management strategies can be built on these observations to preserve natural biodiversity of local crops as well as wild species, and to contribute to sustainability issues, such as recycling strategies, energy production, and fire prevention.



Challenge three: Green products

Environmentally friendly bio-based ‘green’ products are an opportunity targeting the needs of consumers, industry, society and government. European welfare depends, to a large extent, on the emergence of new markets and the growth of existing ones, while respecting the environment and responding to societal expectations. To this end, critical success factors are the ability of companies to innovate their product portfolio and production processes in line with unmet customer demand, and the endorsement of this by the public and government.

In the traditional commodity markets in plant-derived products, a growing number of companies are encountering difficulties in rejuvenating their product offerings. The main reason is that new means of extracting, processing or (chemically) modifying raw materials are running out. Similarly, fossil fuel-based industrial sectors are beginning to face difficulties in sustaining their businesses. This is due to diminishing global reserves and growing public concern about future supply and the environmental impact of burning more fossil fuels.

These trends are leading to a rapidly growing demand for quantum-leap innovations. It is plausible that many breakthroughs may derive from plants and plant-based raw materials with improved or new properties. With the explosion in biological know-how and enabling technologies, developing a broad range of new plant-based products that meet the future needs of consumers and industry, as well as those of society and government, appear feasible.

The underlying concept is that plants are exploited as a production system in the broadest way imaginable. This may include any plant species and range from their use as a production vehicle for proteins and chemicals for industrial and health use, to a renewable, totally redesigned resource for the health, nutrition, materials and energy industries. This would provide the world not only with better, cheaper and safer products, but also with totally new products, production methods, land uses, jobs and ways of living.

In view of the above challenge, the goals for the research community are:

1. Develop advanced plant-based raw materials and pharmaceuticals
2. Develop plants as energy production systems
3. Convert plants into production factories

♦ Goal one: Develop advanced plant-based raw materials and pharmaceuticals

Both society and industry would benefit from exploring the uses of new plant raw materials with better-performing features or an accumulation of new compounds. These benefits may range from cheaper, safer or more environmentally friendly production methods to the ability to develop better products for the consumer. New plant raw materials may include oils, starches, fibres and secondary metabolites, with application in the health, nutrition and materials industries. Similarly, plants may become a major source for the production of pharmaceuticals. The development of new plant raw materials and compounds requires the development know-how on key pathways and participating genes, nutrient uptake and transport, energy metabolism, growth conditions, as well as the appropriate enabling technologies.

Deliverables and research activities include:

Five years

o Fourty prioritised pathways understood at level of participating genes and products
o Efficient molecular gene evolution techno-

logy development applicable to genes participating in the aforementioned pathways
o Optimise plant recombinant protein expression technology
o New transgenic production strategies
o New enabling technologies, such as gene replacement and chemical switch technology

Ten years
o Systems biology know-how for 100+ pathways in three prioritised plant species
o Manipulation of 20 prioritised pathways using on/off switches at all control points and the introduction of foreign genes with new functions
o Sophisticated manipulation of first set of pathways by introducing evolved genes through experimental gene replacement
o Commercialisation of recombinant pharmaceuticals from plants
o Improvement of new enabling technologies, such as efficient gene replacement, chemical switch to bring them up to commercial standards

Twenty-five years
o Predictive systems biology knowledge of 50 pathways in three plant species
o Revalidation of existing systems biology know-how in five additional plant species
o Manipulation of 100 prioritised pathways using evolved genes at multiple control points and the optimisation of foreign genes with new functions

♦ Goal two: Develop plants as energy production systems

Sustainable use of plants to produce energy requires a substantial net energy gain. Simulations that take into account all inputs in the plant-based energy generation process tend to show that the net gain currently ranges between negative and a factor two compared with input energy. This is insufficient to play a role of importance in resolving future energy demand. The challenge is to rethink the concept and dramatically lower energy input requirements for growing and harvesting plant biomass, while maximising energy retention. The ultimate application of this know-how would be the development of an economically competitive, net energy producing system for the energy industry.

Deliverables and research activities include:

Five years
o Development of out-of-the-box options, including some primary feasibility testing of high-energy plant biomass production systems (crops, plant cultures, other) with at least 50% lower energy input requirements than current best production systems (i.e. plants and methods of cultivation and harvesting)
o Development of out-of-the-box options, including some primary feasibility testing, to increase the energy retention of plants by at least fivefold in comparison with today's best performers
o Gene replacement technology to optimise selected, high-energy plant biomass production systems

Ten years
o Prototype development of three prioritised high-energy plant biomass production systems with at least 50% lower energy input requirements than current best production systems (i.e. plants and methods of cultivation and harvesting)
o Prototype development of three prioritised high-energy plant biomass production systems with a forecasted fivefold higher energy retention than today's best performers

Twenty-five years
o Prototype development of two prioritised high-energy plant biomass production systems with at least 50% lower energy input requirements and at least fivefold greater energy retention than current best production systems (i.e. plants and methods of cultivation and harvesting).

♦ Goal three: Convert plants into production factories

Plants may offer an attractive alternative production system for proteins and other compounds. Their use as a production system depends on their cost, quality, environmental friendliness and the time it takes to produce the compound of interest, as well as on the uniqueness of the plants needed to produce a particular compound.

The central theme for Goal three is the optimisation of non-food plants as a vehicle to produce the compounds of interest. A number of factors are likely to determine whether or not industry embraces this new approach: (1) the concentration of the compound, (2) the ability to direct post-translational modifications, (3) the storability of the compound in the plant or (intermediate) extract, (4) the extractability of the compound, (5) the infrastructure requi-

rements (field, greenhouse, growth rooms and 'fermentors') and the acreage necessary to grow the plants, (6) the handling requirements during growth and (7) the time needed to grow the plants. In addition, to minimise plant waste and maximise economic benefit, the plant residue remaining after extraction should have a second purpose.

Deliverables and research activities include:

Five years

- Improved plant gene expression technology for selected non-food plants: mRNA production, translational performance of mRNAs, protein folding, post-translational modification technology
- Compound accumulation and storage technology
- Compound transport and secretion technology
- New technologies (e.g. gene replacement, transfection technologies and chemical switch) applicable to a range of selected species with the potential to meet commercial performance standards
- New manufacturing strategies for production, extraction and processing
- Development of small-scale manufacturing infrastructure and capacity for non-food products

Ten years

- Mainly non-food plants and plant cells optimised for compound production and extraction
- Broadened platform of post-translational modification technologies
- Broad use gene replacement, chemical switch and transfection technologies
- Controlled boosting of plant cell division rates
- Development of large-scale production capacity for non-food products

Twenty-five years

- Compound production and extraction technologies for commercial use and applicable to multiple plants and plant cells
- Development of plants or plant cells suitable for fermentor-like applications

Challenge four: Competitiveness, consumer choice and governance

The successful implementation of the objectives outlined in the previous challenges of this Strategic Research Agenda depends on a strong European resource base: vibrant basic research, skilled and mobile researchers, and access to key research infrastructures.

Vibrant basic research is essential for EU competitiveness, and many of the Technology Platform's key goals are critically dependent on knowledge, tools, technologies and intellectual property derived from such frontier R&D. Knowledge and intellectual property will be critical to fulfilling our goals of securing healthy, nutritious and safe food, developing valuable 'green' products, as well as making agriculture and landscape management more sustainable.

Human resources, research infrastructures and networks are three crucial building blocks of this Strategic Research Agenda. This involves the training and flexibility of researchers and scientists, state-of-the-art infrastructures for research and technology development in general, and strong networking both at the European and global levels.

European citizens and their political representatives have a right to understand the intention, the direction and the process of plant science. The plant science community recognises that it can only be effective in responding to society's needs and building economic competitiveness in Europe if the scientific endeavour is matched with a political one. Without a parallelism of purpose, scientific efforts are doomed to flounder in Europe. None of the laudable purposes outlined in the previous three challenges can be achieved in Europe unless the public is engaged.

Public participation is not only useful but it is also essential in a free and democratic society, particularly when it comes to issues that involve ethical dilemmas or will shape our collective future. Certain aspects of plant science stand right at the frontier of human knowledge and this forward march is taking us into some uncharted ethical territory. Since we share a common future, we should all have some say in shaping it. The optimal way of resolving emerging ethical issues and to ensure that the plant sciences deliver the technology and applications people desire is to engage in a broad public debate.

Legal and regulatory issues, especially those relating to the safety of the use of plants and the products resulting from innovations in genomics and biotechnology, together with the provision of choices for citizens, are important aspects that need to be addressed in a balanced manner. Any dialogue around these issues must take into consideration a careful weighing of the relative risks and benefits associated with these innovative products compared to the status quo. Research can also play an important role in identifying and decreasing potential risks that might be associated with the products of these innovative technologies. For instance, in situations where natural gene flow or cross pollination is deemed undesirable, research could focus on developing more controlled pollination mechanisms and so control or eliminate gene flow. These technologies could be especially important for future 'speciality' crops that may be grown for the production of non-food products, for instance specialty chemicals and pharmaceutical proteins.
The financial environment for private investment in plant sciences and biotechnology depends very much on how markets for these products will develop. At present, plant-related projects can attract some small amount of seed funding in a few EU member states but, in general, commercialisation occurs through large, multinational corporations. While wider funds, proof-of-concept financing, or start-up financing may help to support innovation in this sector, stronger consumer confidence and a regulatory environment supporting open markets for high-technology plant products are likely to be the decisive elements in strengthening investor confidence.

The Technology Platform intends to focus on a number of goals to meet the issues covered in this challenge:
1. Vibrant basic research
2. Human resources, infrastructure and networking
3. Public and consumer involvement
4. Ethics, safety, legal and financial environment

♦ Goal one: Vibrant basic research

The cutting edge of basic plant research is rapidly evolving from understanding the function of single genes to studying networks of genes that control biological processes. This new era of integrative biology enables us to determine how the interconnected networks of genes work together in complex biological processes, how natural genetic variation creates biodiversity. This should ultimately lead to a paradigm shift in how we breed plants, enabling the rational breeding of plant traits.
Basic research is likely to target four deliverables:

1. Genome sequencing and biodiversity, as genome sequences are the primary resource furnishing basic knowledge of a species
2. Plant systems biology aiming to understand how multiple genes function in concert to affect key processes in plant development and environmental interactions, metabolism and physiology
3. Development of improved tools and processes, as advances in biotechnology and genomics are strongly driven by technological innovation
4. Genetic systems for crop improvement, as systems biology research into basic biological processes in model species should be translated to relevant traits in key crops by delineating the molecular basis of genetic systems underpinning crop improvement and innovative agricultural practices. The study of these genetic systems should allow the prediction of 'real world' performance from laboratory studies.

Deliverables and research activities include:

- Major investments in genome sequencing of multiple plant species relevant to Europe, supported by the development of resources and platforms for functional genomics and inventories of natural genetic variation within species as well as among related species. Comprehensive functional genomics programmes should investigate the various molecular levels: the RNA world, the protein world and the metabolome. In addition, appropriate infrastructures are necessary to support the genomics efforts, such as central databases and stock centres.
- Integrated biology research programmes should be established for all basic biological processes relevant to crop productivity and quality, from the molecular to the cellular scale using computational tools for modelling genetic networks that underlie these processes. This research should aid the development and exploitation of new crop properties not apparent from knowledge of the individual components.
- Continued investment to develop improved tools and processes to support basic research and industrial development. This research will be aimed at the development of new tools to support R&D and technologies aimed at the production of industrial prototypes, including the development of novel molecular tools for conventional breeding and innovative transgenic breeding methods. Examples of technologies include integrated genotyping and phenotyping, non-invasive and remote sensing of biological processes, simultaneous process analysis in space and time, high throughput gene transfer and expression testing, predictive screening and directed evolution of genes.
- Examples of what can be achieved include the understanding of the pathways plants use to make small molecules, to extend the repertoire of chemicals produced in crops, and the knowledge of fundamental processes underlying yield stability, flowering time and drought tolerance to enable rational breeding of crops adapted to broader geographical ranges and changing environments.

♦ Goal two: Human resources, infrastructure and networking

Rapidly evolving fields of science and technology are typically driven by young and talented scientists. The proper management of this talent – through training and mobility opportunities – is a critical success factor.

The implementation of the ambitious research programme requires further investment in specialised research infrastructures for high-throughput or large-scale biology research.

Coordination is crucial to the global competitiveness of the European research effort and to achieve the critical mass of resources needed for the realisation of the ambitious goals of the Technology Platform by overcoming the current fragmentation and duplication. This coordination is required at three different levels: between research institutions, between academia and industry and at the international level.

Deliverables and research activities include:

- Training platforms need to be established that are very flexible in subject, capacity and timing to respond efficiently to the needs of scientists and students.
- To attract talented young scientists and counteract the fragmentation of European science, a virtual training network should be created which would link all major research centres in plant biotechnology and genomics in Europe.
- Improving the mobility of scientists between Member States and between academia and industry through post-doc fellowship programmes. 'Landing grants' for scientists returning to their countries and exchange grants between academia and industry.
- Specialised centres for genome sequencing and functional genomics.
- Centres for the maintenance and distribution of the collections of genetic resources developed in the different genomics programmes.
- Centres for data storage and curation, outfitted with state-of-the-art databases that allow flexible queries (mining) of data across genomics platforms and plant species.
- The coordination of academic research at the European level could be enhanced by the creation of a virtual centre for plant science research bringing together the leading European groups in plant science within a single dynamic framework.
- Special grants or programmes can be set up to stimulate active interaction between research institutions performing basic research and private companies developing prototypes and commercialising innovations.
- The goals and deliverables set out in the present Strategic Research Agenda provide opportunities for broader international research cooperation and technology transfer with both developed and developing countries. International collaboration would be particularly suitable for high-cost genome-sequencing projects where the main deliverable is fundamental knowledge that is publicly held.

♦ Goal three: Public and consumer involvement

A large proportion of the Technology Platform's activities will be devoted to involvement with the public. We envisage that each technical programme will have a mechanism that not only provides information but, where possible, allows the public to engage with and influence the course of events.

The challenge is to regain the interest and trust of citizens in plant research and biotechnology. The approach is neither pro-GM nor anti-GM, but it will be decidedly pro-plant. There are, we believe, three key contributors that need to be put in place. They are increasing the knowledge of plants, improving the mutual trust between the public and the plant science community, and making plants fun.

Deliverables and research activities include:

- Knowledge of plants
  The key to increasing public knowledge of plants, we believe, is to increase interest in plants. The information strategy that needs to be developed should place plants in the context of everyday life. Plant science is largely paid for from the public purse, and plant scientists need to recognise the necessity of convincing the public that their work has value. We do not want to encourage plant scientists to see this as a professional obligation: we want them to have fun doing it so that the fun and interest inherent in being a plant scientist is also transmitted along with the information.
  The publics that we want to address include children, students, gardeners, cooks, herbalists, flower arrangers, golfers, hikers, environmentalists, and other people with a specific or indirect interest in plants. We aim to put in place clearing houses of potential speakers, graphics and presentational aids, a list of organisations which might be interested in talks on plants; and a contact system for bringing the elements together.

- Improve mutual trust between the public and the plant science community.
  The approach that we aim to adopt is to accept that all discussions start from a position of shared or mutual ignorance, or lack of knowledge. This is easy for researchers to acknowledge: the complete plant genome sequences tell us what we do not know in a precise way.
  The advantages of starting from a position of shared ignorance are that initial defensiveness is avoided, knowledge-based decisions are

implicitly welcomed but without the antagonism of presupposing whose knowledge that should be, new knowledge is welcomed. A primary thrust of the Technology Platform is the reestablishment of mutual trust between the plant science community, the general public, and the decision-makers who influence both. Rebuilding trust involves increased awareness of public 'holistic' thinking, bolstering the involvement of public stakeholders in setting the research agenda and policy directions, and what we have called "the re-humanisation of plant scientists". We propose that some decisions on spending on plant research could be taken with the direct involvement of the public at both the local and national levels. We want to give the public a stake in European plant science. We suggest that training programme should be developed to help researchers effectively engage with the public (engagement, not public relations).

- Plants are fun

  We want to make plant science itself more engaging and attractive. The political and economic importance of plants means that debates on the subject tend to take a solemn tone. But there is another, perhaps more inviting, side to plants: their fun side.

  Leisure and consumerism now occupy a great deal more people and a much greater proportion of most people's incomes than do basic food requirements. In Europe, 'nice-to-have' products outweigh the essentials. Addressing the fun aspects of plants brings European plant science much more in line with current cultural expectations and acceptance, especially among the younger generation.

♦ Goal four: Ethics, safety, legal and financial environment

A major challenge for the EU in the 21st century is to forge an ethical, legal, regulatory and financial framework that will enable scientific progress to improve our collective quality of life and our economic competitiveness, while allowing us to make the choices that most suit our ideals.

The Technology Platform proposes to improved dialogue and actions around ethics, considerations and actions leading to a legal and regulatory environment providing for safety, consumer choice, coexistence of different farming practices and intellectual property rights, and a financial environment encouraging entrepreneurs and industry to invest in plant science research and development.

Deliverables and research activities include:

- Dialogue around the ethics of the growing global 'need' for plant-based foods, feeds and other plant-based renewable materials and EU citizens´ desires for choice, aesthetics and naturalness.
- Support legislation that ensures chosen standards of human, animal and environmental safety are met before commercialising innovative plant products. This can be done by providing relevant biosafety research and through better communication with EU citizens.
- Support legislation that provides choice, both for consumers and farmers, through the appropriate provision of information to citizens and through the establishment of fair and practical rules for the coexistence of different products and farming practices.
- Research into competitive options for crop management could include refined farming practices and control measures to control pollen dispersal in space (isolation distance, border row management, control of volunteers and hybrids, modelling and monitoring) and seed and grain dispersal in time (cropping intervals, education and training).
- Improve existing and develop new technologies reducing gene flow, in particular for plants used in non-food applications, such as for producing pharmaceutical products. These include biological containment technologies, improved techniques to achieve male sterility of plants or new approaches, such as apoptosis, split gene technology, plastid transformation, apomixis, sexual dimorphism, and transgene mitigation. A non-genetic approach can be used by using chemical molecules, known as gametocides, which can block, at different stages, pollen development.
- Improve investment in plant research at all levels through better coordination at EU, national and regional level for improved public funding; seek create public/private partnerships to increase private funding and establish novel private investment vehicles aimed at enabling smaller companies to reap the benefits of their innovative enterprises.
- Include in school curriculae information showing the importance of plants to humankind, the history of plant development and the importance of continued plant science research and development to meet our present and future needs.

3. Towards Implementation of the challenges

The goals that were set out in the Plants for the Future vision document have in general received strong support from all stakeholders. Implementation of the Strategic Research Agenda (SRA) outlined below will need further commitment from public and private stakeholders and authorities at all levels: European, national and regional.

The current draft version of the SRA proposes, in part two, a comprehensive action plan for the next 20 years. Nevertheless, the level of detail varies somewhat depending on the depth of discussion that took place in the preparatory phases. While the research-related objectives in challenges one to three and some other issues, i.e. public/consumer involvement, have been spelt out in depth and detailed recommendations for actions and timelines are given, the level of detail in other sections needs to be fleshed out following a wider discussion with stakeholders.

The Technology Platform will hold, on the basis of this document, a wider consultation among stakeholders and concerned authorities. So-called national consultations are being organised by members of the Technology Platform's executive committee and SRA working groups, in co-operation with relevant national organisations, stakeholders and national authorities, in particular from national or regional research ministries and funding bodies. These consultations aim to allow a wider – and, in particular cases, more in-depth – discussion of the objectives set out in the SRA so as to take stock of current activities contributing to these objectives and to identify future national contributions and actions that could help realise the SRA. These contributions will likely depend on the specific nature of the major plant resources produced by a given country and the particular processing industries it hosts (such as forestry and woods in the Nordic countries).

These national actions will form the building blocks for the development of a detailed Draft Action Plan for the 2006 to 2010 period, together with European research activities as part of the EU's current Sixth and forthcoming Seventh Framework Programmes, coordinated activities of Member States stemming from ERA-Net projects, private research activities, as well as potential public-private partnerships and international projects.

Member State consultations will take part in the second half of 2005 and a detailed Action Plan is expected by mid-2006. The Technology Platform aims to set up a database and internet site by mid-2006 to gather data on all ongoing and planned research activities that contribute to achieving the SRA's objectives. The Platform will analyse regularly the SRA's implementation status. In 2010, it will conduct a detailed progress report for the 2006-2010 period with a view to hammering out the Action Plan for the 2011 to 2015 period.

4. Methodology

General background

The European Council asked in its conclusions following the Spring Council meeting in March 2003 to “create European technology platforms ... to strengthen the European Research and Innovation Area ... in areas, such as nanotechnology and plant genomics”.

Such platforms should bring together stakeholders – such as companies, research institutions, funding bodies and regulatory authorities – at the European level to define a common Research Agenda which should mobilise a critical mass of national and European, public and private resources.

The **Plants for the Future** Technology Platform aims to strengthen the European Plant Research and Innovation Area, mobilising support – both public and private – at the European, national and regional level. It was launched in June 2004 by then European Research Commissioner Philippe Busquin with a document entitled 2025 a European vision for plant genomics and biotechnology.

Since then, the Platform’s stakeholder forum was developed further to embrace a wide cross-section of companies, research institutions, farmers organisations, regulatory bodies, education and communication experts, as well as financial, consumer and environmental groups.

Using the vision paper as the starting point, the stakeholders have developed this Strategic Research Agenda 2025 to signpost the road to fulfilling this ambitious vision over the next two decades. The Agenda also includes a more detailed Draft Action Plan which will be discussed with EU Member States, the European Parliament and the European Commission during the second half of 2005. It will be amended to take into account their comments in 2006 and to develop a detailed action plan for the 2006-2010 period.

At the end of this process, the Platform will work to support the implementation of the recommendations in the Strategic Research Agenda and the 2006-2010 Action Plan at the European, national and regional levels.

This will not only have an impact on the plant sector in Europe by creating competitive leadership, it will benefit the environment and meet society’s needs.

Current activities the Plants for the Future platform

The Strategic Research Agenda (SRA) was compiled by four dedicated working groups. Four workshops attended by leading experts and stakeholders were held to help draft the document. These were on Sustainability (4-5 October 2004), Basic Research (6-7 October 2004), Horizontal Issues (19-20 October 04) and Products (2-3 November 2004).
The Agenda is divided into four challenges that reflect the areas identified in the vision paper. These are described in the vision paper as follows:

- **Healthy, safe and sufficient food and feed**

Improving living standards and a growing world population are rapidly boosting global demand for high quality and safe food. Food shortages and famines are currently localised phenomena and can be addressed by improving the distribution of the world’s food output. However, as the globe’s 6 billion inhabitants climb to more than 9 billion by 2050, not only will there be more mouths to feed but there will be less arable land with which to do it. This means that food distribution will have to become more equitable and farming will need to become both more productive and diversified. In

addition, to respond to consumer expectations, the quality of plants needs to be improved and their nutritional value boosted.

- **Sustainable agriculture and landscape**

Europe urgently needs to make today's intensive agriculture more sustainable while maintaining its productivity. In fact, we need to increase yields and simultaneously reduce or optimise the amount of fuel, fertilisers, pesticides, labour and water used in the process. The dual challenges of global climate changes and increased seasonal weather instabilities are placing additional strains on the world's agricultural capacity, particularly as more marginal land is farmed.

- **Green products**

Agricultural waste can be reduced to a minimum through the efficient use of bio-waste to produce biomaterials and bio-energy. As we run down our supplies of fossil fuels, we will need to substitute them with renewable and environmentally friendly fuel sources. We will also need to find substitutes for the raw materials that currently come from oil. The traditional uses of plant-based oils, fibres, resins, wood, and so forth will need to be extended in magnitude and scope to counteract the dwindling supply of oil.
In addition, efficient land management will become increasingly necessary to ensure diversity of agricultural production, protection of the environment and conservation of natural resources and biodiversity.

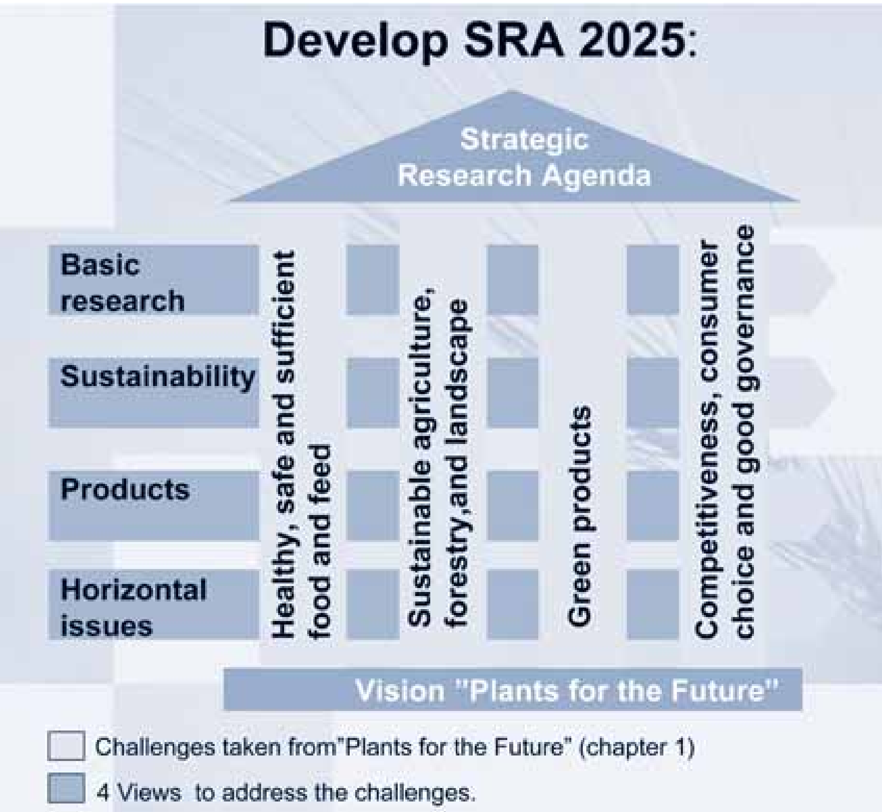


Fig. 2: Methodology used to develop the SRA

- **Competitiveness, consumer choice and governance**

A competitive global position for the EU in agriculture, biotechnology and food production will benefit employment and economic growth across the Union. Developing new technologies and agricultural products can help the environment and have a positive impact on rural development. In addition, it would ensure a strong domestic and sustainable European food supply offering consumers a wide choice of healthy and diverse food.

In the process of developing the Strategic Research Agenda, some of the topics were transferred from one challenge to another to obtain a clearer distinction between them. For example, land management and conservation of natural resources were moved from the 'Green products' to the 'Sustainable agriculture and forestry' challenge.

5. Selected glossary

Agri-food sector:	the sector of the economy that produces agricultural and food products
Agribusiness:	agriculture-related industries
Agro-food industry:	agriculture and food related industries
Bio-economy:	all industries and economic sectors that produce, manage and otherwise exploit biological resources (and related services, supply or consumer industries), such as agriculture, food, fisheries, forestry, etc.
Biofuels:	fuels derived from living organisms, as opposed to fossil fuels
Biomaterials:	materials derived from living organisms, as opposed to synthetic materials
Biotechnology:	technologies for cultivating, modifying or deriving products from living organisms
Co-existence:	the cultivating of conventional, organic and genetically modified crops in the same area without them affecting one another
Genetics:	science and technology of hereditary factors
Genetic modification:	scientific technique for altering the genetic make up of living organisms which results in genetically modified organisms (GMOs)
Forestry:	the cultivation of trees and the management of forests and woodland. Related sectors include paper and pulp industry.
Plant genomics:	the science and technology of the genetic make up of plants

6. Working Groups

The Working Groups, which were set up by the ETP Steering Council to draft this document, are made up of:

Simon Barber (EuropaBio)
Dianna Bowles (Univ of York, UK)
Michel Caboche (INRA, FR)
Marc Cornelissen (Bayer, BE)
Rudy Dekeyser (VIB, BE)
Cherryleen Garcia-Lindgren (M-Real, SE)
Kevan Gartland (Abertey Centre for the Environment, UK)
Yuri Gleba (Icon Genetics, DE)
Jean-Claude Guillon (COGECA, Limagrain, FR)
John Hodgson (Critical I, UK)
Hans Kast (BASF, EuropaBio, DE)
Chris Lamb (JIC, UK)
Andrzej Legocki (Polish Academy of Sciences, PL)
Julian Ma (St. George's Hospital Medical School, London, UK)
Karin Metzlaff (EPSO)
Francesco Salamini (Parco Tecnologico Padano, IT)
Joachim Schiemann (Federal Biological Research Center, DE)
Ralf-Michael Schmidt (BASF, DE)
Paul Schultze-Lefert (MPIZ, DE)
Lothar Willmitzer (MPIMP, Golm, DE)
Frank Wolter (ESA, GABI, DE)
Dick Toet (Unilever, NL)
Marc Zabeau (VIB, BE)

Contact

www.plantTP.com • PlantTP@psb.ugent.be

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Karel Spruyt / EPSO,
Alain Beguey / Inra, Andre Delplanque / Inra,
Christophe Maitre / Inra, Jean Weber / Inra.

Disclaimer :

This Strategic Research Agenda has been drawn up through a collaborative effort by a group of experts representing various stakeholders. It is neither exhaustive not comprehensive and covers only selected aspects of broader issues.

The Strategic Research Agenda, views and information expressed in this document are those of the group as a whole and do not necessarily reflect the opinions of any single member, their organisations, or of the European Commission.

Secretariat Technology Platform 'Plants for the Future'
Mailing address :
Manuela Deckers
c/o European Plant Science Organisation
Technologiepark 927
9052 Gent - Belgium
Tel +32 9 331 39 50
Fax +32 9 331 38 11
Email : PlantTP@psb.ugent.be
Website : www. PlantTP.com

Part two and part three of this Stakeholders Proposal for a Strategic Research Agenda can be downloaded from www.plantTP.com