ANNEXES TO THE RESEARCH ACTION PLAN

“Boosting Research for a Sustainable Bioeconomy

A Research Action Plan to 2020”

Details of specific proposed research solutions to the key actions are given in Annex I of the ETP Research Action Plan (p 1). Annex II provides the headings of the ‘Plants for the Future’ Strategic Research Agenda (p 30). Annex III provides the headings of the Horizon 2020 Specific Programme proposal by EC (p 31). Annex IV provides the Focus Areas of the Horizon 2020 Strategic Programme for the Work Programmes 2014 -2015 EC’s proposal (p 32).

Annex I – RESEARCH SOLUTIONS TO THE KEY ACTIONS

Actions for sustainable plant production and yield

Research solutions to action 1 - Improved resource use efficiency and resource stewardship

S1 - Improving resource use components for water and nutrient utilisation by breeding for root traits

Improved uptake for water and nutrients requires root systems that either have more adequate root geometry to tap into the soil-based resources or better (active) uptake mechanisms. Despite their importance in acquiring nutrients, root traits have rarely, if ever, been used by plant breeders due to the limited information on the suitability and relative effectiveness of different root traits and their heritability. The relationship between root traits and performance in the field strongly depends on the specific environmental conditions. For example, while a deep root system might be beneficial in seasonal rain-fed agriculture or where there is a low but fairly constant water table, a shallow root system is likely to perform better with all-year round rain or in irrigation-based agriculture.

Given the relative paucity of knowledge about root efficiencies and on the mechanisms that control root architecture, the increasing availability of platforms able to quantitatively characterize root geometry and function will provide important information for tailoring more resource-use efficient root systems in all major crops. Making use of symbioses with soil microorganisms may also dramatically improve plant root efficiency.

How far can we go? With the development of basic principles, transfer into practical plant breeding can be quick (3-5 years) for traits controlled by major loci (genes/QTLs). It may take up to 10 years for optimising traits for single resources but more complex optimisation for multiple efficiencies, such as improved phosphate and water use efficiency may require up to 20 years. Interactions among geneticists, breeders, physiologists, agronomists and modellers will be needed to achieve progress in this area, as will the development of improved technologies for root phenotyping and a better understanding of the mechanisms that control root architecture.

S2 - Improving resource use components for water and nutrient utilisation by breeding for improved utilization efficiencies

The second approach to optimise resource use efficiency is to improve the use of nutrients and water that have been taken up into the plant by root systems. This requires crop specific approaches. For instance in cereals increased partitioning to, or accumulation of nutrients in flag leaves that support grain filling might be an appropriate goal to be pursued.

The potential of such approaches will strongly depend on the importance of the limiting factor(s) for yield formation. It will be important to identify control mechanisms (including the corresponding genes) for partitioning of nutrients and to transfer that knowledge to breeding programs. Cloning of corresponding genes will also be important for a better understanding of the target traits and their manipulation to improve crop productivity and its sustainability. There is already significant knowledge about plant hormones as general control factors, and recently identified molecular signals provide a basis for their exploitation in practical terms.

How far can we go? Relying on this knowledge it may be possible to establish novel principles for improving resource use by improved partitioning and enhanced harvest index within the next 3-8 years.

S3 - Improving legumes for more sustainable and effective biological nitrogen input

Cultivation of legumes has steadily decreased in the last 40 years in Europe. Since legumes have a unique potential to improve nitrogen availability to plant production systems using biological N-fixation, this trend needs to be reversed. Moreover, legumes benefit not only soil fertility but also human health. This approach requires significant efforts towards identifying improved traits and implementing them into modern varieties of legume crops. These approaches require identification of mechanisms and genes as well as provision of suitable breeding methods in the diverse legume crops that can be relevant in the different agricultural systems across Europe. A close interaction of molecular sciences, plant physiologists, breeders and agronomists is needed.

How far can we go? This approach can lead to a significant reduction of use of synthetic N-fertilizers as well as to production of protein plants increasing their economic role in European agriculture within the next 5-10 years.

S4 - Improving resource use components for nutrient utilisation by better prediction of nutrient availability to crops in the dynamic environment

An efficient management of nutrient inputs to match outputs requires the ability to predict nutrient transformation and the availability of monitoring methods. Available computer models of nutrient cycle processes need to be improved. Monitoring of nutrients in the soil through sensors allows to measure nutrient status in the field in a wide range of situations at short scales; supply of nutrients through the plants can also be monitored using “smart plants” as potential sensitive indicators of nutrient deficiency. Based on nutrient budget approaches combined with models, methods can be made available to develop anticipatory and more flexible management strategies.

How far can we go? This approach can lead to an increase in crop nutrient use efficiencies with precision input delivery within the next 3-5 years. More complex optimisation for multiple efficiencies will require up to 20 years. Collaboration between physiologists, agronomists and modellers will be needed. Interaction of physiologists, agronomists, engineers and modellers will be needed to realize these benefits.

S5 - Improve resource use components for water and nutrient utilisation by optimising soil biological processes

Pivotal components for enhanced resource use efficiency in agricultural/forestry ecosystems are soil biological processes. Another approach to optimise resource use efficiency is to assess the below-ground ecological processes. A “trait-based assessment” of the diversity of soil microorganisms in term of functional traits of the different groups of microorganism might improve the root / rhizosphere efficiency and lead to high resource use efficiency. New methodologies that can be applied include molecular methods (functionality in term of activated genes, metabolite signalling, etc.). This approach will lead to improved management of soil biological processes.

How far can we go? It may take up to 10 years to optimise traits for different groups of organisms. Interaction of environmental microbiologists, microbial ecologists, geneticists, physiologists, and agronomists will be needed to achieve quick progress.

S6 - Sustainable yield and yield stability with limited resources and on marginal lands

The approaches to achieve higher yielding plants on marginal sites will technically align with those mentioned above for improved resource use efficiency (root structure and function, plant-internal optimisation). However, special characteristics will emerge from the fact that there will be very little to no external inputs. Thus, more extreme root or partitioning traits will have to be selected and bred into the crops and aspects like biological support from the beneficial soil microbiome (microorganisms and fungi) will be of significance. This may include improved mycorrhizal colonization for enhancing the mining of essential soil resources, including water, as well as the possibility of accessing organic sources of N; crop plants in general show poor infection with mycorrhizal fungi, so there is considerable scope for improvement. More novel approaches, such as the use of beneficial rhizosphere microorganisms and fungal endophytes may also prove advantageous. There is also recognition that the production of new associative N_2-fixing partnerships with prokaryotes may be a feasible option.

Mixtures of crops may also become an interesting production option for mainly non-food (incl. feed) production systems. Here the synergy between crops and the effective footprint need to be developed, as well as a better quantification of the mechanisms associated with any nutrient benefits. Legumes will play an increasing role (again) in mixed cropping systems, crop rotations and as target crops for new food and non-food uses. These may also generate opportunities in urban agriculture systems.

Requirements for cooperation are essentially the same as above, but transfer into practical approaches is unlikely to come from industrial organisations and private breeding companies as this work is not of immediate or near-commercial interest. Thus innovation in this sector will require public commitment.

How far can we go? At short-term, crop management techniques for improved performance at marginal resources can be developed. In parallel traits making plants more efficient at marginal soils (esp root traits) as well as adequate phenotyping methods need to be identified in order to use them for breeding programmes. This will lead (mid-term) to integrated approaches of breeding and plant management to provide varies adapted to marginal lands and the respective plant management as an integrated solution.

S7 - Closing nutrient loops and improving soils

The application of fertilizers compensates for the losses of nutrients from the production system as well as those lost in harvestable products that are removed from the site. Closing nutrient loops may be achieved by maximising the retention of material that is of no direct use as harvestable product as well as by the use of waste and residues from the various by-products, part of other novel utilization pathways: e.g. the use of waste material from biogas facilities as organic fertilizer for crops. These are also promising means of improving carbon sequestration in agricultural soils by improved organic inputs on arable lands. The emphasis is here on fully integrated measures using highly-organic wastes from non-food pathways and the development of low-water use crops could be beneficial. Close interactions between plant physiologists, agronomists and soil scientists will be necessary to increase the availability of nutrients for the plants on the one hand, whilst at the same time reducing losses to the atmosphere and soil/ water environment on the other hand.

How far can we go? Improvements here will be fast and available within the next 3-5 years with significant dependency on the intensity of the development of alternative use of plant biomass for non-food use and the options to recycle nutrients from these processes. Integration of chemical engineering for formulation and composition of such fertilizers or even co-optimizing the conversion processes, which generates the “waste material”, with great value-added uses may have considerable potential.

S8 - Soil, water and nutrients in resilient plant production systems

Soil, water and nutrients are fundamental factors in agricultural production. These important resources are exposed to overexploitation. Their availability may be decreasing, partly as a consequence of increasing encroachment by an urban population and by increasing effects of climate change.

Soil performs many functions and services, but is also the primary substrate for growing crops. Soil biodiversity in particular is essential to support plant growth and health. Research aimed at preserving and/or improving soil fertility and functions is important, addressing issues such as on-farm recycling of nutrients and organic wastes, site-specific soil management practices to optimise soil biological, chemical and physical properties and processes, as well as effects of different cropping systems on soil biology and soil fertility. In the past years, the function of soils in global carbon storage has received increased attention, and research is urgently required to test whether increased soil carbon storage is a soil function that is in contrast or in accordance with soils as the base for production of healthy food.

Agriculture is currently the main water-consuming sector. Further research is needed to reduce overall water consumption in agriculture and increase the efficiency of water use, though, for instance, more efficient on-farm water management and improved irrigation methods.

Protected horticultural systems require increased attention in research and innovation efforts. The resource efficiency in such systems must be better understood, to evaluate their potential for future food supply under changing and unpredictable environmental conditions.

Next steps: a) Knowledge on carbon stocks in European agricultural soils must be collected and evaluated, and the effect of farming practices and of dynamic environments on soil carbon stocks must be better described than presently possible. This requires a concerted European effort, and should also involve forestry and environmental expertise. The projects may be "cascading" over time including farmers and academia, so that both basic understanding of soil carbon processes and local experience with different farming systems are included in the knowledge base. First results can be achieved within three years, but to include all European regions the investigations will have to continue for up to a decade. b) Control of environmental factors (irrigation, protected culture systems) is common practice in European agriculture and in particular in horticulture, but resource use efficiency in these systems is not well understood. Such systems may produce highly valuable crops, and may be labour intensive, creating and maintaining a large number of jobs. The efficiency of protected production systems should be the subject of a number of smaller projects with geographical spread across Europe. c) The replacement of synthetic fertilisers by application of organic nutrient sources, such as composts or manure, must be supported by appropriate research. Technology for composting must be developed, and quality control for organic fertilisers must be rapidly improved. The traditional knowledge on manure and compost use in many European regions must be prominently included in this innovation process. The role of microorganisms in compost production and in the use of organic nutrient sources deserves specific attention. d) Breeding programmes for high-value crops in protected plant production systems and for crops with specific properties in resource use should be supported by European research.

How far can we go? Management systems for sustainable resource use are in place in many European farms by 2020 that are accepted by the public because they contribute to a healthy and diverse environment. Farms contribute to production chains that are trusted because they deliver safe and healthy food to the consumer.

S9 - Integrated strategies for optimized fertilizer supply and uptake

Rapid uptake of fertilizers by plants through improved root systems that are matched to the fertilizer application could significantly support GHG reduction. This will also depend on existing, as well as any newly created interaction between the root and the soil microbial science community that will need to take into account to optimise plant availability of nutrients.

In order to transfer solutions for enhancing resource use efficiency in the field, integrated solutions including novel ideas need to be incorporated into more holistic approaches. Modern research on resource use efficient crop systems aim for the best performing plant genotype co-optimized with plant management. Contributions from all levels of organization of plants and crop management are needed to achieve this significant goal, including adapted genotypes.

How far can we go? at short-term idiotypes of root systems and whole plant performance have to be identified, which will lead (mid-term) to the selection of more suitable root systems optimized for less leaching-prone soil management schemes; or crops that use less water and nutrients at the same or even improved yield through optimized stand performance that are tailored to the diversity of agronomic challenges in European crop growing regions.

S10 - Developing perennial and novel crops

Perennial crops have significant advantages with respect to efficiency of nutrient use. This also facilitates early season growth, with a longer period over which resources can be utilized. Due to their durable root system, perennial crops can contribute significantly to reducing soil erosion and to soil health and productivity by higher and more persistent carbon sequestration.

There are a number of basic characteristics to be analysed in order to develop perennial crops from annual crops. These approaches open totally new routes for sustainable production, but need to be integrated with different farming systems.

How far can we go? As an initial step, winter annual forms of typically spring-sown crops, such as e. g sugar beet, should be developed and mechanisms of perenialism need to be identified. At long-term, in parallel to improving perennial plant development they need to be implemented into adequate cropping systems.

Examples: Developing Perennial Rice, Wheat and/or Maize (Global Plant Council)

S11 - Utilising the potential of plant genetic resources

Rapid advances in plant sciences will not only impinge on research into and use of major crop species but will also rapidly expand state-of-the-art genome knowledge in minor and neglected crop species as well as in crop wild relatives (CWR).

Integrated approaches of molecular, breeding and physiological technologies do allow for a systematic analysis of plant genetic resources (i) to identify bottlenecks generated during domestication, adaptation and plant improvement (ii) to identify more rapidly important agronomically important traits by forward genetics approaches (map-based cloning) and (iii) to screen by targeted re-sequencing for novel alleles of a given gene (phenotyping and allele mining). The corresponding findings will radiate to all major levels of plant improvement ranging from the development of knowledge-based approaches for parent selection via the targeted introgression of novel genetic diversity up to the transfer of genes/alleles by transgenic approaches.

There is considerable untapped potential in crop wild relatives for improving major crops such as cereals, oilseeds, protein crops, Solanaceae and many others. The application of modern plant sciences, technology and research can open up pathways that could provide novel genotypes, like perennial crops based on today´s major cereals. In addition, many underutilised and local crops, fruits and vegetables offer significant options for improvement of food security and sustainability in developing countries, but have received little attention from agronomists or plant breeders.

How far can we go? at short-term (3-5 years) technology adaptation to wider crop genetic resources, feasibility studies and development of standards will deliver a unified concept to analyse CWR. First, selected genotype panels from seed banks will be analysed. The long- term goal is to systematically screen seed bank accessions and provide insights into the available genotypic and phenotypic diversity to make these resources available for crop improvement. –

<u>Examples</u>: Underutilised fruits and vegetables and of major crops

S12 - Above and belowground omics of mycorrhizal partners for the sustainability of agro-forest ecosystems

Soil biota comprises an enormous diversity of organisms, including microorganisms (i.e., bacteria, fungi), which interact with each other, with plant roots and with the environment. This flagship idea is focused on important components of the root microbiome, the symbiotic mycorrhizal fungi. Among the several plant-soil fungi interactions, arbuscular mycorrhizae (AM) and ectomycorrhizae (ECM) are those with a greater impact in agriculture and in forest environments. Shifting the focus from "plants" to "the agro-forest ecosystem made up of plants and their interacting (micro) organisms" holds the promise to design innovative strategies for the selection and propagation of strains and plant genotypes useful for the management of these ecosystems under the changing climate scenario. The main goals will be (1) to investigate the use of mycorrhizal fungi to stimulate biomass production from non-food plants that grow on marginal lands and in drought conditions. The selection of efficient fungal strains (also using -omics technologies) represents a preliminary important step; and (2) to address the impact of climate change on Mediterranean forest ecosystems by studying local adaptation. The goal is to unveil the plant genetic traits underpinning adaptive responses and characterize, select and propagate mycorrhizal strains adapted to challenging environmental conditions that might help their host plants to cope with climate changes.

How far can we go? At short-term (3-5 years), results will concern the selection of the most effective arbuscolar symbiotic fungi of non- food plants for biomass production, together with the assessment of forest plant genetic diversity and the characterization, isolation and cultivation of ectomycorrhizal fungal strains in forest ecosystems. The long term goal would be the use at large-scale and industrial level of AM fungi to increase biomass production of non-food plants and the selection and inoculation of forest plants with selected ectomycorrhizal strains to increase the resource use efficiency of forest ecosystems.

S13 - Maximizing the efficiency of fertilizer and water recycling in closed-cycle cropping systems

Greenhouse production is a significant production sector, in which sustainable production needs to be boosted significantly. The objective of the specific solution is to extend the salinity range of irrigation water that is compatible with complete recycling of fertilizers and water in closed-cycle cultivations of tomato and other fruit vegetables in greenhouse from currently 2 to about 4 mM NaCl. This might be attained by grafting elite hybrids onto salt-tolerant rootstocks with an extensive root system characterized by a high efficiency to deposit sodium, thereby restricting the rate of sodium accumulation in the root zone.

As a result, the need to discharge fertigation effluents will be minimized or even eliminated and thus nutrient and water use efficiency will increase and groundwater pollution will be decreased. To obtain such rootstocks, gene expression profiling using cDNA microarray analysis will be applied aiming at establishing biomarkers for selection and breeding rootstocks with the envisaged characteristics.

How far can we go? The short-term perspective (establishment of biomarkers and selection or already existing rootstock genotypes with the desired characteristics) might be completed within 4-5 years from the beginning of the project for one high-value crop spaces (e.g. tomato). The long- term perspective (breeding of new rootstocks with the target characteristics using biomarkers) could be attained within a time-frame of 6-8 years. This flagship idea might be incorporated into a large project on “improving resource use efficiency and reducing the carbon footprint in greenhouse crops”.

S14 - Plants for constructing urban resilience in Europe

Vegetation can improve urban environment in different aspects: by mitigating pollutants, abating noise, sequestering carbon, regulating some aspects of microclimate, and stimulating biodiversity. To provide ecosystem services in the view of a sustainable plant-based bioeconomy, a strategic and coordinated research on urban greening infrastructures (UGI) is necessary. Moreover, European cities are already investing money for maintaining urban green, and novel approaches for designing and planning these investments are urgently needed.

The flagship idea proposes to harmonize and innovate methodologies of planning, designing and managing the next generation of UGI on a functional basis. A holistic and systematic approach to plan and govern UGI in different urban sites should consider some major aspects: the adoption of large scale studies that take into account different urban settings across Europe; the integration with innovative technologies and new approaches for the assessment of the impact on biodiversity, pollutant mitigation and resilience to climate change. A cross-disciplinary approach with the contribution of different disciplines (scientific, technical, socio-economical, planning, and modelling and governance) is fundamental. Interactions with local authorities, as wells as with SME end-user and economic entrepreneurs will be required to achieve quick progress.

How far can we go? Short term results: it may take 3-5 years to analyze and harmonize methodologies, technologies and innovative solutions that can contribute to improve and sustain the development of next generation UGI and to identify best practices for the assessment of the benefits from the environmental, social, and economic point of view. On a longer term (up to 10-15 years): i) the establishment of new and innovative policies for the development of urban environments will stimulate local regulation and legislation regarding UGI, and the provision of ecosystem services; ii) positive impacts on general well-being and health, that in turn will also benefit the economy; iii) the implementation of a new framework for UGI will contribute to job creation in the sector of the green economy, (green maintenance and planning, landscape architecture, agriculture). iv) green spaces and UGI will contribute to increased socialization, will drive citizens participation to the public life with an impact on the management of public goods.

S15 – Selection and characterization of plant genotypes/landraces with high agro-ecological potentials

Aridity affects about 41% of the planet's land surface. Climate change is expected to increase the threat of water shortage, further worsening the water-crisis, threatening livelihoods particularly in rainfed areas. Drought can speed up land degradation. Desertification is already a common threat to the Mediterranean basin. In addition, soil degradation is increasing throughout Europe. The key issue in combating land degradation is the development of an accelerated route for selecting new germplasm and genotypes with enhanced drought tolerance whilst maintaining biomass productivity and quality in water scarce environments and in marginal dry environments. The activity aims to identify the molecular basis of adaptation to drought (through a combination of high-throughput phenotyping and high-throughput genotyping, using new generation genomic approaches) to select “climate proof” plants with high agro-ecological potentials that can be integrated in either farming systems or ecosystem (i.e., forest and the organisms they sustain) rehabilitation strategies in the face of impeding climate change. The main goals will be to valorise superior germplasm/ landraces grown in areas where they have advantages of adaptation to harsh conditions and, consequently, are able to withstand heat, salt, and drought stresses, and then identify the interconnections among dryland functioning, resilience and ecosystem services (water, carbon and food) and their teleconnections with the climate systems.

How far can we go? Short term results will be the identification of functional genetic markers associated with ecophysiological traits involved in plant stress tolerance and water use efficiency in genotypes/ecotypes growing along aridity gradients, linking high-throughput phenotyping and 'omics' technologies, such as genomics, proteomics, metabolomics, and microtechnologies, integrated within systems biology approaches for identifying drought resilient genotypes. At the long-term, the control on water optimisation and carbon sequestration in agricultural and forestry ecosystems and feedbacks on the ecosystem services and interconnection will benefit climate and soil fertility. Development of adaptive interconnected social-ecological measures (prevention and reversal strategies and best practices) for risks mitigation and for increasing agriculture and forestry ecosystem resilience and long-term food security.

Research solutions to action 2 – Enhance yield and yield stability for increased resilience in dynamic environments

S1 - The use of crop germplasm and soil biological resources to increase resilience in plant production

Across whole ecosystems and production areas, increased resilience and competitiveness in dynamically changing environments should be achieved by European agriculture and forestry. Environmental impacts must be decreased and climate change effects taken into account in agriculture, horticulture and forestry, by the development of novel and genetically improved plants and production systems, by crop management through selected plant breeding, by improved plant nutrition, management of soil microorganisms and optimised production systems and by a better understanding of the interaction between different systems (horticulture, agriculture and forestry; fisheries and aquaculture).

For crops, special emphasis has to be placed on low input (e.g. pesticides and fertilisers) and regionally adapted production systems, improved management of resources, integrated management of biotic stressors, and novel plants (crops and trees) with respect to their composition, resistance to stress and dynamic environments, ecological effects, nutrient and water use efficiency, and architecture. The energy harvesting efficiency of crop plants must be improved to enable the adaptation of crops for higher resilience and efficiency, and the genetics, bio-physics, organization and regulation of photosynthesis in plants that can use high-light efficiently should be better understood in order to use this knowledge to improve the efficiency of other less capable plants. This will either result in plants with a higher production (more biomass per ha, higher water use efficiency), or plants that produce high biomass under lower light and/or low temperature conditions. Higher biomass will inevitably create economic opportunities, may ease the discussion on food or fuel, and will have a major impact addressing the challenge to feed a growing world population. Improved methods are required for monitoring, preservation and enhancement of soil biological functions and soil fertility.

Multifunctional agricultural systems, producing food, other goods and services, are important elements for rural development. Environmental integration and sustainable development should be prominently considered in rural and urban development policies. Small and medium-sized enterprises may drive this development, and labour intensive, multifunctional and regionally adapted farming systems may be developed.

Next steps: a) Knowledge on the climate adaptability of existing cultivars and germplasm must be collected and evaluated. This requires a large European effort, involving farmers, extension specialists, agronomists and bioinformatic scientists. Specific care must be taken that all European regions are represented in this effort. Regional experience should be included, using participatory approaches. This requires a large project, but at least for a few crops results can be achieved within three years. b) Biological soil functions have been studied previously, but should now be evaluated for adaptation to dynamic environmental situations. This is best achieved in a number of smaller projects, linked, for example, by a joint Advisory Board of farmers, industry and scientist. c) Inclusion of this knowledge in breeding programmes is a continuing process that may be started immediately but has to continue for a period of up to ten years. A particular focus could be the breeding for purposes of organic agriculture or problematic environments. The best instrument may be a "cycling" project where the participating groups start with a three-year action, and are then asked to suggest modifications for a possible continuation of the project.

How far can we go? A better understanding of the need to adapt plant production systems to dynamic environments will be achieved until 2020, and the appropriate technology will be available. Regional characteristics will be maintained, and regional production systems will be of high quality standard and integrated into world markets. European plant production systems will be less harmful to the environment by 2020 compared to the current situation.

Examples*:*

- The Digital Seed Bank
- The International Wheat Yield Partnership (IWYP)
- The G20 Wheat Initiative
- The plant metagenome

S2 - The use of biodiversity and predictive approaches to increase resilience in plant production

Traditional and "neglected" species, cultivars, local genotypes and the wild relatives of cultivated plants have a large potential to improve crop production in dynamic environments. They can also provide target genes for genetic improvement programmes (see also the topic "1-Resource use efficiency and resource stewardship" in this document). These genetic resources can be used best through the application of predictive approaches (ex ante) and adequate phenotyping (ex post) that allow a directed analysis and exploitation of biodiversity. The continued use of 'omics' technologies, but also the use of biological models, of farmer´s empirical experience and regional knowledge will allow the improved use of diversity for agricultural purposes (for example, the improvement of specific traits for production of plants under changing environmental and soil conditions). In particular, plant breeding tools need to be improved to allow the efficient fixation of many genes and their interactions over generations. As an example, hybrid wheat has shown a much better ability to maintain higher yield than related inbred lines when facing adverse climatic conditions. This may lead to innovation in cultivars and products, including improved management of systems to increase the resilience of plant production systems to abiotic and biotic constraints. It is clear that the microbiological dimension of biodiversity and its impact on crop production still requires special attention (see above). There is also still a particular need to promote under-utilised plant genetic resources (including forest tree species).

Diversification in EU agriculture and forestry must be developed at a faster rate than previously, to give farmers and forester managers alternatives to current management practices where these may be unsustainable or inappropriate. Biodiversity should also be used to address specific regional requirements in crop production across Europe. Research in this context includes how to grow, manage and produce traditional or novel crops in a safe, socially acceptable and cost-effective manner.

Next steps: (a) Based on a wide range of molecular, genetic and advanced phenotyping technologies, databases, gene and seed banks now provide much information and material that can be utilised in concentrated and interdisciplinary efforts. In particular, the recently increasing availability of large genomic resources, multi-site common gardens, and phenotyping infrastructures provide depth and breadth to address the research questions aiming at understanding the molecular basis of genetic adaptation to climate changes in crops and in long-lived species, whose offspring are more likely to be subjected to environmental changes. This may result in stronger selection coefficients per generation than in annual plants. This can be achieved, at least for some species, within the next five years; (b) Activities such as the Digital Seed Bank (Global Plant Council) should also be supported. The highly heterogeneous seed banks across the EU should be linked with the sharing of information and genetic material and further develop, implement and use novel approaches for efficient exploitation of germplasm (efficient identification of "hidden" beneficial genes/alleles and their transfer into elite germplasm). The EU seed banks should address redundancy vs. specialization and the distribution of tasks. Long term high quality conservation must be realized, and common standards for databases must be set. Novel solutions of rapid screening for beneficial variation must be developed and sequence-based prediction of functional variation should be enabled.

A major role for Europe in collecting, describing and using plant genetic resources in breeding programs can be realized within five to ten years. This will also facilitate the use of these resources in European countries with less well developed scientific infrastructure. The use of more diverse agricultural systems could start immediately, but the full development may be a continuing process. (c) Realizing the use of regional diversity requires several research projects across Europe, linked by a common Advisory Board. Regional agricultural research and dissemination institutions must strongly participate in these projects. Increased resilience of regional agricultural and horticultural production can then be achieved within five years. (d) The increasing discussion about the value of urban green, and the increasing interest of urban populations for contact with plant-based biodiversity and even with urban food production, are new social trends. Solutions must be generated to support processes such as urban greening or urban food production in the next years.

How far can we go? Diversification of European plant production systems will increase until 2020, and farmers will have adopted strategies by 2020 to manage biodiversity for high income and high resilience. Seedbanks are widely used in breeding programmes by 2020. Foresight processes help farmers to maintain a stable income over years in spite of decreasing subsidies.

<u>Examples</u>:

- Legume rotations and intercropping - mixed cultivation systems
- Underutilise and local fruits and vegetables
- Increasing / enriching agricultural diversity
- Local level Diversity and Yield stability
- Species information for sustainable adaptation capability to climate change

S3 - Management options to increase resilience in the production of high quality plants

A variable and dynamic environment requires plants that are genetically adapted to cope with a range of environmental situations. However, it also requires the input from farmers and forest managers who can take well-informed decisions on short notice. New and advanced technologies in agriculture are needed to support this development. The focus may be on the development of user-friendly high-performance tools and automated systems that optimise the management and use of inputs. Real-time monitoring of agronomic resources and the use of novel information and communication technologies including remote sensing devices may support this trend, with the help of, equipment integrating responses from the leaf to whole canopy and ecosystem level (e.g. in carbon and nitrogen fluxes). Global Positioning Systems (GPS) and Geographical Information Systems (GIS), sensors, data recording and processing units at the farm level may all help in this process. Application of high-performance technologies should be directed to monitor, understand and predict environmental conditions for crop growth, and thus enhance the resilience of European agriculture. It is most important that such technology can also be used in areas with sub-optimal ecological or economic conditions. It is also important that traditional approaches and local knowledge are recorded and considered, and that all suggested system approaches are acceptable to the respective stakeholders, producers and consumers.

Research should also help to assess the medium and long-term impact of climate variability and climate change on agricultural and horticultural crops. This research should be directed at an understanding of the effects of global change and regional trends on agricultural production, crop and forest growth, soil functions and the water cycle. A projection of experimental data to regional or global levels should always be facilitated. It is even more important than previously for farmers to produce superior quality in terms food safety, but also in terms of inner quality (health-related compounds) and avoidance of toxic substances. The effect of dynamic environmental conditions on plant quality aspects are largely unexplored and deserve further attention in the near future.

Research dealing with adaptation strategies in agriculture requires a broad and interdisciplinary approach. A specific focus should be on the management and recycling of agricultural/organic waste and of corresponding by-products. Carbon sequestration in agricultural soils through land-use measures has become a focus of public attention. Tillage and fertilization approaches and techniques must be adapted to the more dynamic future environments. Technical and policy aspects of biomass production have to be considered in their consequences for agricultural nutrient cycles.

While European agriculture has to adapt to changing climates, it is also important to further reduce the negative impact of agricultural activities on climate change and the pressure on natural resources. Research should contribute to better control of land degradation. European commitments, such as the United Nations Framework Convention on Climate Change, the Kyoto Protocol, the European Climate Change Programme and the EU climate and energy package must be considered and translated into appropriate agricultural technologies.

Next steps: a) A European "Network of Knowledge" on "Agricultural and horticultural management in a dynamic environment" may be created to allow better cooperation between farmers, advisory systems and scientists in information generation and exchange. This "Network of Knowledge" will create European additional benefit because it will help national stakeholders to learn from experience in other European regions. This "Network of Knowledge" may be essential for fast innovation in agricultural and horticultural management, and must combine tacit, practical and scientific knowledge with equal emphasis. b) Technology to help farmers and forest managers in informed management decisions can be developed and applied within a few years. Such projects must have a strong dissemination and education focus, and must build on cooperation with stakeholders. C) Long-term farming decisions (such as the transformation of pasture to crop land or *vice versa*) must also be based on forecasts of the political and economic environment, so that socio-economic developments can be taken into account to achieve long-term resilience of European agriculture. Better alignment of European rural development policies with ecological needs and profitable farming can be achieved within the next decade, under the provision that there are matching activities in European policy and research. d) Effects of dynamic environmental conditions on plant quality have to be studied in several projects where plant physiologists, agronomist and farmers together with breeders explore and test the potential of production systems aimed at superior food quality. At least in some crops and some regions, such systems can be realised within a few years. Covering more crops and all European regions will take more than a decade.

How far can we go? Management systems are in place on many European farms by 2020 that ensure flexibility of management decisions. Labour-intensive production systems are an increasingly valid management option, because high quality produce can achieve reasonable market prices.

S4 - Development of stress cross-tolerance in crop plants

Crops live in a dynamic environment and are continuously challenged by a range of abiotic/biotic factors acting alone or in combination that compromise any potential yield gains that might be exploited for enhancing productivity (yield gaps). Modern agriculture may have compounded the inability of crops to deal with dynamic situations through a range of management interventions and because breeding programmes do not specifically address selections for stress cross tolerance. Cross-tolerance to environmental stresses is a common phenomenon in plants, whereby exposure to one type of stress confers a general increase in resistance to a range of different stresses through synergistic co-activation of non-specific stress-responsive pathways that cross biotic–abiotic stress boundaries. In the future weather volatility and the prediction of more extreme environmental conditions argue for the selection of crops with multiple stress resistance. Also, given the difficulty associated with accurately predicting future conditions enhancing stress cross tolerance would also act as a fail-safe approach to uncertainties surrounding future climate projections. Only by enhancing stress cross tolerance will we be able to develop true all round resilience in crops. Importantly the evidence indicates that stress cross tolerance can be developed without any yield penalty

How far can we go? Short term ~5 years: There is a vast range of genetic material available for examining stress cross tolerance, including existing cultivars, land races and ancestral varieties. The identification of stress-cross tolerance in one wheat variety and Arabidopsis will be important 'tools' for examining the traits required for enhancing stress cross tolerance. This will be aided by new phenotyping platforms that have the capacity to screen large amounts of genetic material. The goal would be to identify breeding lines/traits that could be used in cultivar development. Long term ~10-years: development of flexible crop genotypes for a wider range of abiotic/biotic conditions. Development of specific cultivars suited for particular or problematic edaphic or environmental conditions.

S5 - Enhancing resilience of European forests to climate change by genetic adaptation and assisted migration

Climate change increasingly results in a discrepancy between the current distributions and those areas where tree species and provenances grow best. Moreover, the general effect of climate change on European forests is a decline in productivity and an increase in mortality. Both the mismatch in occurrence and the climate-induced decline of forests jeopardise the contribution of forests to rural economies. Research is required to enhance the resilience of forests to climate change by investigating to what extend forests can evolve locally to adapt to changing environmental conditions, and to what extent modern tree-breeding technology can contribute to counteract climate-induced decline or even improve productivity and thus to inform forest managers which species and provenances best to use.

The overall objective is to assess the possibilities to enhance resilience of European forest to climate change by local evolution and by tree breeding. This in particular in areas most vulnerable to climate change and in areas where the expansion to better suitable areas is restricted by current land use, but also within species areas. The usage of exotic species, transfer of provenances and the assisted migration of species outside the current distribution are explicitly taken into account in the analysis. Genomic analysis on wood-anatomical and -chemical traits, will allow using long-term dendrochronological time series to compare the results on local adaptation, and to reduce uncertainty in model projections on growth and adaptation of European tree species to climate change.

How far can we go? Short term results will be key functional traits related to tree survival and functioning to climate change as well as the genetic background of these traits. Similarly, the genetic background of traits related to wood quality and resistance to stress events will be determined. Resilience of forest to climate change, in terms of genetic diversity and thereby adaptive potential with respect to these traits, will be determined for a wide range of endemic and exotic species both at limits of species distributions and within these tree species areas. As a long term impact, this information will support forest managers in their decision making on the choice of tree species and provenances and on required silvicultural measures to meet their targets considering the management of forest resources, production of high-quality timber and provisioning of other ecosystem services, as well as of the resilience of their forests to climate change. Moreover it will allow to identify the management actions available for preserving genetic diversity and evolutionary processes in forest tree populations (use of natural regeneration, minimum effective population sizes, population connectivity), incorporating the role of gene flow and migration to current static views (use of assisted migration, optimal levels of incoming gene flow).

S6 - Root system optimisation for stress tolerant rootstocks for grafting fruit and vegetable crops

The objective of the flagship idea is the application of root engineering approaches using grafting as a means to maintain sustainable crop production under changing environmental conditions while minimizing the demand for new resources in vegetable and fruit crops. One example is to increase the tolerance of tomato to sub-optimal temperature (T) in heated greenhouses by grafting elite hybrids onto cold-tolerant rootstocks, thereby reducing energy consumption and CO_2 emissions.

Stress-tolerant rootstocks might be obtained by developing biomarkers for rapid selection and breeding based on gene expression profiling using cDNA microarrays. Microarray analysis will enable identification and evaluation of genes controlling biochemical reaction chains and physiological procedures that are associated with tolerance mechanisms to sub-optimal root T and other abiotic and biotic stress conditions.

How far can we go? The development of biomarkers aimed at screening not only rootstocks but also rootstock/scion combinations for their tolerance to abiotic and biotic stress conditions could be achieved within a time frame of 3-4 years. The breeding of new rootstocks characterized by high tolerance to specific abiotic and biotic stress conditions by using the developed biomarkers is expected to take 7-10 years.

S7 - Improved stress tolerance by targeted modulation of phytohormone levels and signal transduction

The objective of this solution is modulation of plant hormone levels or signal transduction in order to increase tolerance of selected crop species to different abiotic stresses, frequency of which is predicted to increase due to climate change. Regulation of hormone homeostasis may be achieved by exogenous application of the specific inhibitor of hormone deactivation or by over-expression of biosynthetic gene under suitable promoter. As the common feature of the responses to different stresses is down-regulation of photosynthesis, the main source of energy for plants, stabilization of photosynthetic machinery under stress conditions might provide sufficient energy for stimulation of the effective defence without severe penalty on growth rate and thus biomass formation. One example is up-regulation of cytokinins, hormones which positively affect photosynthesis, delay senescence and promote attraction of nutrients. Mass spectrometry determination of cytokinin metabolites will enable to evaluate in detail the effect of individual treatments in the different plant tissues. Determination of chlorophyll fluorescence will be used to characterize precisely the final effects of targeted hormone manipulation on photosynthetic performance under stress conditions. Transcriptome analysis will allow follow the achieved physiological impact on stress tolerance as well as cross-talk with other hormones.

How far can we go? Increase of crop stress tolerance by modulation of cytokinine metabolism under different abiotic stress conditions could be achieved in the short-term perspective of 3 – 4 years. Elevation of stress tolerance and simultaneous targeted manipulation of specific developmental processes (e.g. grain filling), which require selection of suitable promoters, can be expected in 7 - 9 years.

<u>Research solutions to action 3 -</u> <u>Improved plant health for resilient production</u>

S1 - Exploring plant genomics to enhance genetic tolerance and resistance to various biotic and/or abiotic stresses

Genome mining: The identification and analysis of genes contributing to pathogen and pest resistances will enhance understanding of potential resistance mechanisms, the underlying cellular and metabolic processes and the genes that confer resistance. The utilization of productive and resistant varieties will prevent the production of toxins, especially from cereal fungi, and will have an indirect impact on environment by reducing the need of chemical crop protection. Crops and trees are also naturally resistant to a number of pathogens and pests, and knowing how this immunity occurs would pave the way to designing strategies for genetic resistance to other diseases. Improving the resistance of crop plants may also require the identification of genetic resources in wild relatives, or even in distantly related species, if the biodiversity of the crop itself is not exploitable for this purpose. If resistance genes from distant relatives are to be used in cultivated crops, strategies to overcome “linkage drag” need to be devised. Technically GM approaches would be most efficient, but if marker assisted selection (MAS) is used, then high throughput methods to speed up the time to introgress traits into improved germplasm are urgently needed. Improved phenotyping of insect resistance traits is needed. Genotyping is now relatively inexpensive and phenotyping can be a bottleneck.

The research will lead to (i) a better understanding of pathogenicity and virulence factors in major crop pathogens, (ii) a better understanding of the mechanisms underlying the HIGS phenomenon, (iii) a solid validation of the agronomic potential of HIGS as novel crop protection strategy, and (iv) transgenic lead events.

Understanding the mechanisms of optimal defense

Plants have evolved sophisticated defense systems to cope with a multitude of harmful environmental conditions. Resistance strategies against biotic threats are very diverse, including constitutive defenses and induced responses. Most types of defense responses are not uniformly expressed across different tissues. Instead, the quality and quantity of various defense strategies are continuously adjusted by developmental and environmental cues. The optimal defense hypothesis (ODH) predicts that tissues that contribute most to a plant's fitness and have the highest probability of being attacked will be the parts best defended against biotic threats. Fundamental studies in plant defense signaling need to be driven forward to practical application, for example, with development of plant defense activators or crops that have better inducible defense to respond to attacking pests and diseases. The basis of non-host resistance needs to be better understood and defined.

S2 - Management of mechanisms and genes contributing to pathogen and pest resistance in the field

Durable resistance will be achieved by improving management of resistance genes in the field and monitoring of the spread of new virulent pathogens overcoming the genetic barriers of resistance. Here especially multifactorial aspects have to be considered including interaction between biota as well as with abiotic factors.

Improve the knowledge of the biodiversity of pests, pathogens and their natural antagonists

A better knowledge of the biodiversity of pests, pathogens and their natural antagonists is needed to develop alternative crop protection strategies. Particularly with the perspective that the use of PPPs has to be reduced future strategies have to resort to natural control mechanisms and make more use of antagonists.

Genome sequencing of all major European pests will greatly benefit our understanding of plant defence mechanisms, will help reduce the use of PPPs and will aid in the development of disease-tolerant plants. This aspect is of considerable importance for evolving pathogens and anticipating future threats from imported pests.

S3 - Development of biological control strategies

Even though most agricultural crops are simple ecosystems they consist of several trophic levels including antagonists of pests and diseases such as parasites and predators. These beneficial organisms represent important control mechanisms which have to be more exploited in order to reduce the use of PPPs. In comparison to pesticides they have the advantage of being rather specific, of not producing any residues and their hosts and preys not being able to develop resistance. However, very often they are susceptible to pesticides and have high demands with respect to the natural environment. Furthermore, the natural equilibrium between pests and antagonists is often not sufficient to completely prevent damage to the crop plants. In such cases inundated releases of antagonists help to increase their population size and to improve their control effects. Reductions in efficacy of biocontrol agents caused by hyperparasitoids need to be addressed. A thorough understanding of the important components of the agro-ecosystem and their interactions is a prerequisite for effective and successful bio-control and requires comprehensive research.

Inventory of beneficial symbiotic micro-organisms in the rhizosphere: Numerous micro-organisms are associated with the rhizosphere and some are also beneficial to the crop. This includes N-fixing prokaryotes, but also mycorrhiza and other micro-organisms and fungal endophytes that act as crop protecting agents against root pathogens. In addition to plant symbiosis and pathogen antagonisms, many soil microbes offer various beneficial functions for the growth of plants and trees. This may include plant growth promotion, plant elicitation, nutrient acquisition and competition for pathogens.

Inventory and exploitation of molecules released by plants and exploitation of the role they play for fitness: Plants synthesize and excrete a diversity of molecules involved in protecting them against pathogens and pests, as well as the attraction and colonization of beneficial micro-organisms and insects, and the protection of their habitat against the invasion of other plant species. A number of the molecules and macromolecules can potentially be incorporated into new biotechnologies to improve farming practices.

S4 - Precision farming and plant protection

More targeted PPP application requires improvements in pest diagnostics, forecasting, risk assessment and the application technology used. In recent years significant progress was made in pest diagnostics with the development of molecular tools which are mobile and can be applied in the field. Though these tools just cover some major pests up to now, they might be further developed to include a broader range of organisms. Similarly forecasting and risk assessment were focused on the most crucial pests, but the approaches used can easily be transferred to additional organisms. New application technology will allow us to differentially treating partial field areas of different sizes with PPPs with different dose rates and according to the actual occurrence of pests. This would lead to lower chemical footprint and reduced application rates. Here better recognition of pests / weeds based on modern sensory equipment and algorithms including image analysis, pattern recognition and neural networks should provide significant improvements. In addition more targeted distribution of PPPs (e.g. optimized technical solutions) will also reduce chemical input into the environment. This will be achieved, in particular, if pest recognition is available at a higher spatial resolution. Therefore essential requirements for application techniques are (i) high spatial resolution, (ii) short delay times, and (iii) switching on or off of PPPs during application.

Cropping-systems approach implementing plant-host resistance and agronomic management practices: Research findings about pathogens, insects and weeds and underlying mechanisms of host-pathogen interactions have to arrive at farm level. Future cropping systems need to combine new resilient varieties which ensure high qualities and yields and novel management approaches utilizing synergistic effects within the rotation and within plant communities.

Examples:

Post-harvest protection: Sustainable methods for post-harvest protection will be further developed and validated. The focus should be on environmentally friendly methods for prevention of post-harvest losses concerning quality and quantity as well as on methods for early detection and control.

S5 – New emerging plant disease in scenarios of global climate and trade change

Specific challenge. Diseases reduce substantially plant productivity and diminish the quality of food, feed and forest products. In addition, plant diseases affect the composition and dynamics of natural ecosystems, in detriment of people's quality of life. Under the present constraints of limited availability of cultivable land, climate change, increased seasonal weather instability, and intensive global trade, the threat posed by plant diseases to mankind most likely will become even more serious, particularly because these conditions favour the emergence of new diseases, which may have the highest impact. Examples of recent introductions of particularly harmful pathogens in Europe are *Xilella fastidiosa* in Italy and Tomato torrado virus (ToTV) and Tomato spotted wilt virus in Spain. ToTV was first reported in Spain and later on in Poland, Hungary, France and Italy. Other recent examples are the citrus greening (Huanglongbing), caused by the bacterium *Candidatus Liberibacter asiaticus* in Brazil and in Florida, wherein has resulted in the loss of millions of trees. This disease is an extremely serious threat for the citrus industry of the Mediterranean Basin, unless preventive measures like those implemented in California, are adopted.

Scope. Globally societies and economies must anticipate, prevent and control new emergent diseases to avoid major social, economic and ecological crises. We should aim at understanding the phenomenon of emergence itself. Epidemiological theory predicts that the emergence of a new disease may result from the complex interaction of a variety of factors, often leading to changes in the host range and/or distribution of pathogens. These factors include genetic changes in the pathogen and/or hosts and vector organisms, and changes in the size, density, structure and connectivity of host and vector populations, which to a good extent are under the influence of human activity. Research work should analyse evolution of plant pathogens in those aspects most relevant to emergence such as estimation of parameters needed for meaningful modelling, adaptation to new environments, virulence evolution, biogeography and molecular epidemiology as well as the host-range determination and host-range modification through molecular and systems analysis of virus multiplication, to increase the knowledge on the mechanisms underlying host-switch and host-range expansion and to evaluate the risks of virus emergence in a changing environment. The analysis of these factors requires a team of scientists with expertise in widely different fields: from the molecular genetics of the interactions between pathogens and their hosts and vectors determining host and vector ranges, to the genetic variations of pathogens, plant and vector populations, and to the ecology of these populations and their interactions.

Expected impact: (1) Elaboration of models describing the population dynamics of viruses and other plant pathogens, hosts and vectors under different scenarios, and of protocols for rapid response against new emergences that could assist policy makers. (2) Knowledge of the durability of commercially available resistance genes/varieties against emerging pathogens and transfer of this knowledge to seed companies and productive sector. (3) Development of different approaches (practical solutions) for preventing and combating the damage caused by viruses and other emerging plant pathogens and thus reduce their impact on crops. Aspects like transmission by vector organisms (including important insect pests, such as aphids and whiteflies) can result in data relevant for a changing environment (in the context of a climate change scenario). Regarding resistance traits, major interest of seed companies is to know how their current and future products will perform in front of new infections. Collaborations between the consortia and the industry are essential.

Actions for quality of food, feed and non-food products

Research solutions to action 4 – Develop plants with improved composition for human and animal nutrition and health

S1 - Improvement of food nutritional quality

Dietary bioactives, which promote health, have to be identified including bioactives available from restricted crops such as isoflavonoids, resveratrol, and other specific polyphenols, plant sterols, and specialized carotenoids. Transcriptomic analysis, coupled with metabolomic analysis, will contribute to the identification and characterization of genes/regulators involved in their biosynthesis. The impact of traditional and new food technology processes on the content and availability of such nutrients needs to be studied to develop technologies that maintain the nutrient and bioactive contents in processed foods.

The effects of specific plant-derived nutrients and bioactives in their whole-food context needs to be studied, *i.e.* their impact on health parameters together with the other metabolites, enzymes, fibre, starch, *etc*., present in the same food, since all these external factors may modify the bioavailability and bioactivity of these compounds. Careful analytical assessment of the phytonutrient contents of different plant foods is also essential for the reliable evaluation of components in recommended health-promoting diets.

To demonstrate the beneficial activity of specific classes of bioactives, comparison of near-isogenic plant-derived foods that vary only in their quantity of the bioactives needs to be made. Such model foods could be obtained either by breeding strategies exploiting existing natural biodiversity or by plant metabolic engineering. The development of near-isogenically derived foods can reduce some of the complexity in the diet-health relationship and provide functional foods to be used for animal feeding studies and human intervention trials. Careful analytical assessments would ensure that high levels of phytonutrients would not exceed doses attainable from a normal, healthy diet.

Discovery of the effects of food products or single food bioactive compounds on the incidence and progression of chronic diseases and on specific biological activities or functions, in simplified and controlled conditions will benefit from suitable *in vitro* and animal models by using “omic” tools (transcriptomics, proteomics, metabolomics and epigenomics) and systems biology approaches. Such models should be used to ascertain the preventive effect of bioactives against chronic diseases and the molecular mechanisms underlying the observed effects, to establish whether dose/response relationships can be established, and to test for any toxicity at high levels of consumption. Another objective should be to identify novel biomarkers that are useful for early, pre-clinical identification of onset of diet-related diseases. Appropriate animal models could help to ascertain the localization of bioactives (*e.g.* identification of target tissues) and/or the fate of their metabolized products.

Examples:

- Improve plant/crop composition and processing to ensure that consumption has positive effects on human health

S2 - Biofortification to prevent deficiency diseases

Restricted diets based on staple crops like maize, rice, or cassava have the potential to cause prolonged vitamin deficiencies, which result in painful and potentially deadly diseases. Well-known human vitamin deficiencies involve vitamin B1 (thiamine), which causes beriberi; vitamin B3, (niacin) which causes pellagra; vitamin C (ascorbic acid), which causes scurvy; and vitamin D, which causes rickets. The first symptom of vitamin A deficiency is night blindness, which can lead to complete blindness in children. Vitamin A deficiency also results in reduced resistance to infectious diseases. Enhancement of these and other vitamins such as folate in staple crops such as rice and maize provide useful biofortified crops for populations (particularly rural communities) reliant on vitamin-deficient staple crops. Other biofortification programs should include enrichment of micronutrients, such as zinc and iron, in rice, wheat and beans, through either conventional breeding or genetic engineering.

Examples:

- Cassava value chain
- Cereals, beans

S3 - Determination of bioavailability and metabolism of phytonutrients

The bioavailability of different phytonutrients needs to be determined, as well as their metabolism within the human gastro-intestinal (GI) tract. The relationship between phytonutrients, foods and the quantitative and qualitative composition of the microflora of the GI tract is a particularly under-researched area, which will reveal additional mechanisms by which phytonutrients promote health. The recent demonstration of the importance of the qualitative composition of the GI tract microflora in relation to obesity provides an excellent example of the need for much greater understanding in this area.

Examples:

- Improve plant/crop composition and processing to ensure that consumption has positive effects on human health

S4 - Development of safe and sustainable food products

Plant breeding strategies will have to take into account the nutritional status and needs of modern populations, *e.g.* by providing new targets for plant genetic improvement and biofortification.

The wide biodiversity existing in crops used for foods will need to be addressed. By maintaining and propagating this biodiversity by protecting both the different species as well as the natural environments in which they are produced will contribute to a diverse and sustainable basis for future food production.

Agronomic and processing (pre and post-harvest) methods need to be developed to evaluate and limit the presence of potentially harmful molecules in foodstuffs, such as microbial pathogens, heavy metals, acrylamide precursors, mycotoxins, biogenic amines, neurotoxins and other organic compounds, as well as the persistent contaminants (dioxins, PCBs, PFOS and PFOA, PBDE, etc.). In the case of acrylamide precursors, for example, cereal and potato products account for ~90 % of dietary acrylamide intake across Europe, yet significant reductions can be achieved by selecting appropriate cultivars and modifying sulphur levels in the soil.

Strategies also have to be developed that provide alternatives to chemical preservatives and synthetic colorants for safe food production, *e.g.* the use of food-grade (QPS) bacteria as biopreservatives, probiotics in zootechnics, herb extracts or functional packaging and natural colorants.

Alternative food sources of nutrients will also need to be evaluated, *e.g.* proteins from insects, recovery of ancient/wild plant cultivars and land races.

<u>Examples</u>:

- Plant proteins as alternatives to animal proteins, improvement of protein quality from plants
- Heavy metal toxicity to plants and accumulation in plant products

S5 - Investigation on the role of feed & animal nutrition on food quality and safety

As in human nutrition, concepts in animal nutrition are changing. Optimal nutrition is now considered fundamental whereas in the past, adequate nutrition was considered sufficient. Optimal nutrition implies that feed must be considered not only in terms of its nutritional properties but also in terms of its ability to promote health and protect against disease.

Food of animal origin (FoA) in the diet contributes significantly to the total nutrients in the current EU diet. FoA are an important source of human nutrients, furnishing about 60%, 55%, 20% and 20% of the dietary intake of calcium, protein, iron, and vitamin A, respectively, in western countries. Furthermore, the concentrations of many specific nutrients (e.g. omega 3 fatty acids, CLA, vitamins, and trace elements) in animal-derived foods can be enhanced by modifying the diet of the animals. Thus, animal nutrition and human nutrition can be intimately linked. A good example of this impact is the significant decline in omega-3 polyunsaturated fatty acids obtained from meat due to the switch from pasture to grain-fed animals.

A feed-to-food approach has to be evaluated to define options to re-position animal products as key foods for the delivery of important nutrients to humans. In this context, it is important not only to define the role of animal models in nutrition and health studies but also to investigate the perceptions of consumers with regard to the effects of feed production processes on animal health and on the quality and safety of the resulting food products, as well as to assess attitudes to functional foods of animal origin.

<u>Examples</u>:

- Feed for less CH4 emission
- Improved feed quality for aquaculture

S6 - Model Foods for comparative nutrition

A major challenge in human health over the next fifty years will be in the area of chronic, non-communicable diseases including heart disease, many cancers, type 2 diabetes and obesity. Because socio-behavioural risk factors contribute significantly to the incidence of and mortality from chronic disease, science and public policies need to be re-oriented towards prevention rather than cure.

The importance of plant-based food components in promoting health and ameliorating the impact of chronic diseases, has been recognized for some time. However, currently, recommendations are unable to identify specific fruit and vegetables that confer the greatest health promotion, meaning that official recommendations are vague and that dietary improvement campaigns are untargeted, and largely unsuccessful. It is therefore important to define the action of phytonutrients through a multidisciplinary approach.

It has been well recognized that food components need to be studied on the context of complex foods and not as purified compounds, since other metabolites, enzymes, fibre etc with which they are normally ingested may modify the bioavailability and bioactivity of specific phytonutrients. Hence there is a need to design a limited number of model foods (near-isogenic plant-based foods that vary only in the quantity of the bioactives under analysis) that can be used in all research activities on bioactives to establish scientifically the relationship between food and health.

A number of well-defined and designed model foods can be used to feed model animals in simplified and controlled conditions. Such model foods should be used to ascertain the preventive effect of bioactives against chronic diseases, to define the molecular mechanisms underlying the observed effects and finally to determine novel potential biomarkers useful for early identification of pre-clinical onset of diet-related diseases. Robustness of such biomarkers should then be verified in human intervention studies using the same model foods. These activities will deliver tools for early diagnosis of diet related-diseases and for scientific knowledge-based formulations of appropriate nutritional interventions to prevent/reverse disease progression.

Research solutions to action 5- Improved composition and performance of plants for non-food products

S1 - Improving biomass yield, composition and processibility for the production of bioenergy/biofuel and biomaterials

Work on model species has led to substantial progress in our understanding of plant physiology and metabolism at the genomic, proteomic and metabolomic levels. This knowledge can now be used to design strategies to increase biomass yield while improving biomass composition and processibility, facilitating its transformation into bioenergy/biofuel and biomaterials. Genes, pathways and regulatory networks that influence biomass generation/carbon accumulation (under low input/stress conditions) and processing-relevant characteristics (e.g. lignin content and composition) have been identified in model species. This information can now be used to identify genetic loci that modulate the accumulation and quality of the biomass in related lignocellulosic biomass feedstock candidates.

As competition between food/feed and biomass crops increases, there is more pressure to grow biomass crops on marginal lands to ensure their economic and social sustainability. The eventual mining of germplasm or the genetic modification of biomass candidate species for xerophytic and halophytic lifestyles would significantly reduce competition between food/feed and biomass production. Extremophiles, particularly model systems, provide the resources for the basic understanding of tolerance and will unlock the potential in other species.

Contributions from genetics, functional and comparative genomics, plant breeding, genetic and metabolic engineering, physiology, biochemistry and agronomy will therefore be required to exploit the potential of non-food/multi-use crops for industrial and energy uses.

How far can we go? Yield improvements could be achieved by translating current knowledge on the role of yield components, such as photosynthetic efficiency and plant architecture, into undomesticated biomass species (4–5 years for herbaceous species, 10–15 years for tree species). There is likely to be significant genetic variation for stress tolerance traits in biomass crops, which in the short term (2–3 years) could be incorporated into breeding programs to improve biomass yield in limiting environments. Lignocellulosic biomass crops that propagate vegetatively will require dedicated approaches for genetic transformation and the engineering of relevant metabolic pathways, so that considerable progress could be achieved in the medium term (5–7 years).

We also need to investigate how and to what extent symbiotic organisms and pathogens affect the performance of non-food crops. Biomass crops can form associations with mycorrhizal fungi, which improve water and nutrient uptake. Mycorrhizae and/or fungal endophyte colonization could be used to enhance biomass production, particularly under drought conditions. A survey of fungal biodiversity in host plants and the dynamics of plant/fungus associations under challenging conditions (i.e.drought) are required. Conservation and management strategies for fungal resources are also necessary.

How far can we go? The selection of the most effective symbiotic fungi can be achieved rapidly (3–5 years) and will require extensive interactions between plant physiologists, mycologists, geneticists, cellular and molecular biologists. The transfer of these results into large-scale practical applications may take up to 10 years.

Clonal propagation is required for some biomass crops, which may carry over intracellular pathogens (viruses and virus-like agents) that cannot be later controlled by chemicals. In addition, limited information is available concerning intracellular pathogens infecting biomass/energy crops because these plants were not considered to be crops until recently or were even regarded as weeds. A combination of breeding (when possible), good agronomic practices and phytosanitary certification of the propagation material has been applied in other clonally-propagated species, such as fruit trees and grapevine, improving both yield and quality.

How far can we go? For biomass/energy crops, a primary goal will be to identify viruses, viroids and phytoplasmas present in accessions, followed by the development of diagnostic tools, as well as phytosanitary protocols and certification procedures to be used in the production stages of mother-plants (this could be achieved in 3 years). Five to ten years will be required to develop transformation methods allowing the engineering of specific traits.

S2 – Improving yield and tailoring the quality of oilseed feedstock as a source of biobased raw materials

Lipid metabolism has been modified in established oilseed crops to adapt the product for either human/animal consumption or industrial needs, and significant modifications in triacylglycerol composition and content have been achieved by manipulating key genes affecting fatty acid metabolism in the seeds of both model species and oilseed crops. Similar strategies, supported by comparative and functional genomics, could now be transferred to candidate feedstock species with higher yield potential in environmentally and agronomically limiting conditions to increase seed oil production and direct fatty acid synthesis for specific industrial requirements (biofuels, biobased plastics and other biobased materials) while ensuring a high yield of lignocellulosic biomass. Engineering the quantity, quality and homogeneity of oils in vegetative tissues is also essential.

How far can we go? At the same time, protein-rich by-products from seed oil extraction should be optimised in the short-to-medium term (3–5 years) for either animal feed or alternative uses. The extraction and utilisation of other high-added-value phytochemicals from lignocellulosic and oil biomass should also be optimised (3–5 years) in order to maximise economic competitiveness and offer new development opportunities to the agricultural sector. Production of new breeding material could be envisaged in 3–5 years through multidisciplinary collaborations involving genetics, genomics, biochemistry, metabolomics, physiology and plant breeding. Obtaining new marketable varieties through traditional and new breeding technologies will require significantly longer timescales.

S3 - Efficient and environmentally-beneficial pre-treatment methods to obtain multiple products from the same crop

In order to fully exploit non-food crop by-products and agro-industrial biowaste, it is necessary to combine the extraction of high-added-value products and biomass conversion into second-generation biofuels. Research should explore more sustainable processes for the extraction of bioactive compounds and high-added-value products and should develop new and efficient processes in order to reduce chemical and energy inputs, and optimize residual biomass treatment and waste processing. In this context, the utilisation of innovative "green chemistry" processes could represent a valid alternative to conventional extraction with organic solvents, without generating substances harmful to the environment and to humans. Significant improvement can be expected through the development of innovative technologies for the extraction of phytochemicals from agro-industrial biowaste and new and efficient biological processes for byproduct and biowaste pretreatment.

How far can we go? These innovative technologies and biological processes can be developed in 3–5 years, whereas full optimization and transfer may require 10–15 years. Interactions among agronomists, plant physiologists, biologists, biochemists and engineers will be needed to achieve progress in these areas. It will be important to integrate the above with the 'cascade' use of crops, e.g. the extraction of valuable products and the use of the remaining biomass as a source of fuels or bulk chemical products.

Relevant to objective: Develop photosynthetic systems for the sustainable production of bioenergy

S4 - Towards efficient bioenergy production by photosynthetic organisms and "artificial leaf" systems

The efficiency of photosynthesis can be enhanced by increasing our knowledge of natural light-harvesting and energy-conversion systems. Generally, less than 1% of absorbed solar energy is converted into biomass. Recent developments in synthetic biology have made it possible to develop biofuel production systems that promise higher efficiency by using photosynthetic microorganisms as production hosts, and these advances could now be extended to whole plants. The smart design of solar energy harvesting and biofuel excretion systems in photosynthetic organisms can enhance the efficiency of such processes even more and make expensive and complicated extraction processes unnecessary. "Artificial leaf" systems that mimic the natural photosynthetic solar energy conversion process, with solar energy conversion efficiencies of up to 40%, are likely to become possible in the future energy market.

How far can we go? The anticipated improvement in production efficiency compared to current biomass crops (not taking into account the expensive extraction of biofuels from the biomass) is at least 10-fold for photosynthetic microorganisms and 40 times for "artificial" leaf systems. It could take up to 20 years to achieve commercially-profitable biofuel production by photosynthetic microorganisms or by "artificial leaf" systems.

S5 - Manipulating epicuticular wax structure and composition to improve photosynthetic carbon fixation and partitioning to increase plant yields

Many modern crop varieties have a glaucous phenotype due to accumulation of large amounts of epicuticular wax crystals (wax bloom) on the plant surface. This is not the result of natural selection but the product of decades of selective breeding, systematically eliminating non-glaucous (glossy-looking) progeny because they were assumed to have no protective wax layer and as a consequence would display reduced stress tolerance. Wax bloom may play a role in the regulation of tissue temperature. However, a number of plants growing in semi-arid environments have a glossy surface. Prevention of non-stomatal water losses is actually achieved by wax embedded in the cuticle (endocuticular wax) and laminar (smooth) epicuticular wax layers. As a result, glossy-looking plants like ivy can have very low cuticular conductances. Significantly increased yields have been reported in the field with non-glaucous wheat and oilseed rape varieties, but these plant have never been characterised biochemically and physiologically, and the underlying mechanisms were never investigated. One factor that can significantly reduce crop productivity is the reflection and scattering of photosynthetically active region of light (PAR; 400-700 nm) by crystal structures covering the surface of glaucous plants. Preliminary evidence suggests that the dense wax bloom covering plant surfaces may be detrimental to photosynthetic activity in non-saturating light conditions. This is consistent with the increased yield reported in the field for non-glaucous wheat and oilseed rape varieties. Hence, reducing the wax bloom on the surface of both food and non-food crops should improve photosynthetic activity in limiting light conditions (i.e. low light intensities or shaded parts of the canopy).

How far can we go? Using reverse genetics approaches, wax composition and structure can be manipulated to reduce the reflection of PAR in non-saturating conditions and optimise photosynthetic activity (3-5 years). The fundamental impact of this research will be to increase our understanding of the relationship between wax structure and photosynthetic CO_2 fixation and of its importance as a component trait of yield. Because of the cumulative effect of significantly increasing carbon fixation and altering carbon partitioning between the epidermis and sink tissues, very significant increases in yield are potentially achievable (5-10 years).

Relevant to objective: Optimize plant-based platforms for commercial recombinant protein production

S6 - Improve the yield of recombinant proteins in different plant systems

The yield of recombinant proteins can be improved by enhancing different steps leading to protein accumulation, including optimised codon usage, transcription, translation, protein stability, intracellular fate and, in the case of in vitro cell/tissue cultures, by improving bioreactor design, medium composition, and culture strategy.

Plants naturally use storage compartments in the endomembrane system to accumulate vast amounts of protein as part of the developmental process of seed maturation, and stable expression of recombinant proteins such as vaccine antigens has been actively pursued in seed crops with accumulation levels of up to 40% of total seed protein. However, our understanding of the characteristics that allow the stable accumulation of proteins in seeds remains rather limited, and trial and error approaches still dominate the field. The definition of the biochemical interactions that lead to the formation of protein bodies will allow to develop rational approaches to boost recombinant protein accumulation in seeds. Another major goal would be to obtain levels above 10% in non-seed tissues that can be used also for the extraction of other compounds.

How far can we go? A major tool that can be used to reach high levels of protein accumulation is the manipulation of the activity of genes that regulate protein folding, membrane traffic and protein homeostasis in the endomembrane system. This can be achieved in the next 10 years and will require a detailed characterisation of the different factors that control these processes (chaperones, regulators of membrane traffic and fusion, degradation pathways), and their interactions.

In plant cell cultures, plant biomass is cultured under sterile conditions in contained bioreactors. This reduces the regulatory burden associated with field-grown plants. Even if the biomass accumulation is high, the overall yields remain often still too low. Significant increases in the yield could be achieved in 5 years through the careful optimization of strategies for gene expression, the utilization of engineered cell lines, and by maximizing the efficiency of downstream product purification. Further research involving different disciplines such as production physiology and bioreactor design are essential.

S7 – Improving the functionality of recombinant proteins expressed in plants

Plants can fold structurally complex proteins and introduce certain co-translational and post-translational modifications that are not introduced by prokaryotic hosts, but the glycan structures are different to those found in mammalian cells. Although plant cells can be modified in various ways to replicate the glycan structures produced by mammals, they can also produce novel 'glyco-optimized' variants with improved properties. Considerable advances have been made during the last decade, e.g. introducing human-like N-glycan structures in plants, using glycans to mask non-productive epitopes in vaccines and ensuring the production of homogeneous glycoproteins.

How far can we go? It will now take 3–5 years to combine the different strategies and generate a plant-based expression platform suitable for the expression of defined, homogenous, tailored N-glycans.

Relevant to objective: Develop plants and plant cells for the production of high value molecules

S8 - Development of medicinal plant based products

Plants are an ideal source of novel drugs because of the diverse and complex secondary metabolism within the plant kingdom. Drugs and medicines have been identified through ethnobotanical studies, targeted discovery, systematic chemical analysis of plants and the scientific scrutiny of traditional medicines to identify active compounds and validate their efficacy. Examples of plant-derived products with significant medicinal value include the anti-cancer agent paclitaxel from the pacific yew tree, the antimalarial drug artemisinin, and compounds such as vinblastine and vincristine from the Madagascar periwinkle. During the past 30 years 1355 new drug entities were introduced to the market; 27% were either natural products or were derived from natural products as semi-synthetic derivatives. In addition, 20% of the drugs were synthesized after the molecule was first discovered from natural resources.

The challenge for plant scientists will be to evaluate the medicinal value of ecosystems that are under threat, to liaise with local communities and test the efficacy of plant-based treatments, and to determine opportunities and pathways for the development of new drugs (e.g. by knowledge transfer to local communities for low cost medicines or liaison with the pharmaceutical industry to undertake the testing and development of new medicines). Such exploitation must be conducted in full compliance with the Rio Convention on Biodiversity. Cultivation and production should be carried out in containment or using tissue/cell cultures to allow production of medicinal products without damaging the source ecosystem. Metabolic pathways controlling the biosynthesis of these target compounds may also be transferred to more amenable hosts, such as tobacco or to microorganisms e.g. yeast.

How far can we go? Identification of new molecules and characterisation of their biological activity can be achieved in 3 to 5 years.

S9 - Plants and plant cell cultures as a source of specialty chemicals.

Plants can be used as green factories for the production of a range of industrial compounds, including specialty chemicals, pharmaceuticals, agrochemicals, biomaterials, food additives, food supplements, surfactants waxes, pigments, flavours and fragrances. Increasing the range of plant species that are currently grown in Europe as industrial crops will require the application of fast-track molecular breeding technologies focusing on target species. Molecular breeding in poorly-characterised species will require genomic and transcriptomic analysis, and next-generation DNA sequencing. It will also require the characterisation of the plant metabolome in order to identify metabolites that accumulate in specific organs or at certain developmental stages and to develop methods for their extraction and functional characterisation. We also need to increase our understanding of metabolic pathways and the ways they interact, in order to design strategies that optimize the accumulation of specific products. It is also important to understand the impact that these modifications may have on plant growth and development under diverse conditions. Similarly, the use of plant cells should be explored including strain and process development as well as scale up strategies for industrial production. Furthermore synthetic biology tools will have a great impact enabling us to increase the biodiversity modifying the complex scaffolds or important intermediates.

How far can we go? In 10 years, it should be possible to use metabolic engineering in plants to manufacture many products that are currently synthesized using organic chemistry, allowing us to replace such processes with those utilizing renewable natural sources.

Actions for a vibrant research environment

<u>**Research solutions to action 6 – Develop and implement horizontal actions**</u>

S1 - Education programs for young scientists

Young scientists need to have a perspective of the significance, role and importance of European science. This requires special training programs to support them and the continuation of effective funding mechanism like Marie Curie. Increasingly young scientists should also develop experience in industry. Here joint career development programs in both the academia and in the industry would be useful. Short-term mobility of young scientists should be supported developing rapid evaluation criteria and quickly accessible funds.

S2 - Programs to support life-long learning and target-oriented incentives

In many countries careers of scientists are too much oriented towards the purely academic perspective and alternative career paths and incentive systems need to be developed to support innovation – especially with respect to technology and knowledge transfer. This is a political process that requires a significant change in the orientation in member states towards the recognition of “excellence of technology transfer” – without damaging the development of science excellence.

S3 - Re-establishing extension services as an exchange mechanism between science, farming and industry

In recent decades public extension services have seen significant erosion. This has strongly increased the gap between science and applications in agriculture. Member states and the commission should support extension services and develop them towards an information hub of active communication between science and practitioners.

S4 - Projects towards sustainable food production and bioeconomy value chains in developing countries

Specific projects are needed to develop cooperation and capacity building in developing countries. It will be important to set priorities in a close dialogue with developing countries and international research and regulation institutions to focus on the most important issues and to develop sustainable cooperation and synergies. Good examples are the recent FAO-EPSO workshop on value chains for sub-Saharan agriculture and the developments of focus programs by the Global Plant Council.

S5 - Open discussion with society and decision makers – Towards a European Forum for Sustainable Bioeconomy

While this has been a major goal for some time, more action is needed to develop fruitful and required long-term support for plant sciences in Europe. Overcoming knowledge deficits and limitations, often leading to uneducated fears is a central issue in the acceptance of European bio-based sectors. Open discourse and discussion with the society at large is supported, for instance, by activities like the *Fascination of Plants Day*. Here discussion should also address issues that are controversially discussed, due to limited popular understanding, like e.g. novel breeding technologies, GMO, ecosystem services and sustainable intensification. Generating a European Forum for Sustainable Bioeconomy – based on the collaboration of national academies, European Technology Platforms and other stakeholders - could deliver a strong message to the public by providing an open discussion forum in the member states, as well as joint statements or discussion papers.

Research solutions to action 7 – Strengthen basic and applied research and research infrastructure to secure innovation

S1 - Integrated projects between member states and linking sectors through an effective EIP process

Target-oriented projects need to be further enhanced by linking resources and competences of member states. The development of effective mechanisms of the EIP including all stakeholders should be strongly supported. This should not develop towards a “central governing body”, but to a supporting and coordinating process that allows for diversity, but also develops synergies. It will also be important to evaluate the efficiency of instruments and – if necessary – to modify or remove specific instruments, if they do not proove to reach the target required. ERA-Nets – if properly developed and if they allow interaction across stakeholders - can also play a strong role in knowledge development and innovation.

S2 - Projects linking sectors and developing the role of agriculture in cyclical sustainable processes

Agriculture is the starting and the endpoint of sustainable biomass use. While presently value-chains are developed that are oriented at the “final product”, cyclic processes need to be implemented that address the need of, for example, nutrients and carbon to be recycled within the cropping system.

Such approaches require specific approaches that link the intermediate and end-product sectors to agriculture and define the best practices for a sustainable management of main end-products generated by agriculture, horticulture and agro-food industry.

S3 - European integrated technology platforms in genomics, phenotyping and experimental farms

In recent years, significant progress has been achieved with national platforms for plant genomics, phenotyping and farm-scale experimental platforms utilising systems approaches. However, this is a very fragmented development and not all member states have reached a sufficient level of integration of these, often expensive, platforms and technologies. A process should be developed to develop integrated, across Europe, networks in the relevant technological fields that support exchange, reduce double investments and ensure long-term funding of cornerstones of the European plant research and innovation area.

S4 - European resource centers

Besides the technology platforms, biological resources and databases need to be maintained, conserved and developed for utilization. National seed banks and omics–databases have to be developed into European strongholds to support maintenance and the utilization of biological resources. Access must be open and secured long-term. International (global) cooperation is of upmost importance.

Annex II HEADINGS OF THE STRATEGIC RESEARCH AGENDA

'Plants for the Future' European Technology Platform
Brussels, June 2007

Links:

Plants for the Future ETP

- Vision:
  http://www.plantetp.org/images/stories/stories/documents_pdf/vision%20paper.pdf
- SRA summary:
  http://www.plantetp.org/images/stories/stories/documents_pdf/strategic%20research%20agenda.pdf
- SRA complete:
  http://www.plantetp.org/images/stories/stories/documents_pdf/strategic%20research%20agenda_part_iiiii.pdf

Annex III HEADINGS OF HORIZON 2020 SPECIFIC PROGRAMME EC' PROPOSAL[1]

Part II – Industrial Leadership

1. Leadership in enabling and industrial technologies

1.4 Biotechnology

1.4.1 Boosting cutting-edge biotechnologies as future innovation drivers

1.4.2 Biotechnology-based industrial processes

1.4.3 Innovative and competitive platform technologies

2. Access to risk finance

3. Innovation in SMEs

Part III – Societal Challenges

1. Health.

1.1. Understanding the determinants of health, improving health promotion and disease prevention

1.5. Developing better preventive vaccines

1.6. Treating disease

1.9. Transferring knowledge to clinical practice and scalable innovation actions

2. Food security, sustainable agriculture, marine and maritime research and the bioeconomy

2.1 Sustainable agriculture and forestry

2.1.1 Increasing production efficiency and coping with climate change, while ensuring sustainability and resilience

2.1.2 Providing ecosystem services and public goods

2.1.3 Empowerment of rural areas, support to policies and rural innovation

2.2 Sustainable and competitive agri-food sector for a safe and healthy diet

2.2.3 A sustainable and competitive agri-food industry

2.3. Aquatic living resources

2.4 Sustainable and competitive bio-based industries

2.4.1 Fostering the bioeconomy for bio-based industries

2.5 Specific implementation actions

5. Climate action, resource efficiency and raw materials

5.1 Fighting and adapting to climate change

5.1.1 Improve the understanding of climate change and the provision of reliable climate projections

5.1.2 Assess impacts, vulnerabilities and develop innovative cost-effective adaptation and risk prevention measures

5.1.3 Support mitigation policies

5.2 Sustainably managing natural resources and ecosystems

5.2.1 Further our understanding of the functioning of ecosystems, their interactions with social systems and their role in sustaining the economy and human well-being

5.2.2 Provide knowledge and tools for effective decision making and public engagement

5.4 Enabling the transition towards a green economy through eco-innovation

5.4.1 Strengthen eco-innovative technologies, processes, services and products and boost their market uptake

5.4.2 Support innovative policies and societal change

5.4.3 Measure and assess progress towards a green economy

5.4.4 Foster resource efficiency through digital systems

5.5 Developing comprehensive and sustained global environmental observation and information systems

5.6 Specific implementation aspects

6. Inclusive, Innovative and Secure societies

6.1. Inclusive societies

6.1.2. Building resilient and inclusive societies in Europe

6.1.4. Closing the research and innovation divide in Europe

[1] COM(2011)0811: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0811:FIN:en:PDF

Annex IV HORIZON 2020 Strategic Programme for the WPs 2014-15 EC's proposal[2]

12 Focus areas proposed in this document and relevance of the Plant ETP input to H2020 are:

• **Personalising health and care**	highly relevant
• **Sustainable food security**	most relevant
• Blue growth: unlocking the potential of the oceans	relevant
• Smart cities and communities	relevant
• Competitive low-carbon energy	relevant
• Energy efficiency	relevant
• Mobility for growth	n.a.
• **Waste:** a resource to recycle, reuse and recover raw materials	highly relevant
• **Water** innovation: boosting its value for Europe	highly relevant
• Overcoming the crisis: new ideas, strategies and governance structures for Europe	relevant
• Disaster-resilience: Safeguarding and securing society, including adapting to climate change	relevant
• Digital security	n.a.

2 http://www.earpa.eu/ENGINE/FILES/EARPA/WEBSITE/UPLOAD/FILE/news/Strategic%20Programme%20Horizon%202020%20(2014-2016).pdf