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POSITION PAPER

Sustainable Future for Bioenergy and Renewable Products

Venice, 21 September 2007 – With the 2007 report from the Intergovernmental Panel on Climate Change (IPCC) stating the need to reduce the anthropogenic emission of greenhouse gases from fossil fuels and the directive of the European Community calling for biofuels to meet 5.75 percent of European transport needs by 2010, and 10 percent by 2020, an urgent need for action in plant sciences arises to obtain an economically viable and sustainable production of biofuels, renewable chemicals and materials. While other countries already attribute significant research money to this field (e.g. more than $800 million in recent projects on biofuels in the USA), Europe still lacks concerted action. In response, EPSO, the European Plant Science Organisation, has established a set of recommendations for how Europe can meet this challenge and provide a basis for integrated approaches towards a future bio-economy. EPSO represents more then 140 academic institutions from 25 European countries with over 20 000 people in plant research.

European plant science is willing to take a responsible role in the implementation of a sustainable future bio-economy by developing the knowledge and skills required for obtaining increased quantities of biomass suitable for conversion to biofuels and to renewable resources, at economically competitive prices, and within an environmentally and economically sustainable agricultural system that is an essential part of a future bio-economy.

Societal and economic relevance. Today's economies are based on **carbon resources of fossil origin**, which provide societies with their major energy sources and raw materials for chemical production. However, several major challenges for mankind arise from this approach:

- the use of these fossil-based resources as fuels, but also as non-degradable substances and composites, causes severe regional and global environmental problems, including CO_2 emissions for which there is increasingly compelling scientific evidence that they are a major contributory factor in global warming and climate change;
- the availability of fossil resources does not match the expected increase in consumption of energy and raw materials in the future;
- the distribution of fossil carbon sources around the globe makes them an even less reliable source in the future.

These aspects make clear that the present high dependence on fossil fuels is not sustainable. Together with the economic fact that energy and raw material prices have drastically increased over the last decade, these factors necessitate the development and establishment of alternative concepts and products.

Bio-based strategies hold great promise for sustainable solutions and are presently being developed worldwide to contribute significantly to the future mix of energy sources. Plants provide the major source of organic substances on our planet. They include relatively under-utilised forms such as cellulose, hemicellulose, starch, lipids and lignin that have major potential for use as raw materials for energy and industrial feedstocks. Significant impact is expected from bioenergy with respect to mitigation of climate change, development of rural areas and employment options as well as the provision of alternative energy forms. This is especially true for fuels used in transportation.
However, in order to make bioenergy a sustainable alternative, a holistic approach is needed, which:

- improves biomass supply with respect to amount and quality;
- improves conversion of biomass into other energy forms;
- reduces or eliminates toxic waste products ;
- develops zero-waste biorefinery concepts for efficient conversion of plant raw materials into diverse products;
- manages bioenergy production systems in a sustainable manner;

- has minimal impacts on the environment.

Effective and multilateral networking between the different, hitherto separated, research communities will be crucial to make bioenergy and bio-economy a sustainable success. This approach will form the basis for the network required for a knowledge-based bio-economy (KBBE) and will also provide new opportunities to farmers, the forestry sector and other stakeholders.

Plant science issues: creating the knowledge base for biomass production and supply. As plants will provide the major resource in a KBBE, plant science will play a major role in developing the capacity and novel opportunities for a bio-economy in line with the environmental and economic settings in Europe. European plant science is very well positioned to contribute with its strong expertise to obtain increased quantities of biomass at adequate qualities for the various optional routes of conversion, at economically competitive prices and with acceptable impacts on the environment.

There are numerous fields of action in which knowledge from plant sciences on agriculture and forestry crops needs to be used to deliver to the overarching aim of a sustainable bioenergy economy:

- **Higher biomass production is urgently needed**. This includes activities that increase biomass potential through direct improvement of growth and biomass production. This can be realised by increased growth rates, prolonged vegetation periods, or improved architecture of crops. It can also be achieved by reducing the loss of biomass due to pathogens and pests, by improved stress tolerance to allow using marginal lands and to lower competition with food production. Since the amount of biomass has to be enlarged significantly, all possible options have to be addressed in parallel.

- **Improved processability of biomass, with respect to the specific conversion options for bioenergy and biomaterials, needs to be achieved.** This requires strong interdisciplinary interactions with microbial, chemical, engineering and process sciences to develop new industrial processing methods. In plant science, activities include modifying cell wall structure and composition to increase the ease with which it can be decomposed into units that are either themselves useful as biofuel, or are good starting points for the production of chemicals. Enhancement other aspects of the organic and inorganic composition of biomass with respect to the conversion processes (e.g. removing compounds inhibiting decomposition or fermentation, reducing alkali for improved combustion behaviour, etc.) and residue handling should also be achieved. Improving composition of harvestable plant biomass will also be beneficial, for example to provide lignin more suitable for making lignin-based composites.

- **Improved resource use efficiency is the key to higher biomass yield at low environmental impact.** This includes improving processes such as energy collection through enhanced photosynthesis efficiency and nutrient use efficiency. This will reduce the dependence of plant growth on the application of additional inputs such as fertilizers that require high amounts of energy for production and have a deleterious environmental impact. Also topics like nitrogen-fixing bioenergy crops, associations with beneficial soil microorganisms and improving phosphate use efficiency are of prime importance to address decreasing availability and anticipated rising costs of fertilisers. Furthermore, minimising the water consumption per unit of energy gained is critical because fresh water will be a key limiting factor for food and energy production in the future on marginal land and with changing climatic conditions. Utilisation of plant varieties that can remove harmful substances from water and soil (e.g. excess nitrogen in overfertilised land, excess salt in highly irrigated land) can even provide additional beneficial effects.

- **Increased genetic diversity of bioenergy plants is key to achieving new properties in bioenergy crops.** A bioenergy roadmap needs to be established and will include (i) the use of traditional food crops for which all the scientific tools are available, (ii) the development of novel crops via genomics-driven domestication of hitherto not or not significantly used species, (iii) the development of specific energy crop rotation systems and (iv) the use of the different options originating from agriculture, forestry or even an biofactory (e.g. algae) approach. Actions include the development of specific energy crops having improved properties in comparison to the classical crops, probably via an initial round of genomics-supported breeding, followed by introducing novel features through smart breeding or genetic modifications. Throughout the introduction of novel species, their potential to displace native species and their potential impact on biodiversity needs to be considered. It will be crucial to address the alternatives of food and energy utilisation.

Plant research in tune with bioenergy and environmental sciences
Plant scientists in Europe are prepared to take this challenge in close coordination with researchers and engineers in related disciplines in order to develop a new, sustainable and economically viable bioenergy sector within the bio-economy of the future. Integration of plant research programmes must be obtained with:

- White biotechnology: in order to obtain new biocatalysis features to form useful energy sources (e.g. bioethanol, biogas, etc.)
- Conversion technology, chemistry and chemical engineering: significant interaction is required to obtain useful breeding targets on quality and quantity of biomass supplied to the alternative conversion routes.
- Agricultural and forestry management, ecosystem and biogeochemical research: as the production of large scale biomass for bioenergy will be done in new production systems, new plant features must be integrated in them and they must be checked for their biogeochemical impacts.
- Agricultural and forestry management and economics: it will be important to consider the potential to utilise non-food components of existing crop plants (e.g. straw, stover) for bioenergy as an added-gain that does not jeopardise food/feed production, and to consider how new dedicated energy crops are best integrated into agricultural practice and rotations in a manner that aids rather than competes with food and feed production.
- Sustainability assessment: for an ecologically, socially and economically viable bioenergy sector, impact analysis on all the above stated aspects must be integrated and evaluated in macro and microeconomic contexts. It is important to provide society with scientifically validated information about options using transgenic and/or clonal plants and on the conversion of marginal land, grass or agricultural land and forests into efficient production units for various energy feedstocks. A thorough discussion of the balance between food-feed-energy outputs from agriculture must be based on sound scientific evidence.

Taking significant steps forward
This concept for a sustainable bio-economy is in agreement with the strategic research agenda (SRA) of the European Technology Platform 'Plants for the Future' published in June 2007. EPSO member institutions are committed to contribute to the implementation of the SRA, but significant steps are required in a coordinated manner between stakeholders from the public and private sector to transfer this plan into action:

- significant investments into research and implementation similar to those presently done in leading countries outside Europe at national and European levels;
- co-ordination with industry as well as governmental agencies and NGOs;
- co-ordination and development of a common research agenda between all platforms committed to the idea of a sustainable knowledge-based bio-economy along the entire value chain.

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Useful links
Position paper webpage: http://www.epsoweb.org/commun/Position_Paper_Bioenergy.htm
Position paper press release:
http://www.epsoweb.org/commun/Position_Paper_Bioenergy/Bioenergy_Press_Release_EN.pdf
European Technology Platform 'Plants for the Future': http://www.epsoweb.org/Catalog/TP/index.htm
Strategic Research Agenda:
http://www.epsoweb.org/Catalog/TP/Launch_25June07/TP_SRA_Summary.pdf

About EPSO
EPSO, the European Plant Science Organisation, is an independent academic organisation that represents more than 140 leading research institutes and universities from 25 European countries. EPSO's mission is to improve the impact and visibility of plant science in Europe.
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Plants for the Future ETP Strategic Research Agenda 2025

Plants for the Future

Extract from the 'Plants for the Future' European Technology Platform's Strategic Research Agenda (SRA). The SRA consists of five challenges each with several goals. Below you will find Goal two, *Bio-energy production,* of Challenge two, Plant-based products – chemicals and energy, which is the chapter most relevant to the renewable energy track of the envietech2008 Congress in Vienna, Austria, 31 January 2008. The full version of the SRA is available online as a pdf: http://www.epsoweb.org/Catalog/TP/SRA_PART_II.pdf

Challenge two: **Plant-based products – chemicals and energy**

The development of the knowledge-based bio-economy – involving a global industrial system based on renewable plant-derived products as an alternative to the current fossil fuel-based system – constitutes by far the most challenging and promising opportunity in terms of economic, environmental and societal potential. Until recently, this concept of a bio-based industry was perceived as a desirable development in the distant future because there were no strong economic drivers to support its development. However, three recent developments have provided the necessary stimulation. First is the sharp rise in crude oil price since 2004. Second is the rapidly growing consensus that the root causes of climate change need to be addressed seriously and urgently. Third is the fact that end users are looking to the development of innovative new raw materials. Thus, the concept of a bio-based industry is rapidly becoming reality through a combination of technology push and market pull. This transition is receiving strong support from policy-makers and a global financial community that is investing billions in novel industrial initiatives, both in developed and developing countries.

The transition from our current fossil fuel-based industries to bio-based industries will have far reaching and immense effects on agriculture, industry and society. Most importantly, the transition will require considerable investments in research into feedstock production, conversion processes and large-scale capital infrastructure. In essence, it is envisaged that agricultural raw materials will become feedstocks for the production of biochemicals, bio-energy and biofuels.

In addition to the contribution of forestry to bioenergy, these basically constitute novel applications of agricultural production, requiring appropriately designed crop species different to those that are currently used for food and feed production. The immense challenge of the bio-based industry will be to develop economically competitive and environmentally compatible novel crop and production systems that will gradually replace the current fossil fuel-based industrial production of materials and energy. To meet this challenge we will need policies to support the sustainable growth and development of bio-based industry across the European Union and globally. In particular, policy decisions will have to be taken in relation to competing demands for land use from food and feed production to non-food products including biofuels. Reform of the Common Agricultural Policy (CAP), in which market forces will increasingly determine which crops are grown across Europe, will have to address these issues.

The deployment of these novel non-food crop species on a scale of tens of millions of hectares in the coming decades undoubtedly constitutes the biggest challenge in agricultural history. The deployment will also require private investments in the order of several billions of Euros. However, the current stringent regulations governing genetically modified crops in Europe represents the most important barrier for private investment in plant biotechnology. If this barrier is not mitigated, the deployment, for example, of high efficiency energy crops in Europe will be seriously threatened, with the consequence that Europe may become dependent once more on imports to meet the targets set out in the EU's Biofuels Directive.

Policy measures are urgently needed to create an environment that is fully conducive to private investment in plant biotechnology. One such policy measure is an implementation of the GM regulatory framework specifically tailored for genetically modified non-food crops that would create a strong incentive for investment in R&D in all plant-based applications, particularly biofuels. Today, the lead market for biofuels is primarily supported by tax incentives and other forms of government subsidies, but these measures are not sustainable in the long term. Biofuel production in Europe can be cost competitive on the international market provided that high-tech energy crops, adapted to the different climatic regions and optimised for sustainable biomass yield under low input agriculture can be realised. The novel implementation of the European regulation for genetically modified non-food crops not only constitutes a condition *sine qua non* for the development of European energy crops, but would also mitigate in part the negative consequences for private investment resulting from the current GM regulations on food crops. It is imperative that these biotechnologies can be used to ensure a competitive position for Europe in the new bio-economy – without these advances the European position in both agriculture and industry will increasingly fall behind other countries in the global marketplace.

A clear vision is urgently required for the research and development activities needed to underpin and optimise the use of plant-based renewable resources. This vision cannot be set in stone, since it is impossible to anticipate the immense technological developments in this field in the coming decades. However, it is essential that the multi-functionality of crops is addressed to optimise the future use of agricultural raw materials in the bio-refineries which will produce a range of products and fuels. This challenge must be updated regularly to capture new developments and innovations.

The specific goals with deliverables that will be explored under this challenge are:

1. **Biochemical production**
   - Pharmaceuticals
   - Specialty chemicals and enzymes
   - Plant-derived oils as industrial feedstock
   - Polymers
   - Fibres
2. **Bio-energy production**
   - Production of biomass
   - Conversion of biomass
   - Innovative concepts for whole plant utilisation
3. **Enabling research for plant based products**
   - Development of production platform crops and extraction processes
   - Systems for plant production

In practical terms, these goals are fully integrated and contribute to a bio-manufacturing base involving integrated bio-refineries. For clarity in the present document, topics within each are described separately. The topics represent realistic goals that can be achieved by building on European expertise.

Goal two: Bio-energy production

The supply of plant-derived bio-energy – which currently provides less than 1% of our energy requirements – is expected to increase dramatically in the coming decades. This bio-energy is provided either directly through simple combustion, primarily of wood products, or after the conversion of agricultural biomass from a variety of plant sources into different liquid and gaseous biofuels, such as bio-ethanol, biodiesel and biogas. The trigger for the rapidly growing demand for bio-energy was the huge oil price increase of 2004. This made biofuels derived from agricultural products, such as cornstarch, cost-competitive with petroleum-based fuels and initiated an irreversible shift in the global economy from fossil fuels to renewable energy sources.

Furthermore, the shift towards biofuels and renewable energy is driven by the rapidly growing consensus that global warming is in part caused by the release of fossil fuel-derived carbon dioxide, concerns regarding the security of energy supplies and shrinking fossil fuel reserves. The use of renewable biomass-based fuels has the potential to be CO_2-neutral or even reduce CO_2 levels. This, together with the recent biofuels policy support measures in both the EU and the United States, has triggered the explosive development of a first generation biofuels industry. In the USA, the large-scale development of biofuels beyond the current level is supported by a national road map for biofuels and the allocation of several billion dollars of structural funds for research and development. In the EU, the continued growth of the biofuels industry will be driven in the coming years by the recent Biofuels Directive which sets targets of 5.75% and 25% market shares for transportation fuels derived from biomass and blended with fossil fuels in 2010 and 2030 respectively. To illustrate the magnitude of these reference values, if the 2010 target is to be reached via the cultivation of oilseed rape, Europe would have to set aside six times the current acreage for this crop, raising it to 5 million hectares.

The key technological challenges for the production of renewable biomass-based fuels are all related to optimising the cost-efficiency of biofuel production, namely biomass yield, nutrient and water-use efficiency, and energy conversion efficiency.

The first generation of biomass fuels, that are currently produced, are derived from special biomass feedstocks that are efficiently converted into biofuels that can be blended directly with fossil fuels as transportation fuels. These feedstocks are either sugars or starches which are fermented into bio-ethanol or vegetable oils that are then converted into biodiesel. The first generation biofuel crops are in fact food and feed crops, such as wheat, corn or oilseed rape which have been optimised for food or feed production, but not for biofuels. Hence, neither the biomass yield nor the input requirements are optimal. Furthermore, the net energy balance – i.e. the ratio of output to input energy – of these first generation biofuels is far from ideal.

The second generation biofuel crop species – dedicated energy crops – will be tailored specifically to the production of biofuels with optimised biomass yield and input requirements, such that their net energy balance is substantially improved. This optimisation will be achieved by defining the key biological processes that underpin biomass yield, and water and nutrient use efficiency.

It is generally envisaged that the second generation energy crops will produce primarily lignocellulosic feedstocks that will be fermented into bio-ethanol using novel saccharification and fermentation technologies. The principal challenge here will be the development of efficient biomass conversion technologies for lignocellulosic material.

To ensure that the economics behind the future energy crops and the associated bio-refineries works, the opportunities presented by by-products, residues and waste should be explored.

In addition to the dedicated biofuel energy crops, improved tree crops will provide renewable bio-energy through simple combustion. It is expected that the plant resources used for energy supply will reflect geographical location (such as forestry, grasses and field crops).

The sustainable production of biomass fuels must take into consideration the environmental impact and societal acceptance of such energy sources. While the environmental impact of the first generation biofuel crops is substantial, the envisaged improvements in the cost-effectiveness of energy production, namely the reduced input and water requirements, will significantly improve the environmental impact. The second-generation biofuel crop species will, by virtue of their minimal input requirements, also have a highly reduced environmental impact, and will contribute to preserve biodiversity. With regard to societal acceptance, many stakeholders are convinced that the stage is now set for the large-scale production of green energy which will constitute the main driver in the emerging bio-based economy. The technological improvements will only expedite this development process. Furthermore, it should be stressed that this mass production will provide new rural employment opportunities which are especially important in light of reforms to the Union's Common Agricultural Policy, especially in new Member States where pressure on fragile rural communities is greatest. However, the production of green energy will also face the exceptional challenge of global industrial restructuring in which the very different value chains of agricultural production and the biorefining industries must be merged with the value chains of the energy providers.

Today, the lead market for biofuels is primarily supported by tax incentives and other forms of government subsidies – measures which are not sustainable in the long run. Biofuel production in Europe can be cost-competitive on the international market provided that high-tech energy crops are grown. These should be adapted to the different climatic regions and optimised for sustainable biomass yield under low-input agriculture.

High-tech energy crops will most likely be based on the application of plant biotechnology and genetic modification, which could be inhibited by the rigidity of current GM regulations in Europe. This problem can be addressed either by developing a new European regulatory framework or by adapting the implementation of the present GM regulation for non-food crops. The mere fact that energy crops will help to mitigate the effects of climate change should be used to raise broad public support and acceptance of GM energy crops.

Ultimately, the economic competitiveness of plant-based energy production may only be achieved by combining energy production with the production of biochemical feedstocks so as to maximise the economic value of agricultural production. This will entail the development of a third generation of biofuel crops – multi-purpose crops – which can produce specific biochemicals, as well as biofuel from lignocellulosic material.

At present, it is only possible to outline broadly how the large-scale production is likely to unfold – i.e. which technologies could become competitive and what mix of conventional crop species and novel dedicated energy crops could be deployed in the different European agricultural regions. At this stage, it is important to support a broad range of technological developments that will enable the European bio-energy industry to implement the most optimal green energy production systems on a local basis.

<u>Deliverable one:</u> Production of biomass [Ref.: C2.G2.D1]
Currently three different types of plant resources are considered for biomass production:

- **Field crops producing sugar, starch or oil feedstocks**. These are the first generation of biofuel crops.
- **Tree crops for bioenergy**. Fast-growing trees as energy crops can be grown in Europe as short rotation coppice: willow (Scandinavia and the British Isles), poplar (central Europe) and Robinia (Mediterranean Europe). Harvests take place after leaf fall in winter in a cycle of two to five years. The established root system and the nutrients stored in the roots and stumps guarantee vigorous growth for the shoots. Plantations yield from 8 to 20 tons of dry woodchip per hectare per year. A plantation can be harvested for up to thirty years before needing to be replanted.
- **Dedicated energy crops for producing lignocellulosic feedstocks.** This will be the second generation of biofuel crops. Perennial grasses show many beneficial properties as energy crops, and have been evaluated as bioenergy feedstocks in both the United States and the EU. A large number of perennial grasses have been grown or tested as energy crops in Europe. Mostly funded by the European Commission, research has focused on four rhizomatous grasses: reed canary grass (C3, northern Europe), *Miscanthus* (C4, central and southern Europe), switchgrass (C4, central and southern Europe), and Giant Reed (C3, Mediterranean Europe). These energy crops can be harvested in late autumn to early spring, when nutrients are stored in the rhizomes. Annualised biomass yields reported range between 5 and 40 dry tons per hectare each year.

The principal technological challenges for improving the production of these three types of plant resources for biofuel and bio-energy production are to boost biomass yield and improve the efficiency of water and nutrition use, as well as enhancing the composition of lignocellulosic feedstocks for biofuel production.

Increased biomass yield and improved efficiency of water and nutrition use [Ref.: C2.G2.D1.S1]
Biomass yield is one of the key success factors for lignocellulosic energy crops. The challenge is to improve both the yield and the yield stability of energy plants. This will be achieved by screening the available biodiversity for highly productive species and analysing the genetic variability within species. Another approach will be to extend the genetic variability by genetically engineering for improved traits, such as dry matter and energy yield, source-sink interaction and stress tolerance. A third means will be innovation in crop production, in particular the development of regionally adapted energy crop rotation systems which allow maximum fixation of solar energy during the whole vegetation period.

The enormous potential of innovative plant breeding and crop production approaches has not yet been explored. It is expected that the yield of dedicated energy crops for whole plant fermentation can be increased by up to 100% within the next decade.

The key factors driving high-yield crops are the availability of water, nutrients and sunshine. Most climate change models predict significantly drier summers within Europe for the coming century. Since most of the growth, even of perennial crops, happens during this period, the increased efficiency of water use will become ever more necessary.

The challenge to meet the demand both for food and for fuel is to generate the highest yields in terms of biomass with the lowest water and nutrient inputs over a wide range of geographies, both for conventional field and energy crops. Comparative studies of the genetics and physiology of different types of crops are needed to establish the basic principles for improving the efficiency of water and nutrient use. To elucidate these basics, research should focus on genetic diversity and plant physiology.

CO_2 neutrality or even absorption are exciting possibilities for biofuels derived from lignocellulosic biomass. This does, however, require limited inputs in the sense of energy expended, such as diesel fuel needed for such things as crop protection and the spreading of fertiliser. Net reductions in atmospheric CO_2 are possible when energy crops fix significant amounts of carbon in stable structures, such as lignin and cellulose, which remain after harvesting, for instance in the root system. Special attention should be given to identifying energy plants which possess this property.

To achieve the projected yield improvements, it will be important to develop basic genetic and genomic tools for trees and energy crops. Genetic diversity in trees and energy crops has only been studied in a limited fashion. For such crops as *Miscanthus x giganteus*, no genetic diversity is available at all. Therefore, it is first necessary to collect and then develop genetic diversity for both trees and perennial grasses. Study of this genetic diversity will help lead to the discovery of the basic principles for biomass yield, as well as the efficiency of water and nutrient use. The poplar genome of one representative variety has been sequenced and switchgrass sequencing has been initiated in the United States. It makes sense for Europe to focus on the other energy crops. Equally important is the development of genetic transformation to enable directed alteration of beneficial energy crop properties. Switchgrass transformation has been established in the USA. Again, Europe needs to focus on the other energy crops.

Finally, it will be important to identify portfolios of energy crops that are fully adapted to local climatic conditions. To deliver high fuel yields across a wide variety of geographies, the best regional energy crops need to be identified. This can be achieved in head-to-head comparative studies of energy crop genetic diversity in across the EU.

<u>Time Frame</u>

Five years:

- Genetic diversity established for selected energy crops
- Sequencing of selected energy crops completed
- Transformation technology developed for each of the key energy crops
- Plant physiology and yield screens developed

Ten years:

- Results from plant physiology and yield screens of genetic diversity over various geographies suitable for the respective energy crops will allow correlation between genotype, plant physiology and biomass yield

Improved composition of lignocellulosic feedstocks for biofuel production [Ref.: C2.G2.D1.S2]

Another challenge is to provide plant biomass specifically adapted to sophisticated conversion technologies. This will be achieved by increasing the dry matter content of energy cropsand maximising the content of energy-rich compounds, Another means would be to improve the digestibility of plant biomass in technical or microbial conversion processes through the use of innovative strategies for post harvest-induced catabolism to release fermentable sugars from polymers, such as cellulose. In addition, the high dry matter and energy content of energy crops will reduce the cost of transporting and storing feedstock. The induced breakdown of polymers will help to reduce fermentation time.

An important goal for the development of energy crops is to increase the fuel yield by improving the biomass for subsequent processing. White biotechnology offers a promising route to turn biomass into transportation fuels. Biomass is first subjected to pre-treatment (such as heating it or adding dilute acid) in order to make the cellulose and hemicellulose fibres accessible for subsequent saccharification using cellulases/hemicellulases. Improvement of the biomass such that subsequent processing delivers high fuel yields is one of the keys to reducing production costs of fuel from lignocellulosic biomass. During fermentation, C6 sugars can be more effectively utilised compared to C5 sugars, whereas lignin remains a leftover that can be combusted to generate process energy and electricity. Enhancing the cellulose of lignin ration and the cellulose over hemicellulose ratio are promising approaches to increasing fuel yields, because they act in a synergistic fashion, both on saccharification and on fermentation yield. Alteration of the ratios of the different subunits in lignin offers additional potential for further fuel yield increases.

The transportation cost of lignocellulosic biomass per unit of stored energy is significantly higher than that of sugar, starch or oil-based biomass. Most US analyses indicate a maximum transportation distance of 50 kilometres from the processing plant. In order to reap the benefits of the significant economy of scale in a processing plant, a large volume of biomass needs to be transported. This is preferably done at low costs, and thus over short distances. This drives the needs towards energy crops having a very high yield per hectare. In addition, land available for agriculture is limited and a significant share of it will be needed for production of food and feed.

<u>Deliverable two:</u> Conversion of biomass [Ref.: C2.G2.D2]

The primary challenge will be the development of efficient technologies for the conversion of biomass into biofuel, using both improved lignocellulosic feedstocks and improved enzymes for saccharification and fermentation to ethanol or other biofuels. While the former is discussed in the preceding section, the latter falls under the remit of the Industrial Biotechnology Technology Platform. In essence, biorefinery improvements will involve improving the efficiency of conversion technologies and the purification of conversion products.

The challenges for improving the efficacy of the conversion processes will be to increase conversion rates and to obtain pure products. This will be achieved by increasing the substrate load of fermenters (dry fermentation). This will entail improving energy efficiency, such as achieving catalysis at low temperatures. It will also involve improving the technical and microbial digestion and conversion of substrates; optimising micro-organisms and enzymes, including broad substrate spectra and high conversion rates. Advanced enzyme preparations and defined microbial inoculates, including novel strains obtained through genetic engineering, will improve turnover rates and thus the overall efficacy of second generation bioethanol and biogas production.

The advanced purification of conversion products requires the development of simple and effective procedures to obtain pure preparations of the conversion products. This will be achieved by improving high throughput separation technologies; developing innovative concepts for improving energy efficiency, such as the use of plant residues including lignin as lubricants. Pure product preparations will then be suitable for different uses and also for the synthesis of bulk chemicals for the polymer chemistry.

Deliverable three: Innovative concepts for whole plant utilisation [Ref.: C2.G2.D3]
The challenge here is to exploit all plant compounds. This will be achieved by establishing zero waste concepts, which allow utilisation of all plant compounds. This also involves closed nutrient cycles; processes for purification of by-products; and the synthesis of novel, value-added compounds in GM plants, such as technical enzymes or fine chemicals.

Commercialisation of all products, including novel value-added compounds from ‘intelligent plants’, will give European bio-energy production a competitive global advantage. This will contribute significantly to a sustainable knowledge-based bio-economy and the socio-economic stabilisation of rural areas in Europe.

Another important direction is the development of multifunctional energy crops which produce value-added chemicals, such as dicarbonic acids, which can be used for the production of polymers or oils used in the production of lubricants. The value-added chemical will be extracted in an upstream process. The rest of the plant will be utilised for fuel production. Such multifunctional energy crops represent a powerful way of enhancing the economies of sustainable bioenergy production.

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Useful links
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About Plants for the Future ETP
The European Technology Platform "Plants for the Future" is a stakeholder forum on plant genomics and biotechnology that was initiated by the European Commission on the request of the Brussels European Council of March 2003. It was supported by the European Commission via a Specific Support Action in FP6 and is today supported by the major public and private stakeholders in the field. It is currently coordinated by EPSO.
The stakeholders are academia, industry (crop improvement, seed, food, feed, new products, retailers etc.), agricultural, forestry, educational, financial, consumer and environmental organisations.
http://www.epsoweb.org/Catalog/TP/index.htm