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EPOBIO – Realising the economic potential of sustainable resources – bioproducts from non-food crops

EPOBIO WORKSHOP 2: Products from Plants – from crops and forests to zero-waste biorefineries

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Title of paper: INDUSTRIAL CROP PLATFORMS FOR THE PRODUCTION OF CHEMICALS AND BIOPOYMERS

EPOBIO Flagship: Biopolymers

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Introduction

EPOBIO is an international project to realise the economic potential of plant-derived raw materials by designing new generations of bio-based products derived from plant raw materials that will reach the market place 10-15 years from now.

EPOBIO is a "science-to-support-policy" project funded by the Framework 6 programme of the European Commission (EC). Partners from the European Union (EU) and United States (US), from academic research institutions and from industry, work together with an International Advisory Board of researchers, industrialists and policymakers. The aim is to ensure a robust and holistic evidence-base is established to inform future national and international decision-making. This "EPOBIO process" considers new science-led projects and products within a wider context of their environmental impact, economics, regulatory framework, social acceptability and expectations of the public and policymakers. This holistic process underpins strategic recommendations that constitute the major outputs of EPOBIO.

The ability of plants to capture solar energy and use carbon dioxide and water to photosynthesise carbohydrates offers the potential of a sustainable manufacturing system. Crop plants already provide cheap commodity chemicals such as starch and sugar. The possibility of establishing industrial crop platforms for the production of a wider range of commodity chemicals and polymers needs to be explored, particularly at a time when alternatives to petrochemicals must be found.

The flagship “biopolymer” aims at studying the various challenges involved in the use of agricultural plants for the production of a range of biopolymers with useful material properties. These include, but are not limited to, the synthesis of polymers with plastics and elastomeric properties such as polyhydroxyalkanoates and rubbers, starch-based plastics, as well as fibres and adhesives based on proteins or poly-amino acids. In particular, the flagship will be addressing the question: how can plant biology and biotechnology contribute to the development of the use of agricultural plants for the production of biopolymers?

Background

The second report of the biopolymer flagship for the EPOBIO project analyses the suitability of three crops for the production of platform chemicals and biopolymers.

Most applications in this theme are in an early stage of development necessitating a longer lead-time to market (10/15 to 20 years). We have considered three quite different crops: sugar beet, tobacco, and *Miscanthus*. The strengths and weaknesses of developing each of these three crops as future industrial crop platforms turned out to be quite different. Central issues are the future acceptance of GM-crops, especially in the case of sugar beet, fitting the new crops in the existing supply chains, and integrating the crops in existing or future processing schemes.

Executive Summary

Alternatives to the use of petrochemicals can be derived from agricultural feedstocks by three basic strategies. One involves chemical synthesis, such as the use of the Fischer-Tropsch process from bio-based source materials. The other alternative uses microorganisms and microbial processes to produce industrial chemicals from agricultural feedstocks by fermentation and biotransformations of plant products such as starch, sugar, and plant oils or co-products and waste. This is the well-established route of industrial biotechnology and forms the chosen process for many products already on the market.

A third route, explored in this report, is the use of crop plants to produce novel industrial chemicals in the field, whether finished product for extraction or precursors for post-harvest modification into product. This route of using industrial crops for large-scale production of commodity chemicals and polymers is not yet in widespread use, beyond the traditional examples of products produced naturally by plants such as sugars, starches, natural rubber and the oils produced by oil crops. Plant oils and cell walls for biorefining purposes are analysed separately in accompanying EPOBIO reports [1] and [2].

Three potential industrial crop platforms for commodity chemical production are considered. These are crops already of relevance or of great promise to agriculture in the Member States of the EU and case studies are developed to explore their potential as new platforms for chemical manufacture. The crops are sugar beet, the perennial grass and energy crop *Miscanthus* and tobacco. The principal question addressed in this study is the feasibility of producing chemicals and biopolymers more cheaply in fields than in bioreactors within the timespan of 10/15 - 20 years. All of the applications described in this study for industrial-scale production of novel chemicals in field crops necessitate the use of genetic modification (GM). It is up to

public acceptance whether these new transgenic crops will be developed and cultivated in Member States throughout the EU.

For each of the crop platforms, the current state-of-the-art is reviewed with a detailed bibliography. The research and development (R&D) needs are identified in terms of the work that will need to be undertaken to achieve an optimised platform. Full consideration is given to recommendations for each of the crops and the possibility that the platforms can be used for multiple products - such as biomass for bio-energy as well as valuable co-products for extraction and processing in biorefineries.

SUGAR BEET

A strength of sugar beet is that it is already an established crop throughout Europe, is a high income generator for the farming community and has exceptional yields of dry biomass per hectare. There is also a considerable science-base underpinning the crop and its current use for production of refined sugar and co-products for the food and feed markets.

Sugar beet, as a producer of sugar, or its close relative fodder beet, is already a feedstock for bio-energy biorefineries, and this use would be further optimised if biomass production and the yield of fermentable materials including sugars were optimised. The R&D needs in the context of industrial use of beet are very different from those that have underpinned development of the crop to date and will need to be refocused urgently if the potential of beet as an energy and industrial crop were to be pursued widely in the EU.

This study is considering sugar beet as an industrial platform for commodity chemicals/biopolymers beyond its potential use as simply a bioenergy crop. It must be emphasised that this extended use for chemical production would necessitate development and field cultivation of transgenic varieties. These varieties would be engineered as appropriate for the specific product(s) that the beets are designed to manufacture. However, in relation to the production of industrial transgenic beet, it is an absolute essential to develop technologies to prevent transgene flow, given the considerable risk from outcrossing and consequent transgene spread.

Also, processing of sugar beet for refined sugar and co-products has been extensively optimised. New processing schemes are already under development for use of sugar beet in the production of energy products such as bioethanol or biobutanol. Should the beet be developed further for multiple uses that combine bioenergy with production of novel chemicals it is highly probable that processing technologies would have to be still further modified and newly designed. For low value co-products, these changes should be minor and relatively easy to implement; for high value-added products, processing would focus on the main novel product with waste streams feeding into bioenergy or biofuel production.

Thus, whilst technologies are increasingly available for development of beet as an industrial crop platform with multiple outputs, there are a number of weaknesses that must be addressed. These range from inherent difficulties of developing a transgenic crop used for both non-food and food purposes, the need to prevent transgene flow, and the high inputs currently needed for high yield. The locked supply chain in place for sugar refining can be considered both as an advantage and a disadvantage since there are some processors already keen to look for alternative uses.

With reform of the Sugar Regime within the Common Agricultural Policy (CAP) it is probable that sugar refining from sugar beet will decline throughout the EU in the next few years, but the crop may be maintained for use in biofuel development. These changes will open up the opportunity to develop new markets for the crop. Given the agronomic expertise available in many Member States for the cultivation of beet, and the technologies available for crop improvement, increased sustainability and novel modification, development of beet as a new industrial platform should reasonably be examined, and indeed this process is already underway.

TOBACCO

This is currently grown as a field crop in many Member States of the EU and in those regions extensive agronomic experience exists. CAP support for the production of tobacco is being switched from direct support to incorporation into the single farm payment, opening up access to new markets. In addition, financial allocation for restructuring in tobacco growing regions also supports the possibility of alternative uses for tobacco as an industrial crop platform.

Alternative uses of tobacco are already in development in that the plant is used for the production of biopharmaceutical proteins in leaves of transgenic tobacco grown in containment. This study raises the possibility of widening the applications of transgenic tobacco to field crop cultivation and its use as an industrial platform for chemicals and biopolymers. In this context, tobacco benefits considerably from established genetics and its use as a laboratory tool which has led to robust protocols for genetic transformation, notably also of the chloroplast.

Research and development should focus on the nature of the chemicals and polymers chosen for production in tobacco. Since tobacco contains little dry matter and is currently unlikely to represent a biomass crop it is probable that bespoke transgenic lines would be developed for each chemical and biopolymer product. Given the costs associated with development of transgenics, it is likely that these products would be mid- to high-value soluble chemicals and polymers, including enzymes. Production of hybrids with other *Nicotiana* species could be a route to increase biomass leading to both increased yields of novel chemical products and increased residual biomass that could be used for fuel generation. In view of the dilute nature of this waste stream, this would most likely be biogas.

Clearly, tobacco is already used as a non-food crop and has no related species in Europe and North America. These features greatly limit the risks from outcrossing and therefore, transgene flow to food crops is not an issue. As a crop grown on relatively limited hectarage, transgenic tobacco would be relatively easier to isolate than other large-scale biofactory crops. Indeed, since tobacco offers versatility in terms of production, R&D should also be directed towards the design and development of small-scale extraction and processing protocols, such that on-farm post-harvest treatments could be both feasible and profitable for small-scale producers and contribute to rural development in tobacco growing regions of the EU.

MISCANTHUS

The perennial grass, *Miscanthus*, has substantial strengths in terms of yield potential and ability to grow successfully under low inputs of fertiliser and pesticides. *Miscanthus* is already recognised to present a considerable opportunity for bioenergy production, given parameters such as biomass yield and low inputs. However, its use for bioenergy is currently severely limited because the grass is not developed as yet as a crop for widespread cultivation. In due course it is likely that experience with related grasses such as sugar cane, maize and *Sorghum* will greatly benefit the development of *Miscanthus*.

Research needs are those associated with any plant species that is undeveloped as an agricultural crop. There are urgent needs to improve our understanding of the genetics of *Miscanthus*, to establish a robust breeding programme and to develop molecular tools for fast-track breeding. Research is also required to establish a robust genetic transformation system for *Miscanthus*. In this context, parameters for successful tissue culture systems need to be optimised for regeneration purposes.

In terms of agronomy, *Miscanthus* is not completely frost-tolerant, with particular issues in the first winter following establishment. Improvements to the crop are required to increase frost hardiness, which in turn would greatly expand the cultivation areas suitable for *Miscanthus* across Europe. Whilst the grass has considerable yield potential, productivity under low input conditions is another target for improvement. Current practice is the use of rhizomes to establish *Miscanthus*. This is labour-intensive and new approaches need to be optimised such as seed sowing or field establishment at the plantlet stage.

In addition to these many R&D needs to establish the grass as a regular agricultural crop, there would be the added needs to establish its potential as a platform for chemical and polymer production to complement biomass use for bioenergy. This added potential will depend on the development of a robust transformation system and much greater understanding of metabolic pathways in the perennial grass to design appropriate change in flux into the novel products, without impacting greatly on biomass yield. There are also R&D needs in terms of extraction methods for application in biomass biorefineries. However, the feasibility of using *Miscanthus* for the production of chemicals or biopolymers can be judged from current developments with sugar cane.

STRATEGIC RECOMMENDATIONS - SCIENCE

Recommendations within this theme of industrial crop platforms for the production of commodity chemicals and biopolymers, must be viewed from the perspective of underpinning work that needs to be undertaken to ensure products in a market place in a 10/15 – 20 year time period. The key question that arises is whether it is appropriate to design any plant platform to make novel commodity chemicals/polymers. Should the community rather focus on platforms to manufacture cheaper and more efficient biofuels from biomass, as well as the more simple feedstocks produced naturally by plants to support the bioreactor production of industrial commodities?

The report has considered three quite different crops: sugar beet, tobacco, and *Miscanthus*. The strengths and weaknesses of developing each of these three crops as future industrial crop platforms are quite different.

The study has revealed the potential of sugar beet to be optimised as an industrial energy crop that could be further modified to produce platform chemicals. The extensive area on which this crop is already cultivated in Europe and the opening of markets through CAP reform are two positive issues that would underpin new development of the crop into an industrial platform. Since sugar beet is currently considered and used as a food crop linked into integrated supply chains for sugar refining, a substantial change in perception would be needed before alternative uses could be taken up. These changes in perception are already occurring, with sugar beet increasingly in use as a biomass crop for bioenergy. Current industrial applications of sugar beet are based on beet that has been optimised for sugar refining. Industrial utility of the crop would be greatly enhanced if new breeding targets aimed at industrial applications were undertaken. Beyond bioenergy, there are opportunities for using beet to produce novel chemicals and biopolymers. However, social acceptability of transgenic beet for this purpose is likely to play a major determining role in decisions.

Tobacco offers interesting potential as an industrial crop and there is extensive agronomic experience with the crop from farmers who already produce tobacco within the EU. Tobacco engineered for the production of chemicals and biopolymers is a transgenic application, but this crop has many strengths for high yield production of designer compounds by GM and the possibility for development into a relatively high yielding biomass crop. Given the cost of the development of a transgenic crop it is likely that the considerable potential of tobacco as an industrial platform will be pursued primarily by the large biotechnology companies. The extent of cultivation of GM across member states of the EU will depend on public acceptability. In the longer term, there may be scope for on-farm processing of relatively small hectarage, which could provide alternative uses of the crop for existing producers.

Miscanthus undoubtedly holds great promise as a bioenergy crop for the mid- to long-term future. This promise can only be realised once the grass has been optimised for large-scale commercial cultivation. *Miscanthus* offers potential for co-production of added value products in parallel to biomass for biofuels.

STRATEGIC RECOMMENDATIONS – POLICY

Our strategic recommendations on policy encompass six specific elements to ensure take up of the bio-based economy.

Policies must be coherent, integrated and coordinated. Integration in Brussels and Member States is essential to develop a policy framework that will support the bioeconomy. As the bioeconomy represents a potentially huge strategic development consideration should be given to applying a 'bioeconomy test' to policies in development, in the same way that policies are assessed for their sustainable development impacts.

Innovation in plant and industrial biotechnology should be supported. Clear research objectives and a framework to achieve them are essential. An adequate level of targeted funding, selecting those novel and innovative processes and products likely to achieve success in the market place and deliver environmental benefit, should be an element of this.

Policies should support development of the whole supply chain. This will need to consider feedstock supply, processing and the production of bioproducts. There is a need to both stimulate the market side and build on the foundation of the Common Agricultural Policy which has moved from production subsidy to market-orientated developments. Financing along the supply chain needs to be considered as one aspect of feedstock supply.

A communication strategy is essential. The acute lack of awareness of the bioeconomy and the potential of biotechnology at all levels in society must be addressed by a strategic communications campaign designed to raise awareness and create an informed acceptance of bioproducts. This will need to explain the benefits of the processes and products delivered by the bioeconomy.

Pilot projects have a role to play. The establishment of proof of concept and testing under industrial conditions is a key step in moving research into product development. Scale-up during the research phase can develop and test industrial processes and also help to develop stronger co-operation between industrialists and academics.

Measurable sustainability indicators should be developed. The absence of validated techniques for the measurement of sustainability benefits needs to be addressed. This is important as these gains need be evidenced to enable all stakeholders to understand the rationale for the development of the bioeconomy.

In addition, Common Agricultural Policy support for perennial crops is currently focused on the energy market with the single farm payment available if the energy crops payment is also claimed. In the future, the development of non-energy products from biorefining will be a major component of the bioeconomy. Permanent crops used as feedstocks for non-energy products would not, under current rules, be eligible for the single farm payment. This is an issue for urgent consideration by the European Commission.

1. Carlsson, A., Clayton, D., Salentijn, E. and Toonen, M. 2007. Oil crop platforms for industrial uses. CPL Press, Berks.
2. Möller, R., Toonen, M., van Beilen, J., Salentijn, E., and Clayton, D. 2007. Crop platforms for cell wall biorefining - lignocellulose feedstocks. CNAP.

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