BIOPOL

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Content

Executive Summary

Introduction

BIOPOL is a two-year research project funded by the European Commission since 2007 through the Sixth Framework Programme. The overall goal of BIOPOL is to assess the status (technical, social, environmental, political, and implementation) of innovative BIOrefinery concepts and the implications for agricultural and forestry POLicy. Biorefinery concepts are aimed at relevant market-competitive and environmental-friendly synthesis of bio-products – chemicals and/or materials – together with the production of secondary energy carriers – transportation fuels, power and/or CHP. BIOPOL was conceived to address the fact that the wider expectations for biorefineries have not yet yielded clear definitions for biorefinery concepts, or an understanding of the current status and prospective benefits of biorefining in Europe. Therefore the BIOPOL project was designed to assess the current status of biorefinery activities in Europe and explore future scenarios for development. By systematically accounting for potential technical, political, social and industrial impacts of such scenarios their outputs will be utilised to inform policy formulation in this area. By drawing from several complimentary research disciplines the insights gained will be able to inform EU policy-making and help frame future research directions both in Europe and elsewhere.

Main results

Technical status
The biorefinery definition that has been adopted in this BIOPOL-project (according to the IEA-Task 42 biorefinery, www.biorefinery.nl/biopol) is the following:

‘Biorefinery is the sustainable processing of biomass
into a spectrum of marketable products including energy’

Currently four complex biorefinery systems are distinguished in the research and development literature:

1. Green Biorefineries: using ‘naturally-wet’ biomass, such as green grass, alfalfa, clover, or immature cereals.
2. Lignocellulosic Feedstock Biorefineries: using ‘naturally-dry’ raw material such as cellulose-containing biomass and residues.
3. Whole Crop Biorefineries: using raw materials such as cereals or maize.
4. ‘Two Platform’ Biorefineries: combine the sugar platform and the syngas platform.

Industry, consumers and NGOs
After intense desk research a literature overview of market introduction and development of biorefinery concepts in industry was delivered. Thereby the focus was set on four economically important and promising industry sectors which could successfully introduce and develop biorefinery concepts and related products in the market: the chemical industry, the pulp and paper industry, the starch and sugar industry, and the biofuels industry.

The market acceptance within these industries was analysed in the year 2007/2008 by means of a standardised questionnaire-based survey among (potential) industrial actors. Overall, the surveyed companies displayed a positive attitude towards biorefinery concepts with 80% of the interviewed companies agreeing that biorefineries are promising concepts. This positive attitude was observed in all relevant sectors, although the chemical industry was noticeably less optimistic than the other branches surveyed.

The second part of the market acceptance investigation deals with the results of a survey among the potential consumers of many end-products manufactured in biorefineries. Consumers' general attitudes towards biorefinery concepts were considered, along with their opinions towards related issues such as economic viability and local impacts. No strong and consistent public opposition to biorefinery plants in the six surveyed countries can reasonably be expected due to a (very) positive assessment of biorefineries by respondents. Eco-friendliness and positive economic effects of biorefinery concepts were the most positively received aspects of biorefining amongst consumers, providing an opportunity to advocates of biorefining for highlighting these features in public communication activities.

NGOs are important stakeholders for the acceptance of the Biorefinery concept and the future implementation of biorefineries in Europe. A survey was conducted among NGOs in the six participating EU countries to learn their views on the biorefinery concepts. It can be concluded that the consulted NGOs are actively involved in the bioenergy field, and to a lesser but growing extent in the biorefinery field. Overall, the view towards the biorefinery concept appears positive, with the caveat that a substantial number of NGOs are currently developing their position on biorefineries.

Rural development, employment and environment

This project concludes that in establishing biorefinery operations the involvement of local people is vital. This is of greatest importance for greenfield biorefineries that bring change in the local habitat and to the local community. Interactions with all local actors in the early stages of building a new biorefinery plant are necessary to increase public acceptance.

The indirect impact on employment is not easy to measure, especially for biorefineries co-located with existing facilities and using existing supply chains. Nevertheless, benefits are apparent wherever new value is created from residues and wherever current jobs are maintained, for instance jobs that could otherwise be lost due to EU sugar reform.

Case studies show that economic factors are currently more important for enterprises than environmental issues. Politics, e.g. biofuels legislation, can be a pivotal driver in the establishment of individual biorefineries. Sustainability issues are recognized as very important by operators of pilot biorefineries in order to safeguard the long-term operations of the plant by accounting for future trends, new legislation and changes in institutional and public mindsets. As a result, current biorefinery strategies reveal trade-offs between economic and environmental factors (for instance, between transport costs and emissions, and between feedstock costs and local rural development).

Political legitimacy

Analysis of perceptions of members of the policy community towards biorefinery-related environmental, social, policy and reputational issues reveals a number of areas where prompt action from the political and scientific communities could yield significant benefits.

The analysis indicates that policy-sphere actors are aware of the very significant levels of resources and support that could be needed to establish sustainable biorefineries Europe-wide. The survey results suggest that policy-sphere informants may be cautious with regards to issues that can pose a significant threat to the social reputation and acceptance of biorefinery concepts – a notable example being that of GMOs in feedstocks. Responses also indicate a perceived urgency to establish guidelines and standards of a technical nature in almost every category of biorefinery activity (from feedstock production to product use). The analysis also conveyed the result that agreeing sustainability criteria is another priority amongst policy makers.

In general, there are indications that political informants have a good working knowledge of biorefinery concepts and largely share the views of the scientific community regarding the relative environmental and social contributions that biorefining can make. However, the possibility that a deeper understanding of the various potential advantages (and trade-offs) of biorefining may not yet be widespread suggests a need for further political engagement.

Implications of the existing political framework

An analysis of EU policies impacting biorefinery viability has been performed. The focus areas for policies are primarily energy, forestry, agriculture and environment. There are also many other relevant policies for the biorefinery concept arising in fields that range from waste management to rural development. The policy areas often overlap and conflict where the proposed biorefinery concepts are concerned, leading to apparent complexity and uncertainty in the policy environment.

The study finds evidence that actions to support innovation (translation of research into technology and products) and the integration of currently unconnected technologies will now need to translate into strong commitment and support for the establishment of pilot and demonstration plants.

Numerous examples of potential overlaps, conflicts and synergies between policy regimes were found in this study. There are a growing number of examples of how development of industries or sectors important to the biorefinery industry can be influenced by unintended consequences of policy interactions. These include areas such as liquid biofuels, rural development, agricultural reform, climate policy and renewable energy.

An immediate observation is that although many policies generated by the European Commission are relevant to biorefinery concepts, very few specifically refer to biorefineries. Most of the policies are much broader than the biorefinery concept or, indeed, bioenergy or renewable energy. For example, policies on rural development may have only a few sections/lines related to renewable energy. However, it may be the conditions created by policies that are crucial the implementation of the biorefinery concepts.

Scenario analysis

With the new biomass supply model, developed by the E3MLab of ICCS, four scenarios were quantified and simulated. The demand for biomass/residues for energy purposes for each country was set equal to the PRIMES model results for the RES and Climate Action Policy Package scenario. Two alternative possibilities were modelled: one case in which only stand-alone biomass processing plants are possible and a second case in which integrated biorefineries succeed to develop enabling lower costs thanks to economies of scale. All scenarios are designed so as to respect the sustainability thresholds imposed by the EU legislation adopted in 2009. Scenarios were also constructed regarding the issue of non energy by-products, such lignin and glycerol. The projections (over the period 2010-2030) include the biomass energy balances, the use of resources, the land to be cultivated, the capacities and operation of existing and new biomass processing technologies, the imports of biomass commodities from the rest of the world and traded bilaterally in the EU, as well as the biomass commodity prices to be supplied to the EU in the future. The report presents four scenarios which are defined as follows:

- Scenario A1: a given demand for energy biomass/residues to be met by the model with the stand alone technologies; production of by-products is not considered as a constraint.
- Scenario A2: a given demand for energy biomass/residues to be met by the model with the stand alone technologies and the introduction of the Integrated Biorefinery; production of by-products is not considered as a constraint.
- Scenario B1: a given demand for energy biomass/residues but also specific constraints on total production of glycerol and lignin only with the stand alone technologies.
- Scenario B2: a given demand for energy biomass/residues but also specific constraints on total production of by-products with both the stand alone technologies and the Integrated Biorefinery.

The main conclusions can be summarized as follows:

- There exist sufficient biomass/residues resources to meet effectively the increased requirements of the RES and climate action policy package of the EU provided that a high portion of available land in the EU is cultivated for raising energy crops.
- The sustainability threshold exerts considerable effects on technology choice for biomass processing and drives early deployment of 2nd generation technologies.
- The 2nd generation biomass supply chain can produce considerable quantities of non energy by-products (e.g. lignin, glycerol) which are valuable components favoring economic effectiveness of new technologies.
- Within such a context of high development of new technologies, there is scope for integration and scale effects along the concept of biorefineries, which induce savings in costs and lower prices.
- Despite high demand for biomass, supply costs and prices are found to stay within a reasonable range over the projection horizon, provided that technology dynamics and scale effects develop sufficiently over the entire biomass supply chain.

Current implementation status

A primary project objective was to provide a valuable overview of existing biorefineries, pilot plants and major RTD projects in the EU. This has been used to ascertain the level of integration of operational facilities in both existing and new industry sectors. It has also been possible to provide information on a number of aspects that are relevant for policy formulation.

34 existing or planned biorefineries have been identified and classified. In addition, 45 biorefinery-related major R&D, pilot and demonstration projects have been identified in the EU.

The majority of the identified biorefineries (23 out of 34) and biorefinery projects (28 out of 45) are located in Western Europe, followed by Northern and Southern Europe. About 75% of the biorefinery sites are located in an area comprising Northern France, Germany, Denmark, Belgium, the Netherlands, and the UK. These 6 countries possess both a variety of suitable feedstocks for biorefinery applications *and* intensive (petro)chemicals production. No existing biorefineries or major R&D projects or pilot plants have yet been identified in the Eastern EU countries.

To enhance results, the identification, classification and mapping of existing biorefinery ventures in the EU was undertaken in collaboration with the Biorefinery Euroview project.

Prospects for further demonstration

The establishment of new biorefineries in a certain region will depend on numerous establishment factors such as land use in surrounding area, presence of animal husbandry, presence of oil refineries and chemical plants, and transport options. A model has been developed to help estimate the likeliness of biorefinery establishment according to a number of such key factors for all EU member states.

Whole crop biorefineries may be most likely to develop in traditional areas of wheat, potato or sugar beet production (e.g. France and Germany), near harbours, and where animal feed is required (e.g. Belgium and The Netherlands). Since wheat is more easily transported over large distances harbour areas may be favoured, whilst potatoes and beet (with higher water content) may be processed closer to harvest.

Lignocellulosic biorefineries are likely to take feedstock from straw regions (e.g. France and Germany), wood regions (e.g. Sweden and Finland), or imports. Thus, countries with large harbours and well developed oil and chemical sites (e.g. The Netherlands and Belgium) could be advantaged.

Green biorefineries will be influenced by the local availability of grass, clover and demand for animal feed. These areas can be found in the whole of Europe, but mostly in Western Europe.

It is considered that biorefineries utilising syngas could preferentially develop in very similar areas to lignocellulosic biorefineries, with an additional emphasis on existing base chemical infrastructure.

Main recommendations

Technical status

Further basic research is required for pilot plants development and installation preferred in combination with green crop drying (or other agriculture) plants for Green Biorefineries and grain processing plants for a Whole Crop Biorefineries.

- For Green biorefineries further basic research is required for pilot plants development and installation, preferably in combination with green crop drying (or other agriculture) plants.
- For Whole crop biorefineries further basic research is required for pilot plants development and installation, preferably in combination with grain processing plants.
- For LCF biorefineries further basic research is required for pilot plants development and installation, preferably in combination with forestry operations and the wood-using industries.

Industry, consumers and NGOs

Main conclusion:

- In order to generate wider support for biorefineries, interested groups (including NGOs) and the general public should be informed about the benefits of these concepts, such as effective use of resources, environmental friendly technologies and products, social and economic benefits etc. The few negative associations raised by the consumers should be also actively treated in public communication activities related to biorefineries.
- The positive characteristics of bio-based products (like “natural product”, sustainability and health benefits etc.) should form the basis for industrial product development processes and should be highlighted within communication activities

targeted to buyers of such products. Interested buyer segments (e.g. LOHAS[1]) should be addressed first but intensive marketing activities seem nevertheless to be necessary to convince them of the advantages and benefits of bio-based products.

- In this context it is suggested to create mechanisms that allow consumers to acknowledge the benefits of bio-based products, e.g. comparative studies, product benchmarking with regard to carbon footprint, systems of labelling for products manufactured locally. Environmental advantages of products from biorefineries could be acknowledged by establishment of a labelling system for bio-based products. Furthermore, public procurement can take a lead in the use of bio-based products, for example by changing the rules of public tenders in the construction business.

Rural development, employment and environment

Currently economic drivers such as low transport costs, biofuels subsidies and limited markets for advanced bioproducts are directing investment towards biorefineries that do not account for ecosystem services and other environmental goods.

- It is recommended that measures are taken to embed factors relating to long-term sustainability (e.g. biodiversity, GHG emissions and agricultural practices) in decision-making processes.
- Environmental advantages of products from biorefineries should be acknowledged for example by establishing of a labelling system for bio-based products (similar to ‘Der Grüne Punkt’ for packaging, which has an awareness rating of 98 % in Germany, and is also one of the best-known trademarks worldwide). If possible this system should be financed on the basis of the ‘polluter-pays principle’ where a ‘polluter’ is a company which does not use bio-based materials in their manufacturing, because it still prefers petroleum-based components or agricultural enterprises which uses synthetic fertilizers instead of natural ones.
- The environment (and sustainability aspects), in addition to the economics, should be prioritised as primary drivers of individual biorefinery establishments.

Policy legitimacy

An interactive process of building understanding and acceptance between policy and entrepreneurial actors can already be observed for biorefineries in Europe.

- Understanding could be enhanced via the open gathering and dissemination of information on the technical benefits – and tradeoffs – of advanced bioenergy concepts in key areas such as land utilisation, energy carrier and chemical lifecycle performance. This information should be presented in forms suitable for a range of social stakeholders.
- Acceptance could be improved by development of common and transparent strategies for communicating the technical complexity, and the potential trade-offs or radicalism in the ‘difficult’ areas such as GMOs. Areas where contentious issues are already present in biomass feedstock streams, or where associated products such as food/feed or pharmaceuticals may be affected might be prioritised.

[1] LOHAS (Lifestyles of Health and Sustainability) is a specific market segment related to sustainable and healthy living. Generally LOHAS are relatively upscaled and well-educated. Experts class as LOHAS e.g. about 30% of US or 15% of German consumers

- Understanding and acceptance could be further facilitated by the encouragement of intra-industry relationships and trade associations with the role of supporting the progress of advanced bioenergy.

Implications of policies

- Research and development (R&D) in relevant science fields should be secured and supported over the long-term. Additional attention should be given to reinforcement and technology transfer. One example of such reinforcement is greater involvement of industry, especially small and medium size enterprises (SMEs), in research activities. Shifting to demonstration, measures should be taken to streamline funding for the development of demonstration plants that is available at national and regional levels for public-private partnerships (PPPs) and define simple guidelines for industry to apply for these funds.
- To facilitate the development of a competitive bio-based economy in Europe, real integration and coordination of the existing policies is critical. Moreover, long-term policy and regulatory certainty should be pursued to support the continuous development and investment in biorefinery technologies and infrastructure, as well as harmonisation of regulatory policy between Member States and at the EU level. For increased effect, such policy measures should also focus on the uptake and demand for bio-based products.
- Agricultural policy: Measures need to be undertaken to allow analysts to better take into account factors such as competition with food and relative price elasticities, the stimulus provided by renewable energy targets, and the competition and synergies with demands from existing biomass based industries. With the on-going health check of the Common Agricultural Policy (CAP) work should be performed to review aid schemes (starch refund, sugar regime, use of set-aside land for energy crops) not only to meet bioenergy requirements but also to secure feedstock supply for bio-based products.
- Energy policy: In order to support policy initiatives such as the Biomass Action Plan (BAP), when these plans are drawn up they should take into account the production of not only food/feed and energy but also fibres, biochemicals and biomaterials. National BAPs that coherently represent the sum of biomass plans at regional levels should also be pursued.
- Environmental policy: The Environmental Technology Action Plan (ETAP) should be translated into action in more areas if it is to have an impact. As one example, recognition of the special inherent characteristics of biorefinery outputs such as bio-based plastic feedstocks should be pursued. The Integrated Pollution Prevention and Control (IPPC) directive could also be used to encourage the use of alternative and more benign processes such as biological processes.
- Facilitating Market Development and Access: Supplementary measures and incentives are deemed crucial to reduce barriers to the establishment of a European bio-based economy. Options to pursue the development of standards and labels that can establish, demonstrate and communicate the specific characteristics of biorefinery products should be supported. The industry should be directly involved in the development of methodology to ensure their practical applicability – however, it appears both prudent and desirable that third party scientific oversight is included so as to maintain the transparency of such processes.

- Finally, the support of communication and dissemination efforts concerning the introduction of bio-based products is recommended. It is also important to create a forum for collecting user feedback on the use of bio-based products and to follow-up the development of new products, in particular those from small companies. Eco-efficiency labelling and defining bio-based products and their properties will likely form an integral part of communicating the benefits of such products.

Current implementation status

- It is recommended to formulate and implement EU wide targets for bio-based products and to promote the production and application of bioproducts by following the recommendations of the current study and from a part of the lead Market initiative e.g. on the development of sustainability and product standards, eco-labelling, Green Public Procurement Policies (based on LCA) and dedicated communication. These instruments should be further elaborated in cooperation with industrial partners and other stakeholders.
- At present the available potential assessments and scenario studies for bio-based products mostly address national markets of (some) EU countries. Studies on the European level are lacking. It is recommended to perform a strategic scenario study at the EU27+ level and to develop a European Roadmap or Strategic Research Agenda on Biorefinery.
- The Biorefinery concept has a substantial potential for the economy and sustainable development of Europe. Investigation of the possibilities for establishing a dedicated European platform for the promotion and coordination of Biorefinery development, including participation by industry, R&D and other stakeholders, is recommended. Such a concerted action on biorefineries should be developed in cooperation with running initiatives including SusChem, EpaBio, KBBE, The Lead market Initiative and IEA task 42.

Prospects for further demonstration

- The following general recommendations could help the establishment of biorefineries: improve regulations, improve profitability (cut costs, increase revenues), solve technological issues, improve image of biorefineries and tackle food and feed issue.
- Establishment and type of biorefinery should depend on the local circumstances (establishment factors). The North of Europe could attract more chemical industry to increase the efficiency of their lignocellulosic biorefineries. This way, the presence of lignocellulosic biorefineries could become an establishment factor for the chemical industry instead of the other way around. In the East of Europe the agricultural yield could be increased. This would also increase the likeliness of biorefinery establishment in this region.

1. Introduction

The European Commission's Biomass Action Plan (2005) highlighted the importance of the biorefinery concept to maximise the value derived from biomass feedstocks by making full use of their components. The potential for improving the cost-efficiency of biofuels using biorefineries is an area of much research and discussion worldwide. However, there remains some uncertainty over how biorefineries can be defined and promoted at a policy level, how biorefinery concepts can be attractive to the market, and how the technologies will develop and be introduced.

BIOPOL is a two-year research project funded by the European Commission since 2007 through the Sixth Framework Programme. The overall goal of BIOPOL is to assess the status (technical, social, environmental, political, and implementation) of innovative BIOrefinery concepts and the implications for agricultural and forestry POLicy. The main objectives of the BIOPOL project per research theme are given in Table 1. Biorefinery concepts are aimed at relevant market-competitive and environmental-friendly synthesis of bio-products – chemicals and/or materials – together with the production of secondary energy carriers – transportation fuels, power and/or CHP. BIOPOL was conceived to address the fact that the wider expectations for biorefineries have not yet yielded clear definitions for biorefinery concepts, or an understanding of the current status and prospective benefits of biorefining in Europe. Therefore the BIOPOL project was designed to assess the current status of biorefinery activities in Europe and explore future scenarios for development. By systematically accounting for potential technical, political, social and industrial impacts of such scenarios their outputs will be utilised to inform policy formulation in this area. By drawing from several complimentary research disciplines the insights gained will be able to inform EU policy-making and help frame future research directions both in Europe and elsewhere.

BIOPOL is engaging research institutions from Germany, Greece, the Netherlands, Poland, Sweden, and the UK. Consortium members are:

- Wageningen University and Research Centre (A&F, Agrotechnology & Food Sciences Group) – The Netherlands
- Research Institute Biopos e.V. - Germany
- Imperial College London (ICEPT, Centre for Energy Policy and Technology) - UK
- Lund University (IIIEE, International Institute for Industrial Environmental Economics) - Sweden
- Institute for Fuels and Renewable Energy – Poland
- Energy research Centre of the Netherlands (ECN) – The Netherlands
- University of Applied Sciences Weihenstephan – Germany
- National Technical University of Athens (ICCS, Institute of Communication and Computer Systems) – Greece

Table 1. Main BIOPOL objectives per research theme.

Theme	Objectives
Assessment of technical status	• To analyse ongoing RTD activities. • To assess the development of the biorefinery concept. • To model the Whole Crop Biorefinery concept for three classes of raw materials: carbohydrates, oils, and fibres (including forest biomass).
Assessment of social and environmental implications	• To assess the market acceptance for the biorefinery concept amongst industry, consumers and NGOs. • To show the impacts for rural development, employment, and environment.
Assessment of political aspects	• To assess market acceptance for the biorefinery concept amongst policy makers. • To visualize the implications of Global and EU policy, such as: biofuel directives, climate change, oil price, and agricultural (sugar, starch, oilseeds etc) reform on biorefinery viability. • To indicate the implications for possible agricultural regulations.
Review of current implementation status	• Identification, classification and mapping of existing EU biorefineries. • To quantify the current processing potential of existing facilities.
Prospects for further demonstration	• To point out the potential and costing for the introduction of pilot or demonstration plants a) alongside existing facilities and b) for the implementation of new plants. • To co-operate with ongoing EU Technology Platforms.
Dissemination of results	• To disseminate the results of the project.

The activities within the BIOPOL project were subdivided in separate, but strongly integrated, Work Packages, for which the main results are all presented in this report:

- WP1 Assessment of technical status (chapter 2)
- WP2 Assessment of social and environmental implications (chapters 3 and 4)
- WP3 Assessment of political aspects (chapters 5, 6 and 7)
- WP4 Review of current implementation status (chapter 8)
- WP5 Prospects for further demonstration (chapter 9)
- WP6 Dissemination of results (chapter 11)

The current status of the most important aspects of the biorefinery concept was assessed in WPs 1, 2 and 3. WP1 assessed the technical development status of the biorefinery concept. The current knowledge on the “green” and the “whole crop” biorefinery concepts was described in models. WP2 dealt with the acceptance of the biorefinery concept among industrial actors, consumers and NGO’s. Furthermore, it studied the impacts on rural development, employment and the environment. WP3 assessed the political legitimacy of biorefineries and gives the implications of renewable policy, forestry policy and agricultural policy for biorefinery. Also, a scenario based analysis for the period 2010-2030 was made for different theoretical levels of biorefinery implementation. After this theoretical assessment of the biorefinery concept, WP4 reviewed the practical implementation status of the biorefinery concept in Europe. Existing EU biorefineries have been identified, classified, and mapped.

Additionally, the current processing potential of existing facilities has been estimated. This was followed by an assessment of the future prospects of the biorefinery concept in WP5. In WP6 the results of the project were disseminated in presentations via two public workshops, a range of publications in the academic and non-academic press, and the publishing of public BIOPOL deliverables on the internet (www.biorefinery.nl/biopol).

Finally, it should be emphasized that part of the results were obtained in close cooperation with the Biorefinery Euroview project, which was also funded by the European Commission. This is especially relevant to the work on the implications of renewable policy, forestry policy and agricultural policy for biorefinery and for the identification, classification, and mapping the existing EU biorefineries. However, in general there has been a good cooperation that resulted in the organisation of two workshops, BioreFuture 2008 and 2009, to disseminate the results of both projects.

2. Technical status

2.1. Definition of the term biorefinery

The young research area of “Biorefinery Systems”, in combination with that of “Bio-based Industrial Products”, is still, in various respects, an open and emerging field of knowledge. This is reflected in the search for an appropriate definition that allows actors to unite around a common cause, but does not exclude some potential technical configurations and their proponents. A selection of suggested definitions is given below.

Biorefining is not a novel concept itself, having been used in the literature since 1981 to refer to the conversion of biomass to liquid fuels and organic chemicals (Levy et al., 1981). However, more recent concerns about industrial sustainability have coupled with technical advances in biotechnology and related fields to produce a number of realistic opportunities for biorefining to be used commercially to manufacture a range of bio-based products. The term “Green Biorefinery” was defined in Germany in 1997 as representing “complex (to fully integrated) systems of sustainable, environmentally and resource-friendly technologies for the comprehensive (holistic) material and energetic utilization, as well as exploitation of biological raw materials in the form of green and residue biomass from a targeted sustainable regional land utilization” (Kamm et al., 1998). The original term used in Germany “complex construction and systems” was substituted by “fully integrated systems”. The US Department of Energy (DOE) uses the following definition: “A biorefinery is an overall concept of a processing plant where biomass feedstocks are converted and extracted into a spectrum of valuable products. Based on the petrol-chemical refinery” (Kamm et al., 2006a; Kamm et al., 2007). The American National Renewable Energy Laboratory (NREL) published the definition: “A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. The biorefinery concept is analogous to today's petroleum refineries, which produce multiple fuels and products from petroleum. Industrial biorefineries have been identified as the most promising route to the creation of a new domestic bio-based industry” (Kamm et al., 2006a; Kamm et al., 2007).

In general there is agreement that biorefining is the transfer of the logic and efficiency from the today’s substantial manufacturing industries, especially the chemical and energy industries, to the biomass processing industry (Kamm et al., 2007). The broad biorefinery definition that has been adopted in this BIOPOL-project (according to the IEA-Task 42 Biorefinery, www.biorefinery.nl/biopol) is as follows:

> ‘Biorefinery is the sustainable processing of biomass
> into a spectrum of marketable products including energy’

A distinction can be made between three phases of biorefineries:

- Phase-I biorefineries;
- Phase-II biorefineries;
- Phase-III biorefineries.

An example of the type “phase-I biorefinery” is a dry milling ethanol plant. It uses grain as a feedstock, has a fixed processing capability, and produces a fixed amount of ethanol, feed co-products, and carbon dioxide. It has almost no flexibility in processing. Therefore, this type does not meet the BIOPOL definition, and can thus be used for comparable purposes only.

An example of a type “phase-II biorefinery” is the current wet milling technology. This technology uses grain feedstock, yet has the capability to produce a variety of end products depending on product demand. Such products include starch, high-fructose corn syrup, ethanol and corn oil, plus corn gluten feed, and meal. This type opens numerous possibilities to connect industrial product lines with existing agricultural production units. “Phase-II biorefineries” are, furthermore, plants like NatureWorks PLA facility (Kamm et al., 2006a; Kamm et al., 2007) or ethanol biorefineries, for example the Abengoa wheat straw to ethanol plant or the Icelandic Alaska lupine-straw-to-ethanol plant.

Advanced biorefineries, so called “phase-III biorefineries”, are viewed in this project as an ultimate objective. They are considered to a mixture of biomass feedstocks to produce multiple products using a number of separate technologies (Kamm et al., 2007). Such biorefineries are yet to be constructed but it is anticipated that either agricultural or forest biomass would be most suitable in Europe. Product streams could include ethanol for fuels, chemicals, and plastics (Kamm et al., 2006a; Kamm et al., 2007).

2.2. Current status of the industrial implementation of biorefinery plants

The production of bio-based products could employ methods and processes arising from work on physical, chemical, biological and/or thermal technologies. Each of these is to some degree currently under development in different initiatives. For this reason a profound interdisciplinary cooperation of various disciplines in research and development is highly desirable. Thus, those working in the field have begun to analyse which combinations might be able to deliver advanced and flexible biorefinery designs whilst still meeting environmental and commercial criteria. These exercises can be referred to by the term “biorefinery design”. Biorefinery design means: bringing together smart scientific and technologic basics with practical technologies, products and product lines in novel biorefinery concepts. Special attention is given to the energy balances of the conversion processes and the integration of chemical and biotechnological processes.

In 2007, four complex biorefinery concepts were clearly distinguished in the research literature (Figure 1) (Kamm et al., 2006a; Kamm et al., 2007):

1. Green Biorefineries: using 'naturally-wet' biomass such as green grass, alfalfa, clover, or immature cereal (Kromus et al., 2006).
2. Lignocellulosic Feedstock Biorefineries: using 'naturally-dry' raw materials such as cellulose-containing biomass and residues (Koutinas et al., 2006).
3. Whole Crop Biorefineries: using all available elements of raw materials such as cereals or maize (Kamm et al., 2006b).
4. Two Platforms Biorefineries: combine a sugar conversion platform and a syngas platform (Werpy & Petersen, 2004).

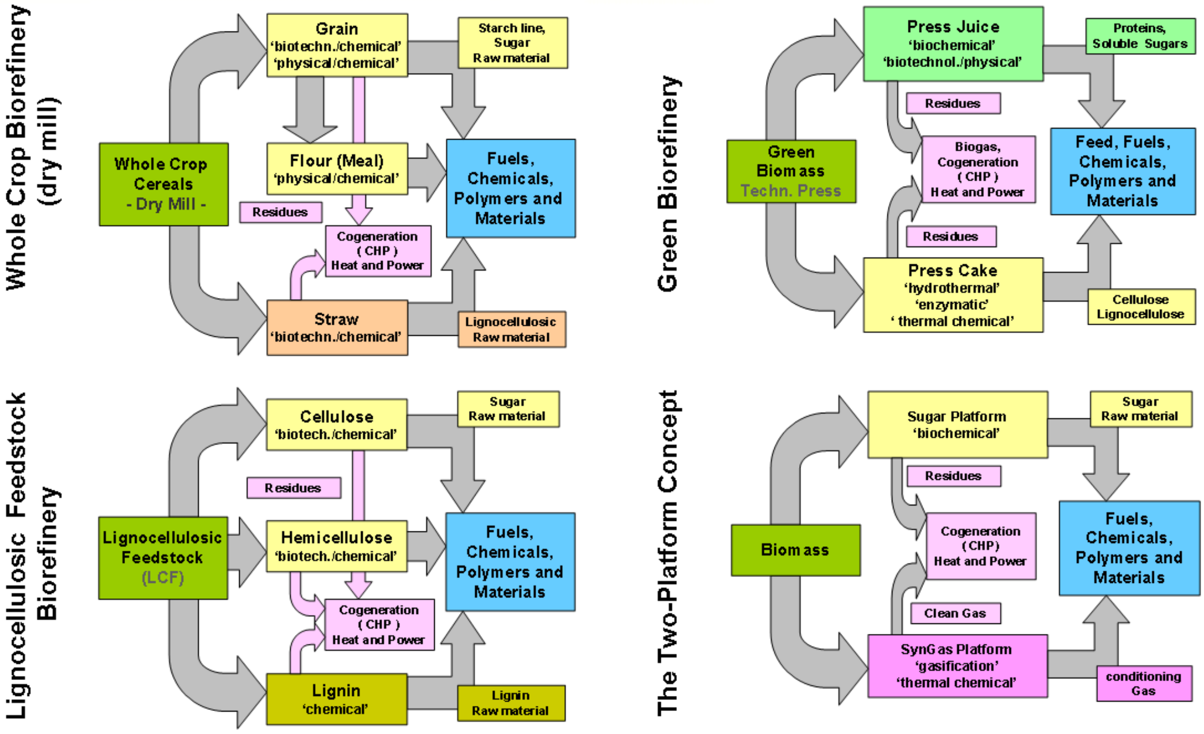

Figure 1. Diagrammatic representations of the four biorefinery concepts.

2.3. Biorefinery development

2.3.1. Biomass, platform chemicals, syngas, lignocellulose, carbohydrates

It is necessary to develop new biorefinery platform technologies, such as:

1. Lignocellulosic Feedstock (LCF) pre-treatment: efficient separation of the LCF into lignin, cellulose and hemicellulose,
2. Advancement of thermal, chemical and mechanical processes, such as new decomposition methods, gasification (syngas) and liquefaction of biomass.
3. Advancement of biological processes (biosynthesis, e.g. Bacterial starch and cellulose decomposition).
4. The combination of substantial conversion processes (such as biotechnological and chemical processes).
5. Cereal whole crop biorefinery concept, which includes platform technologies.
6. Green Biorefinery concept, which includes platform technologies.

2.3.2. Technical and energetic consideration of biorefining

Special attention was given to the combination of physical and biotechnological processes for production of proteins as well as three potential platform chemicals: ethanol, lactic acid and lysine. The mass and energy flows (steam and electricity) of the biorefining of green biomass into these platform chemicals, plus proteins, feed and biogas from residues, are given in the following sections (Kamm et al., 2009). A similar technical description of the whole crop biorefinery utilising corn and straw is also presented (Schönicke & Kamm, 2009).

2.4. Modelling Biorefinery concepts

2.4.1. Green Biorefineries

The advantages of Green Biorefineries are a high biomass yield per hectare and a good integration with existing agricultural production processes. In addition, the price of the raw material remains low. Green biomass is mainly produced in the form of green crops, for example grass from cultivation of permanent grass land, closure fields, nature protected areas or green crops, such as lucerne, clover and immature cereals from extensive land cultivation. This concept benefits from the use of simple basic technologies can be used to generate intermediates with an excellent biotechnological and chemical potential for further conversion. On the other hand, fast primary processing or the use of preservation methods such as silage or drying are necessary, both for the raw materials and the primary products. Each preservation method alters the composition of the materials.

Green Biorefineries are multi-product-systems. The different products can be aligned with the physiology of the corresponding feedstock, which contains components that are naturally active and, in many cases, directly fit for an industrial application.

The following example taken from Kamm et al. (2009) shows how a Green Biorefinery could be configured that is producing lactic acid:

Green Biorefinery		**Lactic acid**	
Input:		quantity	unit
green biomass (lucerne, clover, grass)	DM: 20 %	40 000	t
steam		2 268	GJ
electricity		1.3 Mio	kWh
Output:			
silage fodder	DM: 40 %	13 000	t
fodder-protein 80 %	DM: 90 %	400	t
cosmetic-protein 90 %	DM: 90 %	29.6	t
lactic acid 90 %	DM: 90 %	660	t
residue to biogas plant TS: 2 %		17 690	t
single cell-biomass (as fodder-protein 60 %)	DM: 90 %	33	t

2.4.2. Whole Crop Biorefinery

Whole Crop Biorefineries are similar in concept to Lignocellulosic Feedstock Biorefineries, but could also convert grain that is unusable for food and feed into saleable products. In the calculations it was assumed only to convert the straw. An additional input of grain would be possible without bigger effort, but here it will not be tried to use the grain for food and feed aims. The two-stage straw-pulping takes place as in the Lignocellulosic Feedstock Biorefinery, but next to the cellulose in this scenario the pentoses are also fermented to ethanol and CO_2. The following example from Schönicke & Kamm (2009) shows how part of a Whole Grain Crop Biorefinery could be configured:

Whole Grain Crop Biorefinery (unit: straw)				
Input:		quantitiy	unit	
electricity		47 600	MWh	
steam 155°C	5 bar	262 080	t	552 720 GJ
straw (of grain+corn)	TS=95%	320 000	t	
water		504 320	t	
conz. Sulfuric acid		12 960	t	
lime (CaO)		6 560	t	
nutrients		3 840	t	
Output:				
ethanol 96%		89 600	t	
lignin	TS: 95%	96 168	t	
CO_2		72 000	t	
cell-biomass (60% protein)	TS: 90%	4 480	t	
gypsum	TS: 50%	35 360	t	
water of process	TS: 7.5 %	812 152	t	
warmth of fermentation		171 403	GJ	

2.5. Recommendations

Further basic research is required for pilot plant development and installation. For Green biorefineries further basic research is required for pilot plants development and installation preferred in combination with green crop drying (or other agriculture) plants. For Whole crop biorefineries further basic research is required for pilot plant development and installation preferred in combination with grain processing plants. For LCF biorefineries further basic research is required for pilot plants development and installation, preferably in combination with forestry operations and wood-using industries.

3. Acceptance of biorefinery concepts amongst industrial actors, consumers and NGOs

3.1. Introduction

This chapter deals with the market acceptance of biorefinery concepts amongst industrial actors, consumers and NGOs. The first section focuses on industrial actors and the second on consumer acceptance of biorefineries and bio-based products. The visions of NGOs are described in the third section before a concluding section containing several recommendations for future action.

3.2. Acceptance of biorefinery concepts amongst industrial actors

A literature overview of market introduction and development of biorefinery concepts in industry was delivered within deliverable D.2.1.1[2] following intensive desk research. From this the focus was set on four economically important and promising industry sectors which could potentially introduce and develop successful biorefinery concepts and their related products on to the market. These were: the chemical industry, the pulp and paper industry, the starch and sugar industry, and the biofuels industry. After describing the structure of each of these industry branches by giving an overview of its size, production, actors, or employment, the current activities with respect to the four biorefinery concepts and bio-based products were investigated.

This investigation (deliverable D 2.1.3[3]) involved empirical inquiries that focused both on quantitative and qualitative perspectives. Within the quantitative part the market acceptance of the industry was analysed for 2007/2008 using a standardised questionnaire-based survey among (potential) industrial actors. The first results of this survey were presented and further discussed in different sessions of the BioreFuture 2008 workshop on 12 February 2008 in Brussels.

Although the absolute number of 110 companies headquartered in Western Europe (in particular in Germany, The Netherlands, and in France) that responded to the industry survey is considered sufficient, the corresponding response rate is only 4.8% and thus relatively poor. Nevertheless this survey provides valuable information about firms that could be associated with, or are interested in, biorefineries in the EU. Most of the companies that participated in the survey belonged to the chemicals or biofuels industries. The high response of companies being active in these fields could be an indication that biorefinery concepts are especially interesting for these sectors, indicating potential technical and business opportunities.

[2] D 2.1.1: Note on literature overview concerning the market introduction and development of biorefinery concepts and related products

[3] D 2.1.3a: Report on market acceptance of biorefinery concepts amongst industrial actors; D 2.1.3b: Report on market acceptance of biorefinery concepts amongst consumers

Approximately one third of the respondents already received over 80% of their turnover from biomass-derived products in 2006. Moreover, some companies intend to enter the field in the next five to ten years since they plan to produce bio-based materials, for example biopolymers. With respect to co-products it is noticeable that many companies do not currently valorise their by-products at all. Obviously, there exists further potential application fields for the use of by-products and enhancement of productivity within these companies in the future. 60% of respondents actually have a separate R&D-department dealing with biomass. Most of the ongoing R&D projects, however, are in an early stage of development (laboratory or pilot phase).

The surveyed companies show an overall positive attitude towards biorefinery concepts with 80% of the interviewed companies agreeing that biorefineries are promising concepts. This positive attitude was observed in all relevant sectors, although the chemical industry was noticeably less optimistic than the other branches surveyed.

Advantages attributed to biorefinery concepts arise mainly with respect to decreasing imports, regional economic benefits, ecological factors, and the opportunity to enter new markets. In particular, factors with respect to regional value chains and local raw material basis are mainly evaluated as positive aspects, while factors relating closely to investment costs, technology, and, especially, feedstock quality are estimated as drawbacks of biorefining. Technology and consistency of feedstock are therefore potentially crucial R&D areas for the implementation of biorefinery technologies. According to the opinion of interviewed companies, “sustainability” aspects are also important for biorefinery concepts. This positively evaluated aspect associated with biorefineries is identified as a fundamental competitive advantage of these technologies and as such confers the opportunity to distinguish firms entering this area from competitors through relevant marketing strategies.

Industrial respondents perceive economic and market issues as particular barriers of biorefinery concepts, which is typical for innovations in early stages. Interviewees indicated also that some of the established regulations do not fit with novel biorefinery concepts. To gain a clear picture of specific problems of different sectors at this point further investigations would be necessary.

For a wider adoption of biorefinery concepts industrial interviewees stated numerous different efforts as being necessary. These included R&D activities, feedstock availability, marketing and market, knowledge transfer, skills and industrial interest, as well as financing. Figure 2 illustrates the responses of the different industry sectors with regard to these issues. Since all these issues are evaluated as necessary this indicates that a series of activities ought to be established to some extent in almost all relevant fields in the years to come.

In addition to the described quantitative surveys, interviews with employees of selected firms and representatives of industrial associations were performed in April and May 2008 to broaden the scope of the questionnaire-based survey. The topics of the interviews comprise the following: relevant sectors for introducing biorefinery concepts; raw materials used for biorefinery concepts; attitudes towards biorefinery concepts; advantages and disadvantages of biorefinery concepts; barriers to the development of biorefinery concepts (according to the different sectors); necessary actions to accelerate the development of biorefinery concepts.

Interviewees showed differing opinions in response to these issues, but in general there was agreement with the results of the quantitative survey.

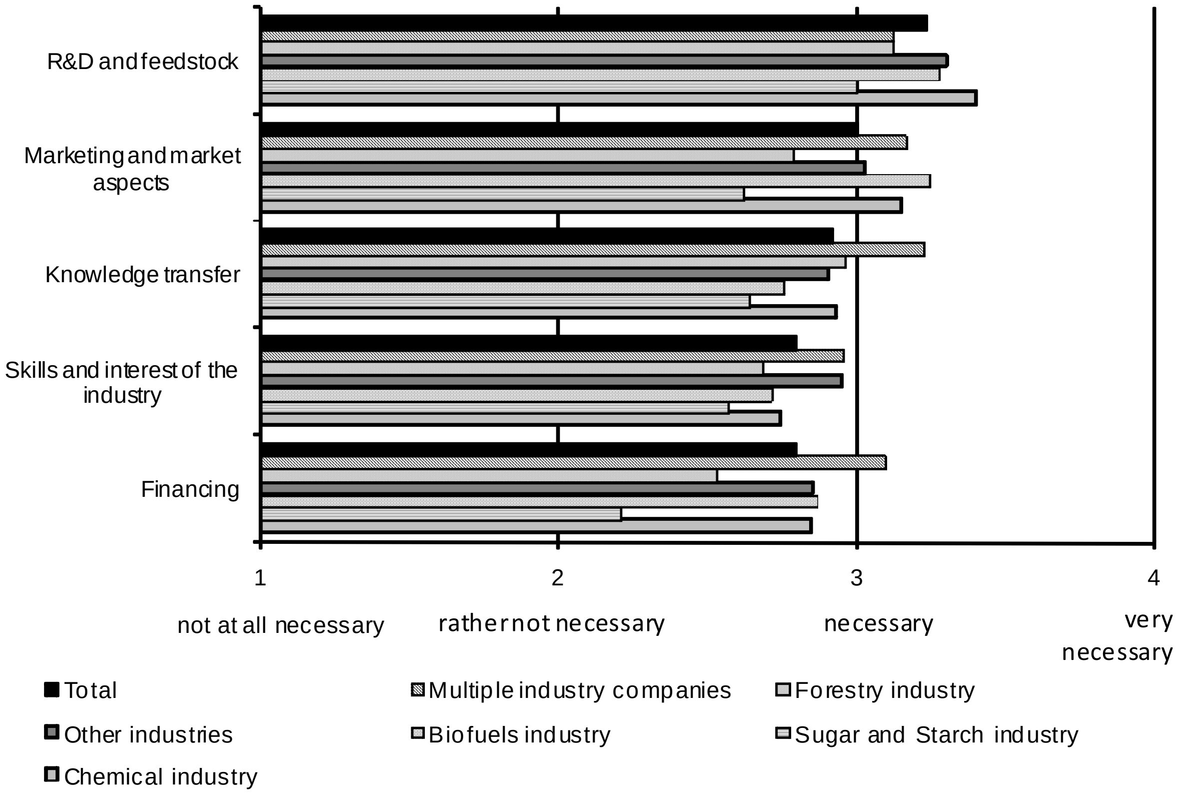

Figure 2. Necessities for accelerating the adoption of biorefinery concepts (Source: Inquiry of University of Applied Sciences of Weihenstephan 2008).

3.3. Acceptance of biorefinery concepts amongst consumers

The second part of the investigation dealt with the results of a survey of consumers, who would be the main purchasers of end-products from biorefineries. Consumer chemicals (e.g. soaps, detergents, perfumes, or cosmetics) for instance represented approximately 10.8 % of total EU chemicals sales in 2007 and their raw materials (e.g. amino acid, lactic acid, or glycerol) are currently accessed from biomass raw materials and are identified within the four biorefinery concepts.

The market acceptance of consumers was analysed by means of a widely distributed standardised questionnaire in a similar manner to the survey of industrial actors. People in the 6 European countries active in the BIOPOL-project (Germany, Greece, The Netherlands, Poland, Sweden, and UK) were surveyed using a postal questionnaire. 682 consumers (response rate of ca. 10%) answered the questionnaires and form the basis of the statistical analysis. The reason for a relatively large part of respondents with higher education levels (62% with university degree or higher) in the survey could be due to the fact that the questionnaire was relatively long and was about the products of a new and innovative technology concept.

Firstly, consumers' general attitudes towards biorefinery concepts and their opinions towards different issues (e.g. their economic viability or local impacts) were considered. It can be concluded that no strong public opposition of biorefinery plants in the 6 surveyed countries should be expected due to a (very) positive assessment of biorefineries by respondents. The eco-friendliness and the positive economic effects of biorefinery concepts were especially assessed positively (see Figure 3) and could therefore be faithfully highlighted by proponents of biorefineries in public communication activities. Since some issues (e.g. monocultures in agriculture, loss of biodiversity, rising food prices) were negatively estimated, there is a suggestion that positive actions by industrial and political actors to concentrate on how biorefineries could overcome some of these problems through demonstration plants and public communication of sustainability standards.

After dealing with biorefineries the survey focused on consumer products that can be manufactured as final products or from intermediates from biorefineries. Since experts consider bioplastics as products with high market potentials for the near future, products like biomass-derived cutlery, toys, or packaging materials were investigated. Respondents were asked to assess the importance of different attributes when purchasing bioplastic products. The results were sought in order to help direct strategies and marketing activities of all actors in the biorefinery community (e.g. product policy or promotion). Three issues emerged as being the most important: environmental impact, resource conservation and health. The ecological motivation seems to be the most important reason when consumers purchase bioplastic products. The conservation of resources for future generations ("sustainability motive") is also a highly important motive for buying bioplastic products. The third, and perhaps surprising, motive that could motivate consumers to buy bioplastic products is "reasons of health". Therefore the success of these products may be assisted by their ability to match public criteria. Furthermore, it is found that especially interested buyer segments (in particular LOHAS[4]) should be addressed primarily.

Additionally, the survey comprised consumers' knowledge about bio-based products and biorefinery concepts. In general, it can be detected that the majority of consumers do not know much about bio-based products. Questions about policy were also answered especially poorly.

Consumers' buying frequency of bio-based products was surveyed. At this point it can be perceived that a market for bio-based products does partly exist and consumers are actually willing to buy some bio-based products. Besides, the greater proportion of non-purchasers represent (high) market potentials for bio-based products for which intensive marketing activities are required to partly convince these consumers.

[4] LOHAS (Lifestyles of Health and Sustainability) is a specific market segment related to sustainable and healthy living. Generally LOHAS are relatively upscaled and well-educated. Experts class as LOHAS e.g. about 30% of US or 15% of German consumers

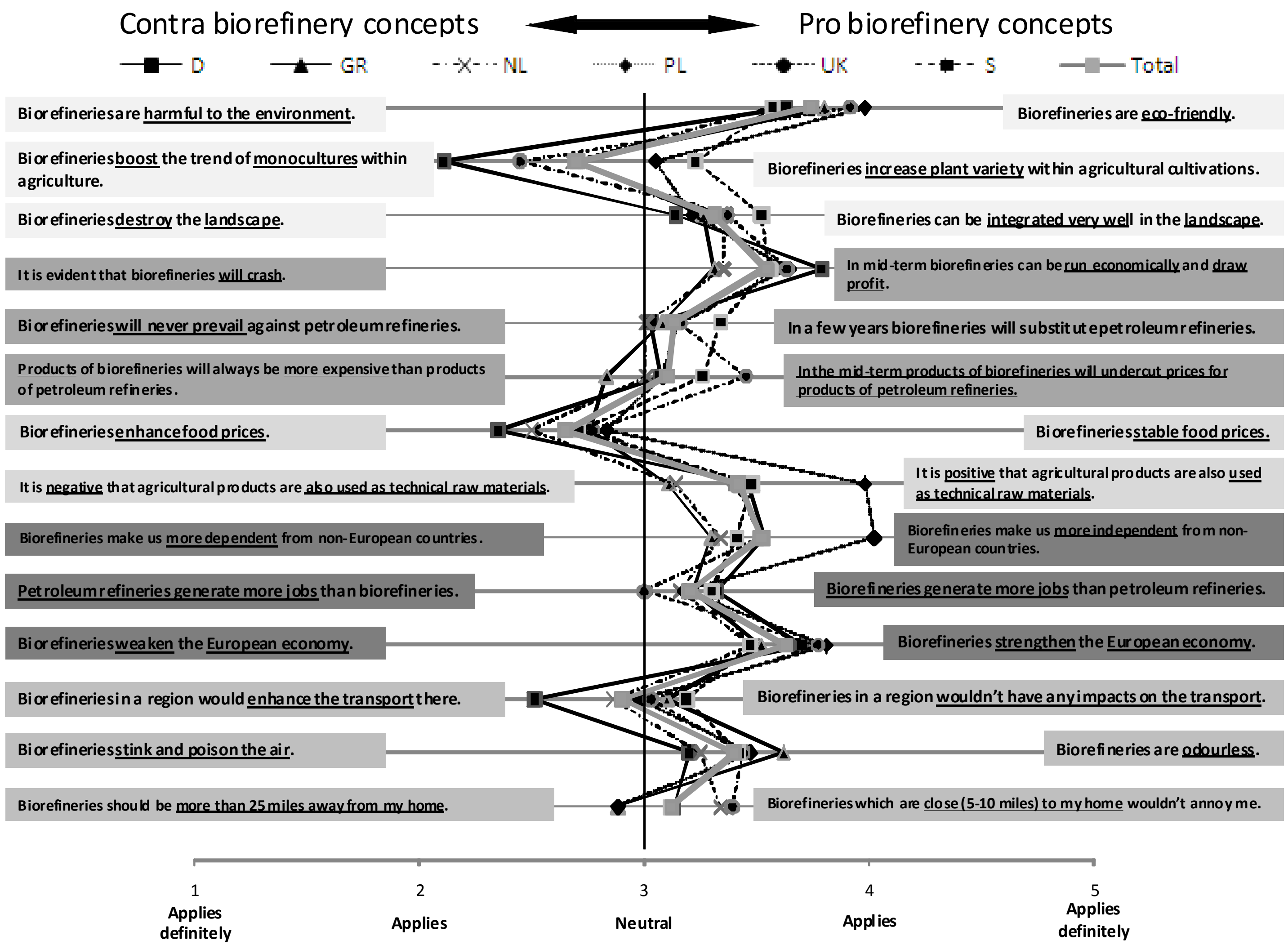

Figure 3. Attitude of partial aspects of biorefinery concepts.

Finally, consumers' willingness to pay (WTP) for bio-based products was examined showing that respondents tend to pay only a limited price premium for the surveyed biomass-derived products (washing-up liquid and shampoo). However, some buyer segments could be identified within the sample that might be willing to pay extra high prices (in particular LOHAS). As a comment on marketing strategy, these interested buyer segments might be addressed first. However, intensive marketing activities appear necessary to convince them of the full range of advantages and benefits of bio-based products.

Positive WTP on the demand side can be interpreted as a positive signal for industrial actors concerned about the lack of established markets for bio-based products. Current barriers/problems of (potential) biorefinery operators (like e.g. high investment costs for biorefinery plants or high prices for biomass-derived raw material) could be partly compensated by relatively higher sales revenues in future.

3.4. Acceptance of biorefinery concepts amongst NGOs

NGOs are important stakeholders for the acceptance of the Biorefinery concept and the future implementation of biorefineries in Europe. ECN has conducted a survey among NGOs in the 6 participating EU countries to learn their view towards biorefinery concepts.

A questionnaire-based survey was performed via e-mail, directed at 14 NGOs from Germany, Greece, the Netherlands, Poland, Sweden and the UK, complemented with telephone follow-up and (limited) desk study. 7 NGOs responded either by filling in the questionnaire (fully or partially), discussing their views by telephone, or by sending their organisation's vision documents on biomass, the EU renewable fuel targets, and future energy supplies.

Overall, the involvement of the consulted NGOs in the bio-energy field covers the aspects of trade issues, environmental issues, social standards and alleviation of poverty, sustainable chemistry, and bio-energy technology projects. It can, therefore, be concluded that the NGO sector is actively monitoring the developments in the field, and is actively pursuing to influence developments, and anticipating future developments. In addition, in some cases NGOs actually participate in renewables projects. The involvement of consulted NGOs in the biorefinery field thus far is clearly lower. More than 60% of the respondents are either not involved, or are currently developing their position on biorefinery. The latter group indicated an interest in being further informed about biorefinery developments. NGOs that are already involved in the field have their main interests in trade issues, gasification projects for CHP/biofuel (and potentially syngas-to-bio-based products) applications. Some NGOs express doubts whether the biorefinery concept will indeed be the panacea as hoped for by some, although they find the concept an interesting approach, that should be further developed.

Biomass for heat and electricity offers, according to respondents, many advantages: security of supply, growth and jobs, and reduced GHG emissions. The transport sector in the EU faces particular challenges in terms of reducing GHG emissions and dependency on imported oil. Increased use of biomass is a key to the transport sector's contribution to meeting these challenges. Policies must be put in place to ensure that the biomass for the range of end-uses is produced sustainably, and work should go forward to replace the use of fossil fuel in the longer term. There are concerns about the development of an infrastructure with no guarantee for sustainable supply of feedstocks. The EU must ensure that transport emissions reductions do not come at the expense of poor people's livelihoods. To do so, the EU must develop social standards (in addition to environmental standards), which apply to all biofuels, irrespective of their origin. In addition the EU should develop mechanisms by which the 10% biofuels target could be appropriately revised if it is found to be contributing to the destruction of vulnerable people's livelihood. With the aim of making better use of renewable raw materials than has been done before, processes for the production of second-generation biofuels (biomass gasification followed by BTL technology, enzymatic production of bioethanol and other compounds which are better suited as biofuels than bioethanol, e.g. biobutanol) are advocated.

The biorefinery concept is supported by NGOs as a way of harnessing the earth's biomass resources in a more efficient way. Biorefineries provide conversion of feedstock into a range of co-products and added-value products from one site, leading to better site/land/feedstock utilisation, better energy consumption and reduced GHG emissions from processing and transport. Benefits are anticipated, including improvement of economic viability, biofuel sustainability, use of by-products, and R&D results from the chemical sciences. However, disadvantages were also mentioned, including possible problems in case of extended land use for biomass production (e.g. forest areas, wetland habitats, etc.), and probably negative impacts in foods availability (fuel versus food).

Biorefining is seen as an important tool for regional development, maximising the social and economic benefits in rural areas. Concerning the employment and environmental aspects, new jobs, positive environmental impacts (none or limited wastes, useful by-products with energy/CO_2 emissions saving) are expected. The technology used is an important parameter for the economy of scale, as well as the logistics in collection and transport of the biomass. For some technologies and types of biomass, local and medium-sized biorefineries would be considered. Subject to scale limitations, biorefineries can provide better energy consumption and lower GHG emissions than other process routes. In general, taking into account the figures of market demands, it seems that regional industrial complexes would be more attractive.

Biomass production should follow the rules of sustainability. Decisions and policies that would lead to very intensive production in a short-term time horizon should be avoided. It is recommended to address sustainability by using guidelines similar to those set out in the UK's "Renewable Transport Fuel Obligation Technical Guidance on Carbon and Sustainability Reporting" (RFA, 2008). An EU-level standardisation and certification scheme, as proposed in the recent EU Renewable Energy Directive, is essential for the successful development of biofuels as part of a biorefinery mix. This should be the precursor to a global scheme, as biofuels and their feedstocks are internationally traded. Differential application of schemes can lead to unfair competitive problems and the withdrawal of investment. The use of biofuels must be supported to give investors confidence. Support for renewable energy (which may be part of a biorefinery) should be made according to the innovative nature of the process. Support should only be segregated using the sustainability criteria, where information is available and there is a long enough lead-time for scheme participants to adjust processes and behaviour. Of particular importance for all feedstocks and all end-uses will be an accurate record of land use change. Special attention should be paid to the production of the feedstocks with no water or limited water requirement and on products whose production process requires a low energy input.

Progress of integrated biorefineries from the current research phase to industrial implementation could, according to NGO respondents, be achieved by consistent and stable policies over a significant period of time, increasing funds, intensive R&D actions, priority on the use of agricultural and forestry residues as feedstock in biorefineries, and realisation of two or three pilot plants in different geographical areas.

In order to generate support for biorefineries, the public should be better informed about the benefits of the concept, such as effective use of resources, environmental friendly technologies and products, social and economic benefits for the local people, and contribution to the global efforts for the protection of the environment and global warming.

Based on the performed survey it can be concluded, that:

- Consulted NGOs are actively involved in the bioenergy field, and to a lesser but growing extent in the biorefinery field.
- Overall, the view towards the biorefinery concept currently is positive, although a substantial number of the NGOs are currently developing their position on biorefinery.

3.5. Recommendations

The results of the consumer survey clearly show that the European population is in favour of biorefinery plants and concepts on the basis of their eco-friendliness (especially regarding climate change) and potentially favourable economic outlook. The positive opinion about “sustainability” aspects of biorefinery concepts could be used by industrial actors for marketing strategies respectively communication activities in order to distinguish themselves from other companies not active in this field. Furthermore to generate wider support for biorefineries, the public could be better informed about the benefits of the concept as well as the possible downsides that are often reported in the media. This includes the effective use of resources, environmental friendly technologies and products, and social and economic benefits. In this context the potential of biorefineries to create highly skilled jobs in rural areas could be highlighted in addition to the maintenance of agricultural employment.

The few negative associations raised by the consumers (e.g. biorefineries increase food prices, boost monocultures in agriculture or lead to higher transport in a region) should also be actively and honestly treated in public communication activities. There is a perception that demonstration plants could redress the balance between the possible positive and negative impacts associated with biorefinery concepts.

Both the industry survey and the survey among European consumers indicate a high interest in biorefinery concepts (especially from industry) and in bio-based products if clearly labelled (especially from consumers). But the results of these surveys also highlight the problems of a fast implementation of biorefineries in industry and a strong penetration of bio-based consumer goods among EU citizens. These problems are focused on higher costs or complex implementation procedures in industry, combined with a limited willingness to pay for bio-based products by consumers. In this context, non-harmonized regulations are stressed by industry as a hindering factor. To gain greater clarity with regard to specific problems in the different sectors further detailed investigation is recommended as a complement to any suggested policy changes or substantial public investments.

The positive characteristics of bio-based products (e.g. “natural”, sustainable and healthy) offer a range of markets that could provide a basis for industrial product development. These could be highlighted within communication activities targeted to actual or potential buyers of such products. Although a substantial proportion of people were identified within the consumer survey as highly motivated by issues of environment, sustainability, or maintaining their own health, there was no clear indication that bio-based products would be an “easy sell” in the markets investigated. As a comment on marketing strategy, these interested buyer segments might be addressed first. However, intensive marketing activities appear necessary to convince them of the full range of advantages and benefits of bio-based products.

In analogy to other technology fields it can be assumed that NGOs will actively participate and substantially influence the public debate related to the pros and cons of biorefinery concepts. Consulted NGOs are actively involved in the bioenergy field, and to a lesser but growing extent in the biorefinery field. Therefore early dissemination activities on biorefinery issues targeted at NGOs are highly recommended. Overall, the view of NGOs towards the biorefinery concept is positive, while a substantial number of NGOs are currently developing their position on biorefinery. Therefore it is also recommended to actively involve NGOs in the further development and implementation trajectory and the development of policies on biorefineries in an early state of negotiation.

Due to the heterogeneity of biorefinery concepts and derived products, biorefineries may be best supported by governments by indirect measures rather than direct support through subsidies. In this context it is suggested to create mechanisms that allow consumers to acknowledge the benefits of bio-based products. Suggestions include:

- Comparative studies;
- Benchmarking of products with regard to carbon footprint;
- Establishment of a recognized labelling system for locally made products;
- Establishment of systems for barter trade within the local communities;
- A free EU hotline and registry of products for consumers interested environmental properties of bio-based products. This might contribute to a further and faster penetration of such products.

4. Impacts on rural development, employment and environment

4.1. Introduction

This section deals with the assessment of social and environmental implications, in particular the impact of biorefineries on rural development, employment and environment. The objective is to provide some comparison with traditionally used approaches or products by analysing specific effects of biorefinery developments on rural development, employment, and the environment.

4.2. Results

On the basis of eight case studies (Table 2) and input from a workshop session held on 30 March 2009 it can be stated that the impact on environment (and sustainability) plays an important role in whether or not biorefineries become established. This is mainly due to the fact that environmental benefits are often viewed as the primary sources of competitive advantage in the long-term. Investors and operators therefore wish to realise these benefits through achieving consensus about their products' environmental excellence. Nevertheless, the bottom line is found to be the economics; investors want to capture a *market* opportunity by employing biorefinery processes. On the other hand, environmental legislation is a driver that bridges the sustainability and economic aspects by creating artificial markets for biorefinery products, or internalising environmental externalities, for example in the case of the ETS[5] or the RTFO[6] biofuels obligation in UK.

It was also stressed that indirect employment effects should be treated very carefully. At the moment it is estimated only on a case-by-case basis and the perspectives of individual's assessments are not always clear. The indirect impact on employment is not easy to measure, especially for biorefineries co-located with existing facilities and using existing supply chains (e.g. Nedalco, British Sugar and Cargill). Nevertheless, benefits are apparent wherever new value is created from residues and wherever current jobs are maintained, for instance jobs that could otherwise be lost due to EU sugar reform.

It should be stressed that green field biorefineries are considered to require much more effort than their counterparts at existing facilities. Therefore, if they are considered to be a political objective, they may require additional policy support. In all cases of policy support biorefinery investors and operators highlighted the importance of being involved in the policy process through consultation. Subsidies, in particular, were found not to be widely endorsed. There was a feeling that consumers do not always like to buy into new and apparently 'high-tech' products that require government help - such subsidies can confer an impression that the

[5] European Emissions Trading Scheme

[6] Renewable Transport Fuels Obligation

	Impact categories & intensity of impacts		
Biorefinery	Rural & regional development	Employment	Environment
Chemrec	• Supports the local pulp & paper industry. • Feedstock always sourced from the surrounding region, forests.	• Unknown	• Full implementation of the technology in all Swedish pulp mills would yield about 6,000,000 tons of CO2 reduction per year (~10% of current Swedish CO2 emissions), and supply 25% of current automotive fuel consumption in Sweden.
British Sugar	• The local workforce and local economy will benefit if British Sugar can stay globally competitive • Is a major local employer. • Renewable energy industry will benefit from the learning experience.	• Keeps farmers able to grow sugar beet in the region. • Farmers will have greater diversity and more resilience for their produce. • Only some research in UK as most technology has been outsourced or purchased.	• British Sugar's bioethanol is certified at 71% less greenhouse gas emissions than gasoline (residual sugar from betaine production is fermented to bioethanol) • CO2 and waste heat are used to grow tomatoes.
Greenmills	• Five new enterprises co-operating will benefit from the existence of the plant.	• No contracts with farmers.	• Lower emissions reduce the carbon footprint of biofuels.
BioMCN	• Revival of a former natural gas-to-methanol plant. • Creation of a biorefinery complex.	• Maintenance of 100 jobs (direct employees of the former natural gas-to-methanol plant). • Overall boost in indirect employment (supply chain and clients) could ultimately amount to 4-5,000 jobs.	• Low-carbon fuels will be possible, including: biomethanol, biodiesel, bio-DME, biogas, biopower and heat, bio-LPG, bio-coal.
Domsjö	• Has influence on business investment and location decisions of other companies/industries. • Local feedstock base: 70% local forests, 30% imported.	• Gradual change to more local employment anticipated.	• Considered to be an efficient use of natural resources.
Biowert	• Strengthens market for injection moulding companies in the region, which buy bio-granulate and produce bioplastics.	• Strengthens farmers' jobs through contracting of raw materials from 7 farmers within radius of 13 km.	• Energetically neutral process thanks to integration with biogas plant. • Bio-plastics recyclable but not biodegradable.
Nedalco	• Unknown	• Not significant locally as materials are mostly shipped in.	• Feedstock is lignocellulosic waste from wheat processing, straw or even wood residue.
Cargill/ Cerestar	• Has contributed to the continuing regeneration of an old industrial site.	• Supports wheat growing and the wheat price in the UK. • Agriculture and food industry benefit the most from it. • The move to wheat feedstock from corn caused a loss of jobs at a plant that was shut near London.	• 2000-2007 (under UK Climate Change Levy) reduced energy input by 33% for a tonne of glucose syrup. • Possible negative effect is the greater number of road deliveries of wheat compared to corn shipments, but cost-effective prevailed.

Table 2. Brief description of the eight case studies for the rural development, employment and environment assessment.

products are inferior in quality. Biorefiners expressed concern that if this impression becomes pervasive, consumers will only be prepared to buy such products at *lower* rather than higher prices. This shows the sensitivity of public acceptance that is revealed by the case studies.

This project concludes that in establishing biorefinery operations the involvement of local people is vital. This is of greatest importance for greenfield biorefineries that bring change in the local habitat and to the local community. Interactions with all local actors in the early stages of building a new biorefinery plant are necessary to increase public acceptance.

In conclusion, the case studies show that economic factors are the drivers behind biorefinery development, often pressuring companies into strategies of diversification as existing business models become threatened. The case studies therefore demonstrate how biorefineries can maintain employment in a region, and how eco-friendly products can be added to the product candidates of existing industries. However, it was not demonstrated that these businesses have adopted biorefining as a method of optimising environmental performance. Politics, e.g. biofuels legislation, can be an important economic driver to the establishment of a biorefinery and thus provide a strong basis for incorporation of sustainability criteria. These sustainability issues are certainly recognized as very important concerns by biorefinery investors and operators in order to safeguard the long-term operations of the pilot and subsequent plant by accounting for future trends, new legislation and changes in institutional and public mindsets. As a result, current biorefinery strategies reveal trade-offs between economic and environmental factors (for instance, between transport costs and emissions, and between feedstock costs and local rural development). Biorefinery operators are highly aware that in order to proceed in the long term they must be long-term competitive but they have to make profits from the beginning. This may overshadow the sustainability unless the policy environment or social culture changes markedly.

4.3. Recommendations

The job creation effect of biorefineries should be recognised and thus promoted (if it is considered to be a desirable policy outcome) as an element of rural employment because:

- Biorefineries can be catalysts for the creation of high-tech jobs, especially in the white and green biotechnology field, thus generating skilled jobs in rural areas and;
- The present lack of focus on rural economy in EU biofuels and innovation policy risks creating new centres of biorefining in existing industrial sites located near ports and cities, where imports can be more attractive than use of local feedstock.

Biorefineries catalyse a more efficient utilisation of rural resources and thus contribute to job creation in the agricultural sector (being the supply chains of biorefineries).

Governments should consider a broader range of policy measures than subsidies for bio-based products (direct support) in order to support biorefineries. Indirect methods could include support by co-funding of biorefineries’ appearances at various trade fairs, to showcase the technology and products.

Environmental advantages of products from biorefineries should be acknowledged, for example by establishment of a labelling system for bio-based products (similar to ‘Der Grüne Punkt’ for packaging, which has an awareness rating of 98% in Germany, and is also one of the best-known trademarks worldwide). If possible this system should be financed based on the ‘polluter-pays principle’.

It is recommended that measures are taken to embed factors relating to long-term sustainability (e.g. biodiversity, GHG emissions and agricultural practices) in decision-making processes. In order to further penetrate biorefineries and derived products, for example, public procurement could take a leading role by giving priority treatment to bio-based materials. The construction industry is considered to be an interesting area for such an initiative.

When setting up a biorefinery, local people must be considered. Greenfield biorefineries follow this recommendation, because they bring change in the local habitat and to the local community. Biorefineries at the existing facilities do not need much interaction with local communities.

5. Political legitimacy of biorefineries

5.1. Introduction

The study presented in this chapter – designed to satisfy Deliverables 3.1.1[7] and 3.1.2[8] – examined how the processes of building cognitive and socio-political legitimacy are relevant to the formation of a biorefining sector.

The first part of the work examined management theory addressing challenges faced by emerging industries and how these can relate to the formation of a biorefining sector. The second part involved the conduct of an initial exploration of understanding, acceptance, and support for the biorefinery concept among a sample of actors in the EU policy community. General conclusions of this study are provided in these two areas.

Addressing theory versus evidence from the field, it is found that many phenomena predicted by theory do indeed appear in the empirical results and seem immediately relevant to the formative biorefining industry.

Analysis of the perceptions of members of the policy community towards biorefinery-related environmental, social, policy, reputational and policy issues reveals that there are a number of areas where prompt action from the political and scientific communities could yield significant benefits.

We conclude that much of the discussion and analysis included in the field of industrial management enfolding the concepts of cognitive and socio-political legitimacy is relevant to biofuels, bioproducts and Biorefining and that the industry can utilise many of the experiences detailed in such literature. This in turn implies that proponents of the biorefinery concept can draw upon a broad body of knowledge generated in both related and non-related industries to support their work reducing barriers hindering the emergence of commercial biorefineries. A key area in this regard will be improved communication of biorefinery contributions to sustainable development.

5.2. Results

The results (conclusions) presented in this report are based on the content of a questionnaire distributed amongst actors in the EU policy comunity. The parameters addressed – and the phenomena referred to in this summary are detailed in Table 3. Full details of the study and of the literature sources it utilises are available in the relevant BIOPOL reports and in the journal

[7] D3.1.1 Note with contributions from the national questionnaires and in-depth interviews concerning the political legitimacy of biorefineries

[8] D3.1.2 Note with results EU assessment political legitimacy of biorefineries

paper by Peck et al. (2009): *Examining understanding, acceptance, and support for the biorefinery concept among EU policy-makers*.

Responses from a sufficiently wide spectrum of political informants were received from three of the five countries in the BIOPOL consortium that were examined in the study (Sweden, UK and the Netherlands). There was a high degree of consistency of responses across the 3 countries and as a result, findings have been drawn from a compound sample of responses. Results reflect the views of 48 policy-sphere informants from these jurisdictions.

Comparisons of policy-sphere responses are made with "control responses" generated from a survey of 49 biofuel, bioproduct and biorefinery scientists drawn from more than 10 EU countries. The results of this study are considered most applicable for jurisdictions in Western Europe.

5.3. Conclusions

This work commenced with a working assumption that significant political support is required for the progression of advanced bioenergy and biomaterial systems from their current research stage to the demonstration (or pilot) phase in the short time frames (which is called for in a number of policy goals and targets). Very large investments will be required to provide the infrastructure and logistical structures required to realise visions of biorefining.

We consider this study has found evidence of several issues that could lead to real difficulties in maintaining and broadening the apparent 'favoured status' of bioenergy, advanced bioenergy systems, and new biomaterial production systems within the EU policy sphere. We also believe that this work provides insights that could assist the research and development community in achieving progress towards sustainable biorefining. Communication strategies that better recognise these issues and present them in transparent and understandable forms to the stakeholder community could be essential to the progress of the industry. Specific conclusions related to the two categories of legitimacy on which we have sought evidence are presented below, and followed by a number of suggestions for action from stakeholders that may serve to better enhance and protect the interests of biorefinery development.

5.3.1. Socio-political legitimacy (acceptance)

The analysis indicates that policy-sphere actors are aware of the very significant resources and support needed to operationalise the biorefinery concept Europe-wide. The survey results suggest that policy-sphere informants may be cautious with regards to issues that can pose a significant threat to the social reputation and acceptance of biorefinery concepts – a notable example being that of GMOs in feedstocks. Responses also reveal perceptions of a significant or urgent need to establish guidelines and standards of a technical nature in almost every category of biorefinery activity (from feedstock production to product use). Closer examination of the informant views revealed that sustainability criteria are a priority.

Table 3. Perception themes examined by questionnaire.

Legitimacy function/parameters	Question categories for exploration of policy-sphere perceptions
Cognitive knowledge base	
Knowledge in policy-sphere.	General levels of understanding (e.g. as evidenced by knowledge of the operation and processes of advanced bioenergy and bioproduct systems).
Status of trust, reputation & perceptions of reliability	
Technologies and consequences of the industry as perceived by policy-sphere actors.	Social/environmental benefits or otherwise and views on relative merits of the concept (e.g. as evidenced by views on impact in areas such as greenhouse gases, biodiversity, rural development, employment etc.).
Policy-sphere beliefs regarding the perceptions held by other stakeholders of technologies and consequences of the industry.	Nature of support/opposition of stakeholder groups for areas enfolding the biorefinery concept and how influential they are (e.g. the stance of stakeholders such as multi-national, EU and national governmental agencies, industry, the media, educators and researchers, NGOs, etc.). Sources, volumes and credibility of information received pertinent to advanced bioenergy and bioproduct systems.
Factors that have potential to erode stakeholder trust.	Importance of a range of 'reputation and general acceptance issues' (e.g. GMOs in feedstocks, competition for feedstocks, deforestation, etc.).
Status of system reliability and function	
Frameworks: • that impact establishment and convergence, • can reduce potential challenges with conflicting standards, competing designs and so forth.	The role of current legislative frameworks as a barrier or driver for progress at international, national and local/regional levels.
Synergistic or antagonistic inter-and intra-industry relationships.	Competition related issues with incumbent sectors (e.g. petrochemicals, starch, sugar, forestry, heat and power, syngas, biofuels). Competition for feedstocks.
Enhancing system reliability, function, trust and knowledge.	
Policy intervention(s) required to: • promote establishment and design convergence, • promote third-party review of sector activities, • reduce potential challenges with conflicting standards, competing designs and so forth.	Need for guidelines or standards (e.g. regulating areas such as biorefinery operations, biofuel production, crop production, crop import, 1^{st} and 2^{nd} generation processing technologies and bio-based product performance standards).
Resources for progress towards reliability: • enhance reliability of technical system, • develop knowledge base by linkage with educational curricula, • promote institutionalisation of information dissemination, • indicate commitment of high level politicians.	Need for support to move biorefineries or advanced bioenergy/bioproduct systems through the formative stage (e.g. resources to support process technologies, crop production, educational curricula).

Thus, it can be inferred that activities undertaken by biorefinery stakeholder groups, such as the dissemination of information to policy-makers, have raised socio-political legitimacy in the surveyed categories. Evidence that the status of trust of this information is positive overall was found. More varied results were obtained with regard to system reliability and function, suggesting that concerted legitimation activities in the areas of regulatory frameworks and inter-industry support are not yet proven.

5.3.2. Cognitive legitimacy (understanding)

Indications are that political informants generally have a good working knowledge of biorefinery concepts and largely share the views of the scientific community regarding items such as the relative environmental and social contributions that biorefining can make. We have also received indications that deeper understanding of the full suite of potential advantages (and trade-offs) related to biorefineries may not yet be widespread.

Evidence of understanding of biorefinery-related issues amongst policy-sphere actors was sought and found. This was not the case, however, for informants' knowledge-base regarding the interacting policy systems (EU, national, regional), nor for consistency in the informants' beliefs of the standpoints of other stakeholder groups. Absence of cognitive legitimacy in these areas was not anticipated and suggests a possible policy-level barrier to the emergence of sustainable biorefining.

5.4. Recommendations

The theory that underpinned this study claims that innovative entrepreneurs need strategies to promote the shared expectations, reasonable efforts, and competence of a new business concept to stakeholders in the absence of reliable information and evidence of their competence. Moreover, it indicates that an innovative entrepreneur must 'engineer consent, using powers of persuasion and influence to overcome the scepticism and resistance of guardians of the status quo' and that whilst 'packs of entrepreneurs' work to improve legitimacy, policy-makers have a role of providing a regulatory space in which these 'packs' can work.

We believe that these beliefs, that have arisen from research into innovation systems and organisational evolution, are valid in the context of biorefineries, and that an interactive process of building understanding and acceptance between policy and entrepreneurial actors can be observed. As simple starting points for future work, we suggest that efforts to improve understanding and acceptance be pursued in the following ways:

- that *understanding* be enhanced via the open gathering and dissemination of information on the technical benefits – and tradeoffs – of advanced bioenergy concepts in key areas such as land utilisation, energy carrier and chemical lifecycle performance, and that this information be presented in forms suitable for a range of social stakeholders;
- that *acceptance* be improved by development of common and transparent strategies for communicating the technical complexity, and the potential trade-offs or radicalism in the 'difficult' areas such as GMOs. Areas where contentious issues are already present in biomass feedstock streams, where associated products such as food/feed or

pharmaceuticals may be affected might be advantageously prioritised (or where all these issues coincide);

- that ***acceptance*** be promoted via efforts to align advanced bioenergy and bioproduct systems with established, better understood or 'taken for granted' systems such as the petrochemical refining sector, the forestry sector, the specialist chemical sector and more. Whilst such efforts are evident today, we recommend an explicit strategy of highlighting positives and dealing with potential negatives (see above);
- that *understanding and acceptance* be facilitated by the encouragement of intra-industry relationships and trade associations with the role of supporting the progress of advanced bioenergy. The development of consistent communication strategies based on the key findings of this discussion, and working closely with the policy community are recommended.

In closing, we consider that this study has uncovered several non-technical issues with the potential to damage the apparent 'favoured status' of biorefinery type initiatives in EU policy-making circles. Further, we recommend the development of strategies for communication between the policy sphere and the research and development community that are objective, transparent and recognise these problematical issues and potential trade-offs. Such strategies can follow the theory-based approaches that we outlined and tested in this project and should seek to engender trust and acceptance in the stakeholder community. To support such work, we consider that research encompassing a survey of industrialists and researchers that complements this work, and targets a larger sample would be of considerable value.

6. Implications of renewable policy, forestry policy and agricultural policy for biorefinery

6.1. Introduction

The study presented in this chapter – designed to satisfy Deliverables D 3.2.1[9] – was delivered as a combined report in close collaboration with the project Biorefinery Euroview[10]. It provides background and input context for the scenario-based analysis (Chapter 7) but does not address that work.

The deliverable from this work provides an overview of an analysis of EU policies that impact biorefinery viability. This study was undertaken using extensive desk research and discussion with experts in the field. The focus areas for policies are primarily energy, forestry, agriculture and environment. However, there are many other relevant policies for the biorefinery concept that encompass fields ranging from waste to rural development. Within this work, the term "policy" has been interpreted broadly to include almost all official documents published by the European Commission or related bodies. This encompasses regulations, communications, and strategies.

The study finds evidence that actions to support innovation (translation of research into technology and products) and integration of different technologies to create modern biorefineries will now need to translate into strong commitment and support for the establishment of pilot and demonstration plants. These are perceived by many actors in the field as necessary steps towards scale-up and industrial applications. As for the development of demonstration plants, comparable funding to the USA is difficult for the EU, but there appears to be consensus that it is crucial to streamline funding available at national and regional levels for public-private partnerships (PPPs) and define simple guidelines for industry to apply for these funds.

6.2. Results

Numerous examples of potential overlaps, conflicts and synergies of different policy regimes were found in this study (Figure 4). It was also identified that there is a growing number of examples of how development of industries or sectors important to the biorefinery industry can be impacted by such policy interactions. These include areas such as liquid biofuels, rural development, agricultural reform, climate and bioenergy policy developments.

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[9] D3.2.1 Analysis of broad scenarios concerning the implications of renewable policy, forestry policy and agricultural policy for biorefinery viability results

[10] Delivered with EUROPABIO deliverable to Project no. 044275 – FP6-2005-SSP-5A Biorefinery Euroview (D2.4 Mapping and analysis of European legislations and policies influencing the development of biorefineries).

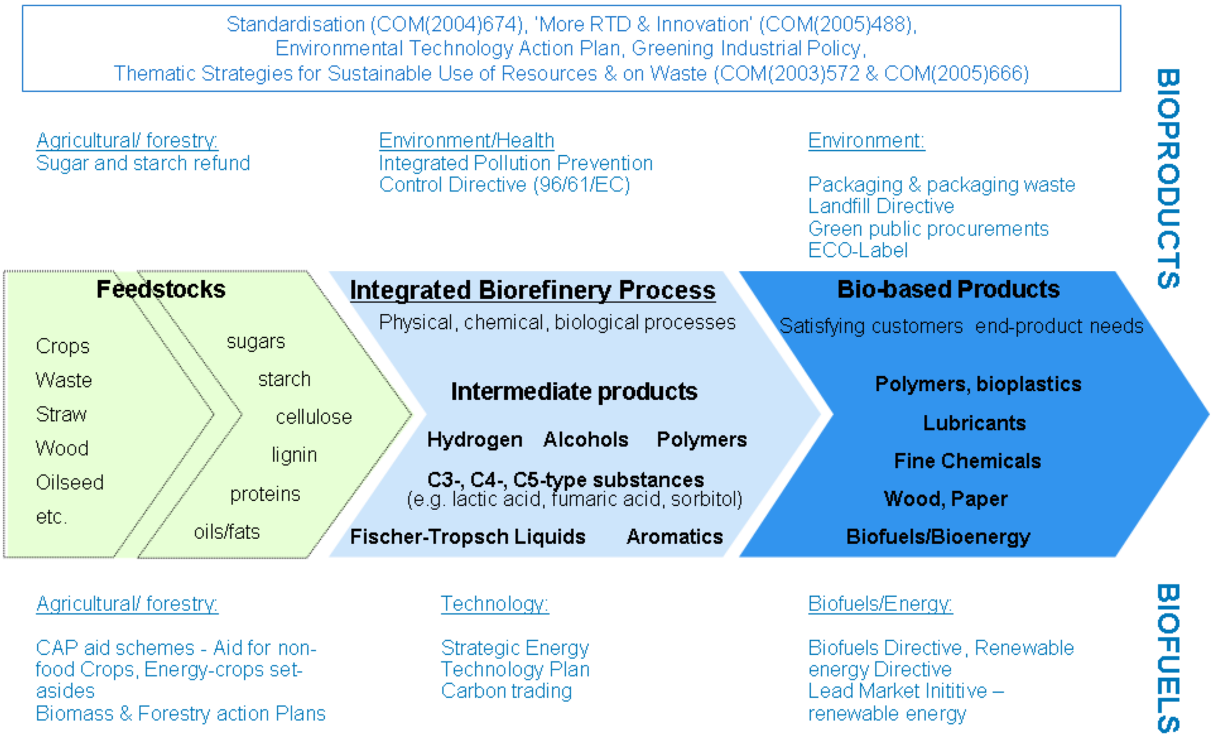

Figure 4. Overview of policies and legislation.

An immediate observation is that there are many policies produced by the European Commission that can be considered relevant to the biorefinery concept. However, very few specifically refer to biorefineries. Most of the policies are much broader than the biorefinery concept or bioenergy, or even renewable energy. For example, policies on rural development may have only a few sections/lines related to renewable energy. However, these policies remain very important to creating favourable conditions for the biorefinery concept to be implemented. A number of more specific observations arising from the study are included below.

6.2.1. Stimulating Research and Innovation

Research on biorefinery technologies is relatively new and immature. This represents a key bottleneck to greater exploitation but also offers tremendous opportunities for research and breakthrough innovation. Significant efforts are already being made on research funding in basic and applied science up to pre-commercial stages. There are widely held views in the policy literature and debate that key actions to support innovation (translation of research into technology and products) and integration of different technologies to create modern biorefineries will require strong commitment and support for the establishment of pilot and demonstration plants and that these are prerequisites for scale-up and industrial applications.

6.2.2. Developing the Policy Framework

There are many political and scientific initiatives in Europe concerning industrial biotechnology and the biorefinery concept, however they are largely uncoordinated. There is also a relatively high degree of policy and regulatory uncertainty – particularly when viewing over the time frames required to establish integrated biorefinery operations.

In addition to an apparent absence of long-term strategies, specific policies in the field of agriculture, energy, environment and forestry do not always act consistently. Some constitute potential support for the development of the biorefinery concept while others still appear to pose barriers for introduction or development (e.g. of bio-based products to the market).

- *Agricultural policy*: There appears to be insufficient data on the availability and supply cost for biomass feedstocks – and also of market price dynamics. At present these do not appear to adequately taken into account factors such as competition with food and relative price elasticities, the stimulus provided by renewable energy targets, the competition and synergies with demands from existing biomass based industries (e.g. wood-based, paper, starch and fermentation) or the evaluation of feedstocks necessary to support biorefinery development.
- *Energy policy*: Current policy, such as the Biomass Action Plan (BAP), encourages the use of biomass with a range of conversion technologies for the production of energy and biofuels. The implementation by Member States represents an opportunity to increase such production and secure feedstocks for energy and non-food applications. However at present, BAPs are developmental and do not address or account for the production of fibres, biochemicals and biomaterials, rather they focus on food/feed and energy. National biomass planning does not yet reflect the sum or coordination of regional biomass action.
- *Forestry policy*: A technology platform for the forest-based sector has been developed along with a Forest Action Plan (FAP). This plan supports the implementation of the BAP and utilising forest biomass for energy purposes. Additionally, a 19 point plan to address the challenges facing forest-based industries, such as climate change and increased global competition, has also been introduced by the European Commission. All of these are generally creating more favourable conditions for the biorefinery concept.
- *Environmental policy*: The Environmental Technology Action Plan (ETAP) sets out some principles and identified barriers for technology development but these have not been translated into substantial action. Some legislation for instance does not recognise favourable characteristics of bio-based plastics and therefore creates implementation problems for their recycling.

Any “new” policy to support the biorefinery concept will unavoidably and automatically interact with existing policies for the agriculture, energy, environment and forestry sectors. Such interactions can be complementary and mutually reinforcing, but there is also the risk that different policy instruments will interfere with each other, and undermine the objectives and credibility of each.

6.2.3. Facilitating Market Development and Access

The barriers slowing the establishment of a European bio-based economy (such as lack of market breakthrough of new technologies, absence of or for new logistics systems, unproven business models, high investment costs etc.) are not likely to disappear in the short-term, even with forecasts of relatively high oil prices. At this point in time, there appears to be general consensus that high levels of investment are needed to create bio-based plants that can operate in synergy and/or competition to conventional production plants or industrial processes. The real costs for a transition to sustainable processes however, remains very high and the long-term cost/benefit ratio of a move to biotechnological processing has to be both more transparent and better demonstrated to motivate the engagement of companies in different industrial sectors.

The development of *standards and labels* appear to offer promise to establish, demonstrate and communicate the specific characteristics of biorefinery products. This can address parameters that range from carbon intensity, biodegradability to the broader assessment of their eco-efficiency. Life cycle analysis (LCA) and scientific evaluation of product characteristics appear to be vital to underpin the implementation of emerging sustainability or eco-efficiency standards. It appears that deep industry involvement would be required for the development of methodology and to ensure their practical applicability. Inclusion of bio-based products in the European eco-label scheme and in demands for specific product requirements (e.g. related to green purchasing) is also held by some to provide promise of new opportunities for bio-based products.

Though it is considered possible to build on existing EU “green” *public procurement* and practice that is applied in the USA and some Members States (as well as parts of the USA) as a basis for ongoing support, it remains difficult to include “soft” criteria such as environmental and social benefits in general procurement rules. These are often based on quality/cost criteria. There are also some barriers to overcome such as the fragmentation and differences between European companies and jurisdictions. The European Commission is beginning to address such issues through national action plans to promote “green” public procurement.

Indications from the study are that there is currently inadequate support for *communication and dissemination* efforts concerning the introduction of bio-based products. It was also noted that there is a lack of a forum for collecting user feedback on the use of bio-based products and follow-up the development of new products, in particular those from small companies.

Finally, although this study notes that *economic incentives* play a vital role in stimulating action and investments. There are many different types of economic incentives that are already being utilised, such as subsidies, investment grants, tax exemptions, and obligations. There are clear indications that support of this kind will be required for a considerable period if the EU is to transform the biorefinery concept into a reality.

6.3 Conclusions

As indicated above, numerous examples of potential overlaps, conflicts and synergies of different policy regimes were observed. The study also identified a number of areas where intervention can contribute to progress. These are summarised in *Recommendations* below.

As overarching themes, the study notes that the products of bio-processes are often similar to “conventional” products (bioplastic is plastic, biofuels are fuels, biochemicals are chemicals, etc.), and although they can often be produced in a more sustainable fashion, in many cases any potential or actual improvements are ‘invisible’ to the consumer. Pursuing pathways to both differentiate biorefinery products and communicate their advantages will be an important area of work for the future. In addition, market prices generally do not reflect the real benefits for society or the environment, or both. As such, clearer communication to consumers of the benefits of the technologies, production process or products and specific and/or temporary incentives could help to change consumer and industrial investment behaviour, a change that arguably will create a market pull for such products.

Moreover, it is noted that industrial biotechnology processes and bio-based products already co-exist with conventional ones and will continue to do so. Conventional processes are also being incrementally improved to become more sustainable and have lower environmental impact. However, greater use of renewable materials and industrial biotechnology processes has the potential to speed up and facilitate the establishment of a sustainable industrial base, through breakthrough innovations. Therefore, as technologies improve, the application of specific support would help to promote industrial transformation to processes and products that are clearly more eco-efficient, or have more improvement potential than existing ones.

6.3. Recommendations

Pursuant to the observations listed above, the following recommendations are provided for consideration.

Stimulating Research and Innovation: Research and development (R&D) in relevant science fields should be secured and supported over the long-term. Additional attention should be given to reinforcement and technology transfer. One example of such reinforcement is greater involvement of industry, especially small and medium size enterprises (SMEs), in research activities. Shifting to demonstration, measures should be taken to streamline funding for the development of demonstration plants that is available at national and regional levels for public-private partnerships (PPPs) and define simple guidelines for industry to apply for these funds.

Developing the Policy Framework: To facilitate the development of a competitive bio-based economy in Europe, real integration and coordination of these existing policies is critical. Moreover, long-term policy and regulatory certainty should be pursued to support the continuous development and investment in biorefinery technologies and infrastructure, as well as harmonisation of regulatory policy between Member States and at the EU level. For increased effect, such policy measures should also focus on the uptake and demand for bio-based products.

- *Agricultural policy*: Measures need to be undertaken to allow analysts to better take into account factors such as competition with food and relative price elasticities, the stimulus provided by renewable energy targets, and the competition and synergies with demands from existing biomass based industries. With the on-going health check of the Common Agricultural Policy (CAP) work should be performed to review aid schemes (starch refund, sugar regime, use of set-aside land for energy crops) not only to meet bioenergy requirements but also to secure feedstock supply for bio-based products.
- *Energy policy*: In order to support policy initiatives such as the Biomass Action Plan (BAP), when these plans are drawn up they should take into account the production of not only food/feed and energy but also fibres, biochemicals and biomaterials. National

BAPs that coherently represent the sum of biomass plans at regional levels should also be pursued.

- *Environmental policy*: The Environmental Technology Action Plan (ETAP) should be translated into action in more areas if it is to have an impact. As one example, recognition of the special inherent characteristics of biorefinery outputs such as bio-based plastic feedstocks should be pursued. The Integrated Pollution Prevention and Control (IPPC) directive could also be used to encourage the use of alternative and more benign processes such as biological processes.

Facilitating Market Development and Access: Supplementary measures and incentives are deemed crucial to reduce barriers to the establishment of a European bio-based economy. Options to pursue the development of *standards and labels* that can establish, demonstrate and communicate the specific characteristics of biorefinery products should be supported. The industry should be directly involved in the development of methodology to ensure their practical applicability – however, it appears both prudent and desirable that third party scientific oversight is included so as to maintain the transparency of such processes.

Finally, the support of *communication and dissemination* efforts concerning the introduction of bio-based products is recommended. It is also important to create a forum for collecting user feedback on the use of bio-based products and to follow-up the development of new products, in particular those from small companies. Eco-efficiency labelling and defining bio-based products and their properties will likely form an integral part of communicating the benefits of such products.

7. Scenario based analysis

7.1. Introduction

This section focuses on scenario building regarding production of biomass/residues and its conversion into final products that are to be used for energy purposes. The aim of the scenario analysis is the exploration of economic and technical possibilities of biomass/residues energy supply under varying general policy objectives in the European Union. Another aim is to evaluate the importance of early introduction of more advanced biorefinery technologies into the market in order to achieve more ambitious policy objectives in a cost-effective manner.

The general policy objectives assumed for this study are inspired from the recently adopted Climate Change Action and Renewables policy package of the EU. A remarkable feature of this package is to include an autonomous RES[11] objective in addition to the existing GHG emission reduction objective. The EU, by using the PRIMES energy system model operated by E3MLab, proposed an impact assessment study which included a model-based estimation of how the effort should be distributed among sectors and countries in order to obtain maximum cost-effectiveness and less impact on lower GDP member-states. This distribution of effort is a full-scale energy scenario suggesting energy restructuring, fuel-mix and investment per sector and country dynamically over the period 2010-2030.

A key conclusion from this impact assessment is that biomass-residues for energy purposes should play an important role in the restructuring. A particular domain in which biomass-residues get a priority of use is the market of fuels used for transportation. For this domain the EU package includes a specific target for 2020, according to which biofuels should get at least 10% of the market provided that they are produced in a sustainable manner: the net effect on GHG emission reduction of using biofuels considering emissions over the entire lifecycle should at least be 35% (in 2015) and 60% beyond 2018 in order to qualify as sustainable and compliant with the RES obligations. Such qualification requires investment in new technologies for production and conversion processes in order to supply biofuels in the future. This implies consideration of biorefineries and specific sustainable biomass production chains.

The policy package includes also use of biomass-residues in combustion processes. The policy scenario suggests significant deployment of biomass-residues for combustion, in a large variety, ranging from small scale boilers in houses, up to large scale power generation and co-generation, both in biomass dedicated stations and in co-firing.

Finally, biomass-residues end-products can be produced by a variety of primary resources, including existing agricultural products, new energy crops, forest resources and a variety of residues.

[11] Renewable Energy Sources

7.2. Approach

The biomass system model is linked with the PRIMES large scale energy model for Europe covers all the EU countries performing dynamic future projections from 2000 until 2030 in a 5-year time period step. It computes endogenously the energy and resource balances, the investments, the costs and prices and the greenhouse gas emissions.

The biomass module topography is divided into three process categories which all together constitute the biomass logistics chain, i.e. from the primary stage (e.g. field) to the conversion plant for the final biofuel production. Figure 5 presents a general outline of this biomass conversion chain.

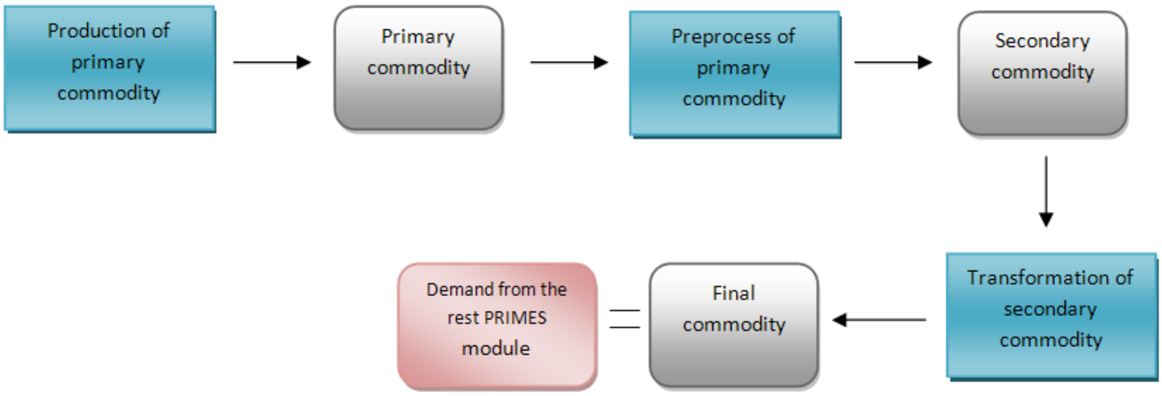

Figure 5. General Biomass Conversion Chain.

Primary commodities are classified into three categories: energy crops, forestry and residues. Energy crops, depending on the type of plants cultivated, are further distinguished into starch, sugar, oil and wood crops. For the BIOPOL project wheat has been considered for starch, sugarbeet for sugar, sunflower/ rapeseed for oil and short rotation coppices (poplar, willow etc.) along with herbaceous lignocellulosic crops (miscanthus) for wood crops. Forestry is split into a wood platform, i.e organised and controlled cutting of whole trees for energy use, and wood residues, i.e. the collecting of forestry residues only. Table 4 shows this classification of primary commodities and the included feedstocks in each category.

Energy Crops	Forestry	Residues
Starch crops (=wheat) Sugar (=sugar beet) Oil Crops (sunflower/rapeseed) Wood Crops (SRC & miscanthus)	Wood Platform Wood Residues	Agricultural Residues Waste Industrial Solid Wood Waste Used Vegetable Oil Waste Industrial Pulp (black liquor) Waste municipal Solid Waste Sewage Sludge Waste Landfill Gas Organic Manure Waste Animal

Table 4. Classification of primary biomass.

Based on the general outline of the biomass to energy conversion chain, a complete list of the different conversion routes, from primary resource to final commodity was identified. The secondary processes are in fact the pretreatment processes, for example drying, densification, or packaging. The final transformation technologies are biochemical (anaerobic digestion, 1st and 2nd generation fermentation), thermochemical (Pyrolysis, HTU, Hydro Deoxygenation, Gasification), transesterification and gas-to-liquids.

Table 5 lists the wide range of possible transformation processes included in the model, while Table 6 lists the final energy products based on their physical state (solid, liquid, gaseous).

Secondary Transformation	Final Transformation
• Starch Pretreatment • Sugar Pretreatment • Plant Oil Pretreatment • Agr.Residues Pretreatment • Lignocellulosic (SRC & Miscanthus) pretreatment • Solid waste pretreatment • Liquid waste pretreatment • Gas Waste conditioning • Pelletising	• Biochemical o Fermentation o Acid/Enzymatic Hydrolysis o Transesterification o Anaerobic Digestion • Thermochemical o Pyrolysis o HydroThermal Upgrading (HTU) o Hydrodeoxygenation • Gasification o Entrained Flow o Fluidized Bed o FT Synthesis • Other o Charcoaling

Table 5. Secondary & final transformation processes.

Solids	Liquid	Gaseous
• Charcoal • Pellets • Mass Burn Waste (MBW) • Refuse Derived Fuel (RDF)	• Bioethanol • Biodiesel (esterification) • Fischer Tropsch Diesel • HTU Diesel • Pyrolysis Diesel • Biocrude • Pyrolysis Oil • Pure Vegetable Oil (PVO) • Black Liquor	• BioGas (from Anaerobic Digestion) • Sewage sludge gas • Synthetic Gas (from Gasification technologies)

Table 6. Final energy products.

Figure 6 shows in detail the mapping between the feedstocks and the various technologies. It is clear that some technologies besides the primary energy product also produce a by-product (Table 7). In reality, these by-products are an income for producers and this is the how they are treated in the model. Furthermore, two of the scenarios are based on the potential of glycerol and lignin to produce high value marketable products.

Process	By-product
• Plant Oil Pretreatment	• Seed cake
• Fermentation (sugarbeet)	• Vinasses (animal feed)
• Fermentation Starch	• DDGS
• Fermentation of Ligno- cellulosic feedstock	• Lignin
• Transesterification	• Glycerol
• Anaerobic Digestion	• Fertilizers
• Anaerobic Digestion (Sewage Sludge)	• Compost

Table 7. Technologies and Byproducts.

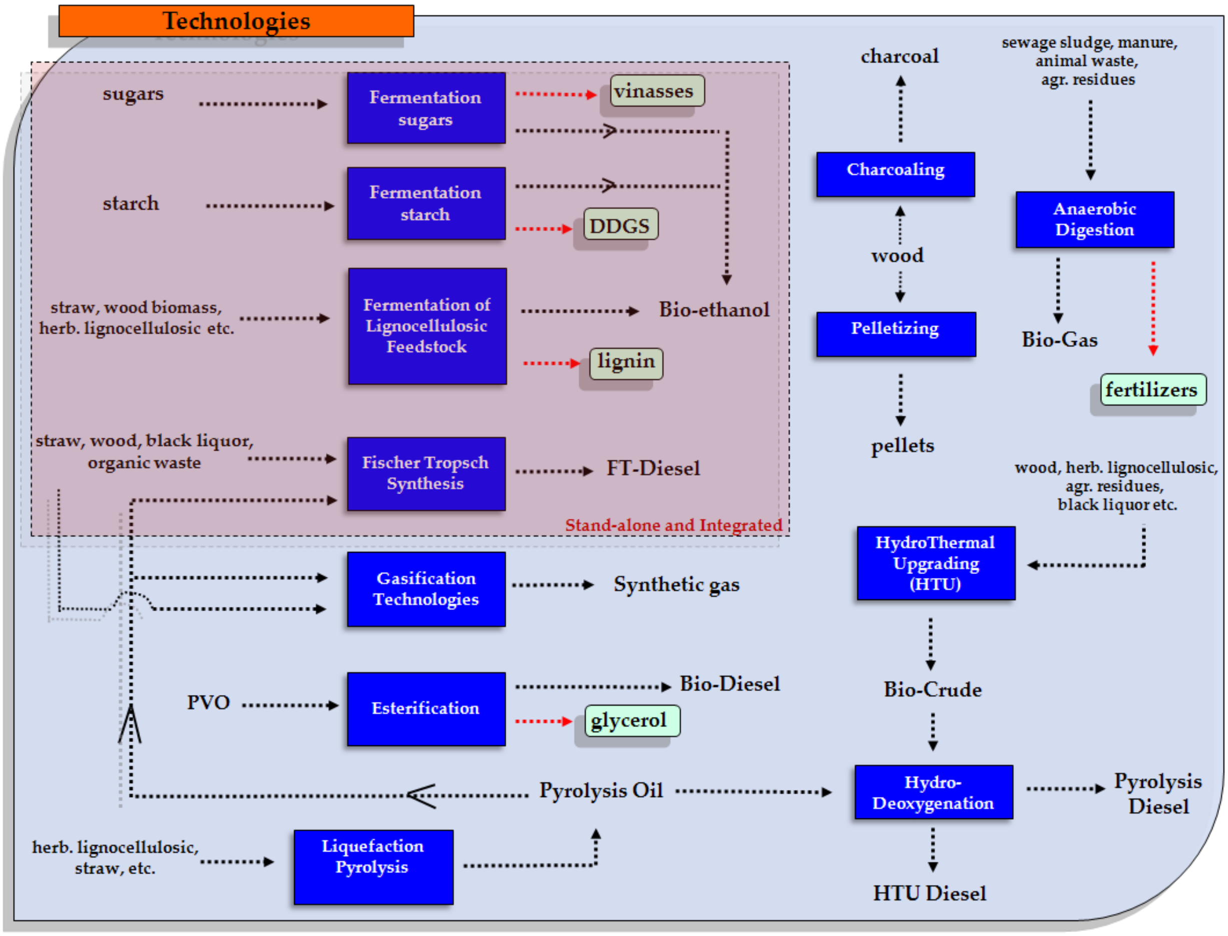

Figure 6. Feedstocks and process outputs in the model.

7.3. Scenario Definition

As stated above, a demand of final biomass/residues energy products is given from the rest of the PRIMES model which the biomass-module model must meet. The demand is in line with the EU's 20/20/20 climate and energy package and is split into five categories: biodiesel, biogasoline, bioheavy, small scale solid, large scale solid, biogas, waste solid and waste gas. The type of final bio-products included in each category can be seen in Table 8.

Demand Categories	Bio-products included
• Biodiesel	• Biodiesel (from 1st & 2nd generation technologies)
• Biogasoline	• Bioethanol (from 1st & 2nd generation technologies)
• BioHeavy	• PVO, biocrude and pyrolysis oil
• Small Scale Solid	• Pellets and charcoal (for small scale use)
• Large Scale Solid	• Pellets, charcoal and black liquor (for large scale use)
• BioGas	• Biogas (from anaer.digestion) & synthetic gas (from gasification technologies)
• Waste Solid	• Mass burn waste (from industrial & municipal solid waste)
• Waste Gas	• Sewage sludge gas and landfill gas

Table 8. The demand categories with the included products.

Besides the various processing technologies already in use or likely to be introduced independently, the concept of the Integrated Biorefinery is also introduced in the Model. In contrast with these technologies that are single plants, spread all over Europe, the Integrated Biorefinery is envisaged to combine multiple processes in order to take advantage of the efficiency benefits and exchanges of by-products associated with integration. Facilities adopting integrated biorefining could process multiple forms of feedstock and produce both biofuels and valuable co-products. In the BIOPOL project the Integrated Biorefinery concept has been limited to consist of fermentation processes (simple and lignocellulosic) and gasification-based processes (for 2nd generation biodiesel) to enable its manageable incorporation into the Model. Due to economies of scale and the intense R&D the Integrated Biorefinery is expected to have lower capital, variable and fixed costs.

The scenarios chosen are pursuant to the EU's adopted Climate Change Action and Renewables policy. The sustainability of the already existing 1st generation facilities (for biofuel production), spread all over Europe, is revised in terms of the greenhouse gas abatement target which must be met throughout the entire logistics supply chain from field to final process plant.

Analytically, the scenarios chosen for the BIOPOL project were the following:

- **Scenario A1**. A given demand for energy to be met by the Model in line with the GHG and RES criteria using the afore mentioned stand-alone technologies (see Table 5).
- **Scenario A2**. A given demand for energy to be met by the Model in line with the GHG and RES criteria using the stand-alone technologies *and* the introduction of the Integrated Biorefinery.
- **Scenario B1**. A given demand for energy to be met by the Model in line with the GHG and RES criteria but also specific constraints on total production of *glycerol* and *lignin* using stand-alone technologies.
- **Scenario B2**. A given demand for energy to be met by the Model in line with the GHG and RES criteria but also specific constraints on total production of by-products using *and* the introduction of the Integrated Biorefinery.

Schematically, this can be seen in Table 9.

	No Integrated Biorefinery	With Integrated Biorefinery
PRIMES demand (no extra demand on by-products)	A1	A2
PRIMES demand (with extra demand on byproducts)	B1	B2

Table 9. The chosen scenarios.

7.4. Results

For detailed results we refer to the BIOPOL deliverable D3.2.2. 'Report with results targeted scenario analysis concerning the implications of renewables policies, forestry policy, and agricultural policy for biorefinery viability'.

7.5. Conclusions

The conclusions drawn from the model-based analysis are summarised as follows:

- Total EU demand for biomass/residues for energy purposes reaches approximately 200 Mtoe (of final products) in 2020 and 250 Mtoe in 2030. The results show considerable development of energy crops cultivation. The demand for biomass is so large that land available for energy crops must be used at a high degree in all scenarios: this gets close to 90% in 2020 and 80% in 2030 in the A1/A2 scenarios. Lignocellulosic crops become gradually the dominant crops cultivation and provide with feedstock various processes (e.g. 2nd generation fermentation, Gasification, Pelletizing, FT-Synthesis etc.). Land utilisation is lower in the B1/B2 scenarios as shown in Table 10 and 11

% of available land	2010	2015	2020	2025	2030
A1 scenario	26.9	75.4	88.0	86.7	78.7
A2 scenario	26.9	75.8	89.7	88.4	80.5
B1 scenario	26.9	69.4	77.7	75.8	69.5
B2 scenario	26.9	68.8	77.3	76.3	69.9

Table 10. Land used for energy purposes in the EU27 as % of available land.

% of used land	2010	2015	2020	2025	2030
- A1 scenario					
Starch+Sugar	56.16	28.11	20.43	18.91	17.09
Lignocellulosic	0.00	62.15	75.26	81.09	82.90
- A2 scenario					
Starch+Sugar	56.16	23.51	16.86	15.58	14.00
Lignocellulosic	0.00	66.80	78.94	84.41	85.99
- B1 scenario					
Starch+Sugar	56.17	16.22	12.51	10.37	7.37
Lignocellulosic	0.00	73.24	82.64	89.63	92.63
- B2 scenario					
Starch+Sugar	56.16	16.89	13.94	11.44	8.92
Lignocellulosic	0.00	72.44	81.14	88.56	91.07

Table 11. Structure of Crops Cultivation in the EU27.

- The amount of indigenous biomass and residues production for energy purposes ranges between 155 and 165 Mtoe in 2020, depending on the scenario, and between 163 and 177 Mtoe in 2030. Dependence on imported biomass commodities is found more significant for ethanol and for large scale solid biomass (for combustion purposes). Rather modest imports are found for pure vegetable oil.
- A clear result of the model-based analysis is that the sustainability threshold has important consequences on the future mix of biomass processing technologies and on the structure of crops cultivation. When removing the sustainability threshold, the projection shows slow and late emergence of second generation technologies.
- Driven by the sustainability threshold and the production economics as second generation technologies become dynamically mature the model suggests within the

A1/A2 scenarios to close all esterification plants and introduce instead the Fischer-Tropsch Synthesis for biodiesel production.

- The scenarios A1/A2 assume no limitation on production of non-energy by-products, notably the *lignin*. Assuming constraints on total production of lignin, as in scenarios B1/B2, so as to produce exactly quantities that can be absorbed by demand in the EU has important consequences on technology mix. Second generation technologies, pushed by the sustainability thresholds, develop less than when no limitations apply on by-products and conventional esterification remains partly in operation. In the by-product constrained cases (B1/B2) where some esterification facilities stay in operation in order to produce glycerol, FT-synthesis develops less than in the unconstrained cases.
- The closure of 1st generation biodiesel facilities in the A1/A2 scenarios reduces drastically the oil-crops cultivation especially from 2025. Sunflower/rapeseed cultivation for energy purposes is progressively declining, while imports of PVO help meeting the BioHeavy demand.
- In all scenarios second generation fermentation technologies emerge. In the A1 and A2 scenarios their capacities become quite large but remain lower than 1st generation capacities which continue their operation. The consideration of constraints on *lignin* production within the B1 and B2 scenarios, limits further development of lignocellulosic fermentation capacities (within the IB or as stand-alone plants) otherwise by-product production would exceed demand. Stand-alone fermentation plants maintain operation but show a declining trend (in terms of production) over time. This is due to the sustainability thresholds which push for using more the 2nd generation fermentation technologies. This also explains why less land is utilized in the B1/B2 scenarios compared to A1/A2 and why more imports of bioethanol are required.
- Regarding the cases assuming development of the Integrated Biorefinery, the results show that 2nd generation technologies, i.e. the lignocellulosic fermentation and the FT-Synthesis, tend to develop within the IB and less as stand-alone plants. This is more pronounced within the A2 scenario, contrasting the B2 scenario which shows some development of 1st generation fermentation technologies integrated within the IB. The IB is introduced in most of the EU countries and its enabling economies of scale have beneficial effects on costs and prices of the order of 5% in terms of total production costs.
- For meeting the demand for solid biomass (used in combustion for power and heat production) the results show impressive development of pelletizing than other technologies.
- Gasification technology emerges and gradually replaces Anaerobic Digestion. Hydrothermal Upgrading also emerges for production of bio-crude used to supply Bio Heavy commodities. The results do not show development of pyrolysis oil production and Hydrodeoxygenation technology.
- The model results show continuous imports of bioethanol in the EU from the rest of the World. The introduction of the IB implies lower imports of bioethanol. The imposition of constraints on by-product production induces higher bioethanol imports.

Share of EU27 demand covered by imports from rest of World				
%	2015	2020	2025	2030
- A1 scenario				
Bioethanol	19.4	17.4	23.4	34.3
PVO	3.4	23.6	32.8	22.1
- A2 scenario				
Bioethanol	12.64	7.73	14.68	27.88
PVO	4.69	25.55	33.79	25.22
- B1 scenario				
Bioethanol	27.91	29.85	36.35	39.84
PVO	29.30	29.45	33.54	36.26
- B2 scenario				
Bioethanol	24.68	16.69	31.05	38.68
PVO	30.91	29.43	33.54	36.19

Table 12. Imports of bioethanol and PVO.

- The introduction of the FT-Synthesis technology has beneficial effects on biodiesel prices. This result is more pronounced in scenarios A1/A2 where no byproducts constraints are imposed. Bioethanol prices remain rather stable over time, as rising cost of imports compensate for falling domestic production costs. The introduction of the IB induces reduction in costs between 2 and 5%, compared to stand-alone plants. The prices of the other biomass energy commodities do not display strong variations over time.
- A remarkable result obtained by the model, in all scenarios, is that the prices of biomass energy commodities remain rather stable over time despite the considerable increase in biomass energy production induced by the demand scenario which has reflected the ambitious use of biomass for meeting the RES and Climate action targets adopted by the EU. This conclusion depends on the degree and the pace at which the new technologies will become mature and benefit from economies of scale over the entire biomass supply chain. The models' database has taken an optimistic view to that respect. Should economies of scale develop less than expected and should commercial maturity of technologies be delayed, the results in terms of prices and availability may be altered considerably.

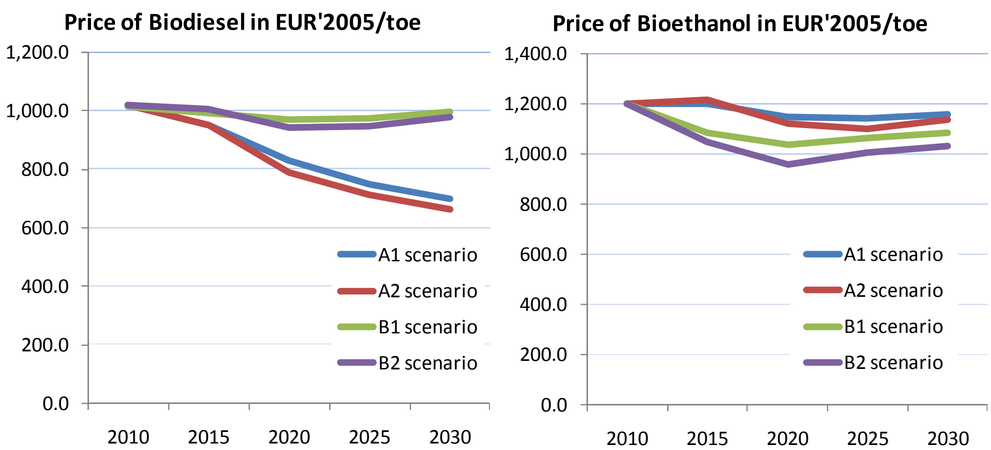

Figure 7. Prices of biodiesel and bioethanol.

8. Current implementation status

8.1. Identification, classification and mapping of existing and future EU biorefineries

This chapter presents an overview of existing biorefineries, pilot plants and major RTD projects in the EU, undertaken to generate a view of the integration level of biorefineries in existing and new industry sectors and to provide information on other aspects relevant for formulation of policy recommendations. To enhance results, the identification, classification and mapping of existing biorefinery ventures in the EU was undertaken in collaboration with the Biorefinery Euroview project.

The BIOPOL Consortium conducted a review of the practical implementation status of the biorefinery concept in Europe by identification, classification, and mapping of existing and future biorefineries in the EU27 plus Norway, Switzerland and Iceland (EU27+). For this work a “top-down approach” was used consisting of several elements:

- A quantitative assessment and mapping of the presence of industry sectors in the EU27+ where current biomass processing plants are in operation or under development as indicated by the results of the industry survey. Sectors in which current or future biorefineries may be expected or could potentially evolve were the main focus, including: Chemical industries, Agricultural and Sugar & Starch sectors, Forestry sector and the Biofuels sector.
- A quantitative assessment and mapping of the availability in the EU27+ of specific feedstocks for various types of biorefinery, i.e. wheat, sugar beet, maize, potato, rapeseed, agricultural residues of food and feed crops, grass, wood and wood products. The aim is to assess the potential relationship between the availability of these feedstocks and the presence of related biorefinery initiatives.
- Identification, description and mapping of the occurrence of existing and planned biorefinery plants as well as biorefinery related R&D, pilot and demonstration projects in the EU27+. This analysis was based on the results from the mapping exercise performed by Biorefinery Euroview (24 advanced biorefinery sites) and supplemented by the BIOPOL consortium based on partner expertise and additional sources.

A total of 34 existing or planned biorefineries have thus been identified in the BIOPOL and Biorefinery Euroview projects (Figure 8). These biorefineries are based on the various concepts of Cereal biorefineries, Whole crop biorefineries, Oilseed biorefineries, Green biorefineries, Lignocellulosic feedstock/forest-based biorefineries (including the 2 platform concept), Multiple feed/integrated biorefineries, as defined in the BIOPOL and Biorefinery Euroview projects. In addition 45 biorefinery-related major R&D projects, pilot and demonstration projects have been identified.

The majority of the identified biorefineries (23 out of 34) and biorefinery projects (28 out of 45) are located in Western Europe, followed by Northern and Southern Europe. About 75% of the biorefinery sites are located in an area comprising Northern France, Germany, Denmark, Belgium, the Netherlands, and the UK. These 6 countries possess both a variety of suitable feedstocks for biorefinery applications *and* intensive (petro)chemicals production. No existing biorefineries or major R&D projects or pilot plants have yet been identified in the Eastern EU countries.

Figure 8. Existing and planned biorefineries in Europe.

The mapping results confirm a positive correlation between existing and planned biorefineries and the occurrence of chemical industries, biofuel industries and agro-industries mainly in the starch and sugar sector and with the availability of the feedstocks wheat and sugar beet.

A relatively high number of green biorefineries using grass as feedstock (7) were identified, given the fact that grass can be considered a second generation feedstock that requires innovative processing technology. The availability in the EU of grass that is currently not used as animal feed is mapped in Figure 9. Furthermore a substantial number of current and planned lignocellulosic feedstock biorefineries (11) were identified that are positively correlated with the availability of wood (including forestry residues) and straw. Based on feedstock availability there is a large potential for expansion of these advanced concepts in the EU.

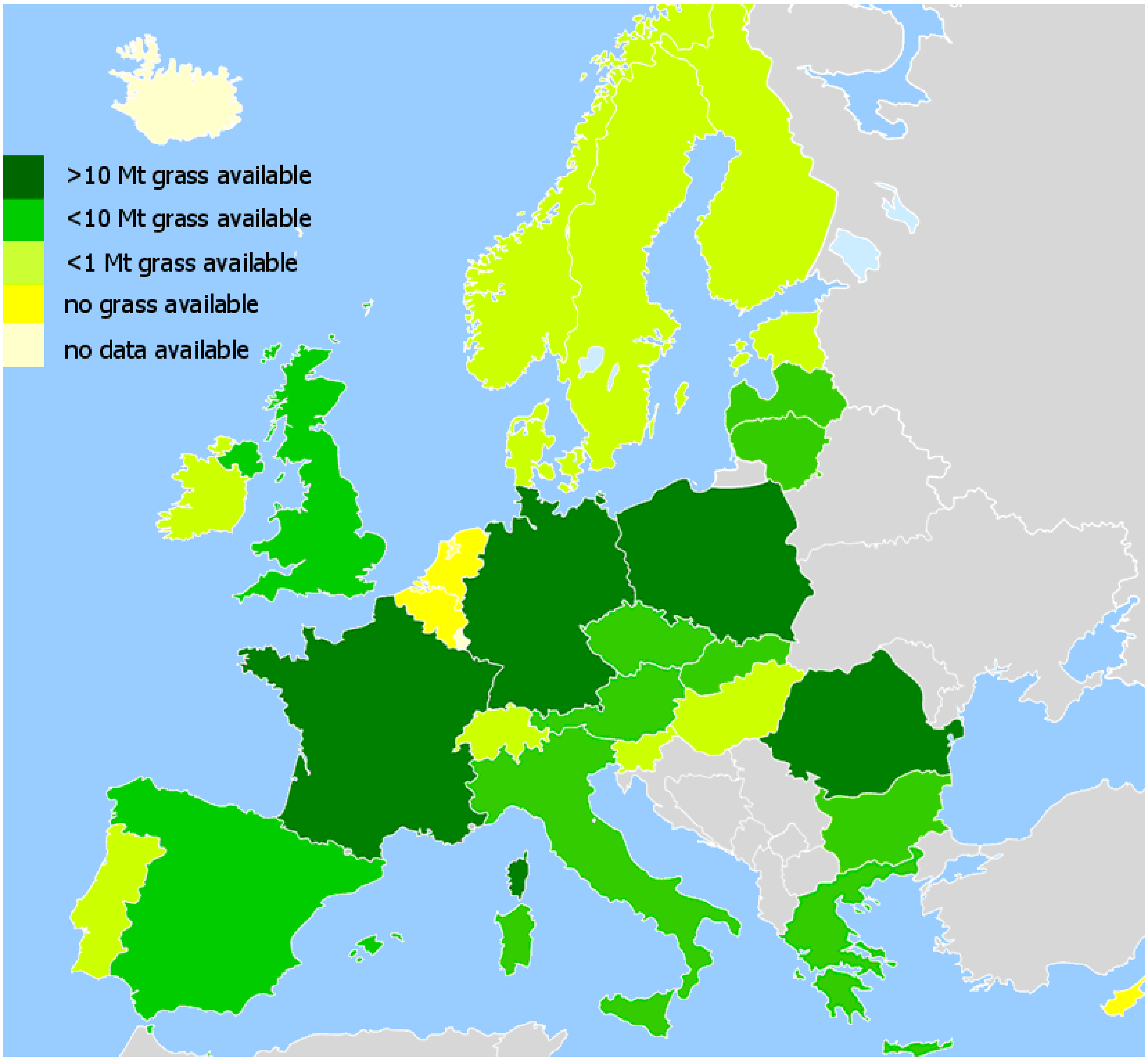

Figure 9. Grass currently not used as feed and potentially available for biorefinery applications. Data refer to the year 2000 in the EU27 plus Norway, Switzerland and Iceland. Based on Fischer et al, 2007.

The mapping of feedstocks in the EU27+ shows, that several Eastern EU countries have a high potential for biorefinery based on feedstock availability. The fact that no biorefineries, or biorefinery-related R&D, pilots and demonstration projects were identified in these countries seems to imply that beside feedstock availability other factors such as a good infrastructure, the presence of (petro)chemical industries, and possibly other factors are required for the development of biorefinery plants.

8.2. Current processing potential of existing facilities

In order to obtain insights into current and future biorefinery processing potentials, a desk study was performed addressing the following topics:

- Indication of current biorefinery processing potential resulting from the questionnaire based industry survey (see Chapter 3) and the mapping of existing and planned biorefineries in the EU-27+ [12];
- Estimates of the total amounts of bio-based products produced today and projections for the growth of the share of bio-based products in the chemical sector.
- The availability of biomass feedstock in the EU for biorefinery and projections of the potential use for bio-based chemicals production.
- Indication of the technological improvement potentials of biorefinery concepts.

According to the results of the industrial survey, mainly oilseed-based and lignocellulosic-based feedstock is used. This is dominated by rapeseed, wheat and maize. The energetic use of biomass predominates and is planned to be increased in future. Especially important is the production of first generation biofuels, heat and power. Some of the surveyed companies intend to produce e.g. biopolymers or other bioproducts in five to ten years. An expansion of the production of bulk chemicals derived from biomass, which is expected to be a promising application field, could not be observed within the survey due to lack of information. This shows that potential exists in this field in Europe which is yet to be capitalised upon.

In total 34 existing or planned biorefineries have been identified:

- The total feedstock processing capacity of the 34 identified existing and planned biorefineries in the EU27+ is estimated to be on the order of 15 million tonnes of processed feedstock per year.
- The scale of the identified biorefineries ranges from 5 ktonnes to 1,000 ktonnes of processing capacity per year.
- More than half of the identified biorefineries are relatively small scale plants, with a capacity <50 ktonnes feedstock processed per year. This illustrates the early development stage of these biorefinery facilities and also seems to indicate that most of these plants are not (yet) operating on a commercial basis.
- Several large scale biorefinery plants (with a capacity >500 ktonnes per year up to several 1000s of ktonnes per plant per year) have been identified. These biorefineries are in all cases based on existing processing facilities in the agro-industrial sector, the oil seed processing/biofuels sector and the pulp and paper production sector.

Current policy targets formulated in the EU and the USA address the implementation of renewable energy including electricity and heat from biomass and transportation biofuels. There are no formal targets in place for bio-based products.

The current estimated bio-based products market volume is ca. 250 € billion in the EU25 with an estimated potential growth to 330 billion € per year based on technical potential. Published techno-economic assessments and scenario studies for the EU and the US indicate a realistic

[12] Jointly undertakem by the Biopol and Biorefinery Euroview teams.

potential for a substantial additional share of bio-based products and materials in specified market categories. A potential for further penetration/substitution of bioproducts ranging up to 30% by 2030 is estimated by various sources. A large potential exists for bioproducts in the categories organic platform chemicals (“building blocks”), polymers, organic acids, alcohols and solvents. Other categories with expected growth are lubricants, surfactants, and fibre materials including composites.

The environmentally compatible bio-energy potential according to the EEA increases from 7,950 PJ in 2010, to approx. 9,800 PJ in 2020 and to ca. 12,350 PJ in 2030. The bio-energy potential is sufficient to attain the EU renewable energy target in 2010, which requires an estimated 6,300 PJ of biomass use. It also allows ambitious future renewable energy targets beyond 2010. The bioenergy potential in 2030 represents 15-16% of the projected primary energy requirements of the EU25 in 2030.

A 10% extra share of bio-based chemicals would require 860 PJ and 1160 PJ of biomass in 2020 and 2030 respectively. This is 8-10% of the available biomass in the EU25 in 2020 and 2030. A 20% substitution level would require 1700 PJ in 2020 and 2300 PJ in 2030 or 18-19%. A 30% substitution will require 2580 PJ in 2020 and 3500 PJ in 2030 or 26-28% of the biomass potential.

In principle sufficient domestic biomass is available in the EU to realise ambitious targets for bio-based products. However, if only domestic biomass produced in the EU25 is used, this will lower the ability to produce biofuels and bioenergy. A choice for one or the other option will depend on a quantitative comparative assessment of the ecological and economic benefits of biomass use for bio-based products versus other, energetic purposes. Therefore a quantitative evaluation of the improvement potential of biorefinery versus current processing and bioenergy production is required. An alternative (or additional) option could be to import additional biomass.

The improvement potential of biorefineries could not be reliably estimated with the available data. Nevertheless a positive improvement potential in economic and ecological terms is indicated in particular when considering the processing of lignin and the production of bioproducts using biotechnological processes. Lignin valorisation and upgrading is an important tool for techno-economic feasibility and the realisation of added economic and ecological value especially in combination with the expected roll-out of biofuels production from lignocellulose.

8.3. Recommendations

The majority of identified biorefineries and biorefinery-related R&D projects, pilots and demonstration projects are located in Western Europe, followed by Northern Europe. It is recommended to perform a more detailed analysis of the factors that have led to the relatively successful implementation of the biorefinery concept in Western and Northern Europe.

No existing biorefineries or major R&D projects or pilot plants have been identified in Eastern EU countries. The mapping of feedstocks in the EU27+ shows however that several Eastern EU countries have a high potential for biorefinery based on feedstock availability.

This seems to imply that beside feedstock availability other factors such as a good infrastructure, the presence of (petro)chemical industries, and possibly other factors are required for the development of biorefinery plants. It is recommended to analyse the existing barriers for the development of the biorefinery concept in Eastern EU countries and to identify potential solutions to alleviate these obstacles.

As a result of the study an up-to-date, elaborate mapping of existing and planned biorefinery plants, R&D projects, pilots and demonstrations in the EU27+ is available. It is recommended to continue monitoring of the evolution of biorefineries in Europe by periodic updates of the mapping results. In particular this should be done employing a more regional approach with respect to feedstock availability, the presence of specific industries and other relevant factors.

The improvement potential of biorefineries could not be reliably estimated with the available data. Nevertheless a positive improvement potential in economic and ecological terms is indicated in particular when considering the processing of lignin and the production of bioproducts using biotechnological processes. To obtain insight in the improvement potential of biorefineries a detailed quantitative analysis is recommended of well defined, real-life biorefinery case studies preferably based on existing plants where actual process data can be made available for detailed modelling and calculations (mass and energy balance, costs and emissions) and an LCA type analyses. Such integrated analyses are required for quantitative comparative assessments of the ecological and economic benefits of biomass use for bio-based products versus other, energetic purposes.

In principle sufficient domestic biomass is available in Europe to realise ambitious targets for bio-based products. However, if only domestic biomass produced in the EU25 is used, this will lower the ability to produce biofuels and bioenergy. It is recommended to perform an assessment of the EU wide opportunities of large-scale biomass imports for biorefinery in general and for specific applications in products, fuels etc.

Lignin valorisation is an important tool for techno-economic feasibility of advanced biorefineries and the realization of added economic and ecological value especially in combination with the expected implementation of biofuels production from lignocellulose. It is recommended to stimulate R&D on lignin processing and upgrading and the development of new applications for lignin and derived products.

No specific EU targets for bio-based products are in place. It is recommended to formulate and implement EU wide targets for bio-based products and promotion of production and application of bioproducts as suggested also in the recommendations in Section 6.4. This could be performed preferably by following the recommendations from the Lead Market Initiative e.g. on the development of sustainability and product standards, eco-labelling, Green Public Procurement Policies (based on LCA) and enhanced, dedicated communication. These instruments could be further elaborated in projects with industrial partners and other stakeholders.
At present the available potential assessments and scenario studies for bio-based products mostly address national markets of EU countries such as Germany, France and the Netherlands. Studies on the European level are lacking. It is recommended to perform such studies at the level of the EU27 and to develop a European Roadmap or Strategic Research Agenda on Biorefinery.

9. Prospects for further demonstration

9.1. Introduction

This report was produced to serve as a reference for biorefinery development in Europe. It contains an analysis of the current states of biorefinery and a model to estimate biorefinery establishment in Europe. The costs of pilot and demonstration scale biorefinery projects were estimated. Recommendations were formulated.

9.2. Current status of biorefineries

Four different biorefinery types were defined and evaluated based on information from the preceding work packages. The following topics were reviewed:

- Technical and economical evaluation of 4 different biorefinery concepts;
- Opinion of industry on biorefinery concepts;
- Opinion of consumers on biorefinery processes;
- Opinion of politicians on biorefinery concepts and strategies;
- Presence of factors that will enhance future biorefinery establishment.

The information from the other work packages was collected, processed, combined and presented in graphs. Through these graphs the strengths and weaknesses of biorefinery in Europe were visualised. General results, biorefinery concept-specific results and region-specific results were derived.

9.2.1. Results of general analysis

The general opinion (from industry, consumers and politicians) on biorefineries is positive (Figure 10). Some improvement is possible on the following issues:

- Regulations;
- Economic issues (profitability);
- Feedstock/raw material problems;
- Plant/mill/manufacturing problems;
- (Perception of) Eco-friendliness of biorefineries;
- Acceptance of use of agricultural products for non food non feed applications;
- Opinion of several political stakeholders on biorefineries;
- Food and feed competition.

Label	Issue
1	Promising concept
2	Economical potential
3	Implementable
4	Interesting markets
5	Fits into regulations
6	Economical barriers
7	Political/legal barriers
8	Technological barriers
9	Other barriers
10	Feedstock/raw material problems
11	Plant/mill/manufacturing problems
12	Problems with market conditions
13	General attitude
14	Biorefineries are eco-friendly
15	Technical materials
16	Birefineries are odourless
17	Willingness to pay
18	Stakeholder opinion
19	CO_2 reduction
20	Security of supply
21	Food and feed competition
22	(Rural) economy

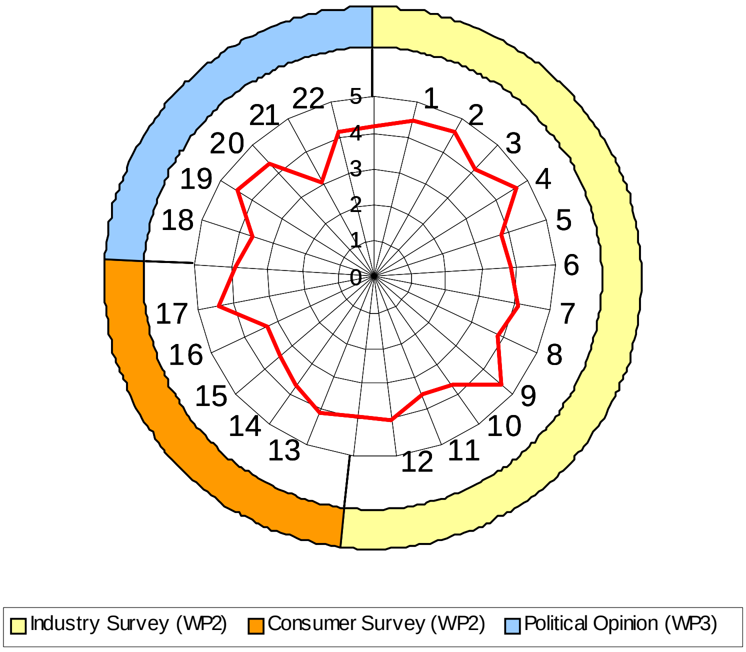

Figure 10. Likeliness score biorefinery establishment based on selected parameters from the industry survey, the consumer survey and political opinions.

9.2.2. Results of biorefinery type specific analysis

The *whole crop biorefinery* is ready for demonstration. High feedstock costs are expected for crops but low feedstock costs for currently under-utilised fractions such as straw. Technological improvement is expected for processing of lignocellulosic feedstocks. The high availability of crops and straw in Western Europe, and good side-products markets present in Western Europe are positive for this biorefinery type.

The technical feasibility of the *lignocellulosic biorefinery* is currently low, but further development might well result in much better feasibility. Low feedstock costs are expected for biomass that is currently left behind on the field or in the forest. Again the high availability of straw and wood in Western Europe, the high availability of wood in Northern Europe, Western and Eastern Europe and good side markets present in Western Europe are positive circumstances.

The *green biorefinery* is ready for demonstration and improvement is still expected. It has relatively low capital costs and low feedstock costs. It is driven by a high production of grass in Western Europe.

Finally the *syngas biorefinery* is ready for full scale implementation. Little technical improvement is expected. It has relatively high capital costs, but low feedstock costs for biomass (especially biomass that is currently left behind on the field or in the forest). The high availability of straw and wood in Western Europe, high availability of wood in Northern Europe, Western and Eastern Europe, and good side-product markets present in Western Europe are positive circumstances again.

9.2.3. Region specific analysis

Western Europe has the best prospects for biorefinery development. It has: high agricultural yields, vast amounts of lignocellulosic agricultural side streams, considerable forestry and good possibilities to sell biorefinery side products. The countries in the East of Europe have good opportunities to improve agricultural yields. Thus they could become interesting countries for biorefinery establishment. Northern Europe is currently a natural market leader of lignocellulosic biorefinery due to the presence of large forests.

9.3. Likeliness of biorefinery establishment

A model was produced to estimate likeliness of biorefinery establishment based on establishment factors. The establishment of new biorefineries in a certain region will depend on numerous establishment factors such as land use in surrounding area, presence of animal husbandry, presence of oil refineries and chemical industry and transport possibilities. As a calibration test, the model was used to 'predict' the establishment of current biofuel production facilities and pulp and paper facilities. The current biofuel production facilities and paper and pulp facilities are indeed situated in countries with high biorefinery establishment likeliness.

The model was then used to estimate the likeliness of biorefinery establishment in all the countries of Europe (Table 13).

- *Whole crop biorefinery* will develop in traditional areas of wheat, potato or sugar beet production (France and Germany) and near harbours and where feed is needed (Belgium and The Netherlands). Wheat is more easily transported over large distances than potatoes and sugar beets (which have far larger water content). Therefore, wheat is more likely to be processed in harbour areas such as Rotterdam and Antwerp and potatoes and sugar beets are more likely to be processed in the area where they are grown. The analysis shows opportunities for whole crop biorefinery in Belgium, Czech Republic, Denmark, France, Germany, Hungary and the United Kingdom.
- *Lignocellulosic biorefinery* will mainly develop in straw regions (e.g. France and Germany) and possibly in wood regions (like Sweden and Finland). Lignocellulosic biorefineries might also develop in countries with large harbours that can import lignocellulosic feedstocks and countries with well developed oil refineries and base chemical production sites (like The Netherlands and Belgium). The likeliness of lignocellulosic biorefinery in the analysis is high in Austria, Belgium, Czech Republic, Denmark, Estonia, France, Germany, Hungary, Latvia, The Netherlands, Slovak Republic and Sweden.
- *Green biorefinery* will develop in regions where grass and clover are produced (wet agricultural land) and where feed for animals is needed. These areas can be found in the whole of Europe, but mostly in Western Europe. Countries that show high

opportunities for green biorefinery in the analysis are Belgium, France, Germany, Ireland, The Netherlands and the United Kingdom.

- *Syngas biorefinery* will preferentially develop in an area with large availability of lignocellulosic raw materials (wood or straw), harbours (supply of feedstocks) and traditional oil refineries and base chemical production (to further process the synthesis gas). The transport of lignocellulosic raw material is relatively easy (no decay) and therefore, syngas biorefinery might also develop in regions with less lignocellulosic biomass, but better harbour facilities. Syngas biorefineries have high chances of development according to the analysis in the countries Austria, Belgium, Czech Republic, Estonia, Finland, France, Germany, Latvia, The Netherlands, Slovak Republic and Sweden.

Country	**EU code**	**WCBR**	**LCBR**	**GreenBR**	**SynBR**
Austria	AT	Light green	Dark green	Light green	Green
Belgium	BE	Dark green	Dark green	Green	Dark green
Bulgaria	BG				
Cyprus	CY				
Czech Republic	CZ	Green	Dark green		Green
Denmark	DK	Dark green	Green		Light green
Estonia	EE		Dark green		Green
Finland	FI		Green		Green
France	FR	Dark green	Dark green	Dark green	Dark green
Germany	DE	Green	Dark green	Green	Dark green
Greece	EL				
Hungary	HU	Dark green	Green		Green
Iceland	IC				
Ireland	IE			Dark green	
Italy	IT	Light green	Light green	Light green	Light green
Latvia	LV		Green		Green
Lithuania	LT		Light green		Light green
Luxembourg	LU	Light green	Light green		Light green
Malta	MT	Light green		Light green	
The Netherlands	NL	Dark green	Green	Dark green	Green
Norway	NO				
Poland	PL	Light green	Light green	Light green	Light green
Portugal	PT		Light green		Light green
Romania	RO		Light green	Light green	Light green
Slovak Republic	SK	Light green	Green		Green
Slovenia	SL		Green		Light green
Spain	ES		Light green	Light green	Light green
Sweden	SE		Dark green		Green
Switzerland	CH		Light green	Light green	Light green
United Kingdom	UK	Green	Light green	Dark green	Light green

Legend

Color	**Establishment**
Dark green	Very likely
Green	Likely
Light green	Possible if proper measures are taken

Table 13. Summary of countries with high establishment factors

9.4. Cost estimates

Costs of pilot and demonstration-scale biorefineries were estimated from a full-scale plant perspective, from a research project point of view, and from real world pilot- and demonstration-scale biorefineries.

- The costs of demonstration plants can be estimated from the fixed capital investment, the costs of raw materials and the costs of utilities. Adaptation has been employed to account for higher labour costs.
- The fixed capital costs will be higher for stand-alone plants than for plants alongside another plant.
- The costs of pilot plants should be calculated from the research perspective.
- The real world pilots and demonstrations show a huge spread of investment costs ranging from 3 M€ to 200 M€.

9.5. Recommendations

The following general recommendations could help the establishment of biorefineries: improve regulations, improve profitability (cut costs, increase revenues), solve technological issues, improve image of biorefineries and tackle food and feed issue.

If the image of biorefineries is improved and if the food and feed issue is tackled, it is expected that the negative opinion of some political stakeholders will also change.

Establishment and type of biorefinery should depend on the local circumstances (establishment factors).

The North of Europe could attract more chemical industry to increase the efficiency of their lignocellulosic biorefineries. This way, the presence of lignocellulosic biorefineries could become an establishment factor for the chemical industry instead of the other way around.

In the East of Europe the agricultural yield could be increased. This would also increase the likeliness of biorefinery establishment in this region.

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Chapter 3 - Acceptance of biorefinery concepts amongst industrial actors, consumers and NGOs

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Chapter 5 – Political legitimicy of biorefineries

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Chapter 8. Current implementation status

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11. Dissemination activities

Project results were disseminated via three primary means: two public workshops, a range of publications in the academic and non-academic press, and public BIOPOL deliverables.

11.1. Workshops

The two workshops were held on 12 February 2008 and 30 March 2009. The first workshop was used to ask the stakeholders to provide suggestions and recommendations concerning the biorefinery concept. The second workshop presented the biorefinery assessments and recommendations to European Stakeholders and policy makers. Correspondingly, both one-day workshops included a lecture program. The first workshop included parallel discussion sessions on specific topics that could feed information into the relevant work packages. The second workshop included an interactive panel discussion session to engage participants in a discussion about the implications for industry and policy.

Each workshop attracted over 100 people from 15 European countries, plus representatives of Canada, Nigeria, and South Africa. Representatives of the European Technology Platforms (Biofuels, Plants for the Future, Forestry and SusChem) were specifically invited to both workshops. The second workshop was addressed by an external speaker from Natural Resources Canada, who was joined for the panel discussion by representatives of the Port of Rotterdam, the Biofuels Technology Platform, North-Rhine Westphalia state and the European Commission DG Research.

In addition to disseminating project work and results, the workshops provided important inputs. One conclusion that emerged from these events was that even amongst groups of experts there remains a great deal of inconsistency regarding definitions, expectations and recommendations for biorefinery development. Interaction between project partners, policymakers, industrialists, researchers and others during the events revealed the importance of understanding and incorporating the current strategies behind actors in the biorefinery field. Industrial actors found it difficult to reconcile their activities (products or facilities) against the optimised biorefinery concepts developed by the project. The influence of this input is evident in the work on biorefinery demonstration and scenarios. The demonstration strategies modelled include the possibility of incorporating biorefinery processes into existing operations. The techno-economic scenarios look at the opportunities for using by-products to deliver additional value to current enterprises.

Reports of the workshops have been published in the Green Chemistry Newsletter and at www.biorefinery.nl/biopol.

11.2. Publications

Submitting four papers containing project results for publication in peer-reviewed journals was a project deliverable. This number was exceeded and hopefully further papers will be published after the project close.

11.2.1. Papers submitted and accepted for publication as of April 2009

Bennett, S. J., Annevelink, E. (2009) Establishing a sustainable biorefining industry. In Focus Editorial. *Biofpr*. 3 (3) Forthcoming.

Kamm, B., Schönicke, P., Kamm, M. (2009) Biorefining of green biomass - technical and energetic considerations. *CLEAN*. 37 (1) 27 – 30.

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Kamm, B., Schönicke, P., Kamm, M. (2009) The whole crop biorefinery - technical and energetic considerations. *Biofpr*. Forthcoming.

Kurka, S., Menrad K. (2009) Biorefineries and bio-based products from the consumer's point of view. *Proceedings of the ICABR International Consortium on Agricultural Biotechnology Research 2009*.

11.2.2. Papers that are expected and are forthcoming as of April 2009

Paper arising from Work Package 5 on 'Demonstration potentials'.

Paper arising from Work Package 3 on 'Techno-economic modelling of biorefinery processes in the European energy economy'

Paper arising from Work Package 2 on 'View of consumers towards biorefinery concepts.'

Paper arising from the final project report and summarising how the various research activities inform the overall conclusions.

11.2.3. Other publications publicising Biopol work

Annevelink, E. (2007) Assessment of BIOrefinery concepts and the implications for agriculture and forestry POLicy. Poster presentation at European Biomass Conference, Berlin, May 2007

Bennett, S. J., Pearson, P. J. G. (2008) Institutional barriers to industrial biorefineries: A study of developments and attitudes in the UK. Oral presentation at RRB4, Rotterdam, June 2008

Bennett, S. J., Pearson, P. J. G. (2008) Unlocking the petroleum-chemical complex. Oral presentation at RSC ‘Future Energy: Chemical Solutions’, Nottingham, September 2007

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Bennett, S. J. (2009) Bioplastics: Growing a new industry. *Cleantech*. 3 (1)12

Kurka, S. Menrad K. (2009) *View of consumers towards biorefinery concepts*. Poster presentation at Biorefinica 2009, Osnabrueck, January 2009

The BioreFuture 2009 Workshop. Article in Green Chemistry Network Newsletter. Forthcoming

11.3. Public BIOPOL deliverables

Del. no.	Deliverable name
1.1.1	Note with a description of the general biorefinery concept, consisting of a chain of linked composing sub-processes
1.3	Report with results technical, economic and ecological system assessments which outlines the theoretical market perspective for biorefinery concepts based on carbohydrates, oils and fibres (incl. forest biomass)
2.1.1	Note on literature overview concerning market introduction and development of biorefinery concepts and related products
2.1.3 combined with 4.1	Report of market acceptance of biorefinery concepts (including results of written survey and interviews) Note with results questionnaire and interviews market acceptance for the biorefinery concept amongst industry (and other stakeholders)
2.1.3b	Consumer acceptance
2.2.3	Note Report with the assessment results concerning the impact of biorefineries on rural development, employment and environment
3.1.1 combined with 3.1.2	Note with contributions national questionnaires and depth interviews concerning political legitimacy of biorefineries Note with results EU assessment political legitimacy of biorefineries
3.2.1	Note with results analysis broad scenarios concerning the implications of renewables policies, forestry policy, and agricultural policy for biorefinery viability
3.2.2	Report with results targeted scenario analysis concerning the implications of renewables policies, forestry policy, and agricultural policy for biorefinery viability
4.2	Note with results identification, classification and mapping of existing EU biorefineries
5.1.2	Report with results scenario-analyses showing the potential and economic profitability of biorefinery concepts a) alongside existing facilities and b) for the implementation of new plants
5.2	Common agenda partners BIOPOL project and running EP Technology Platforms (and potential other EU biorefinery-related activities – if wanted) for the promotion of new biorefinery pilot and demonstration plants
6.3	A project website fully operational (www.biorefinery.nl/biopol)