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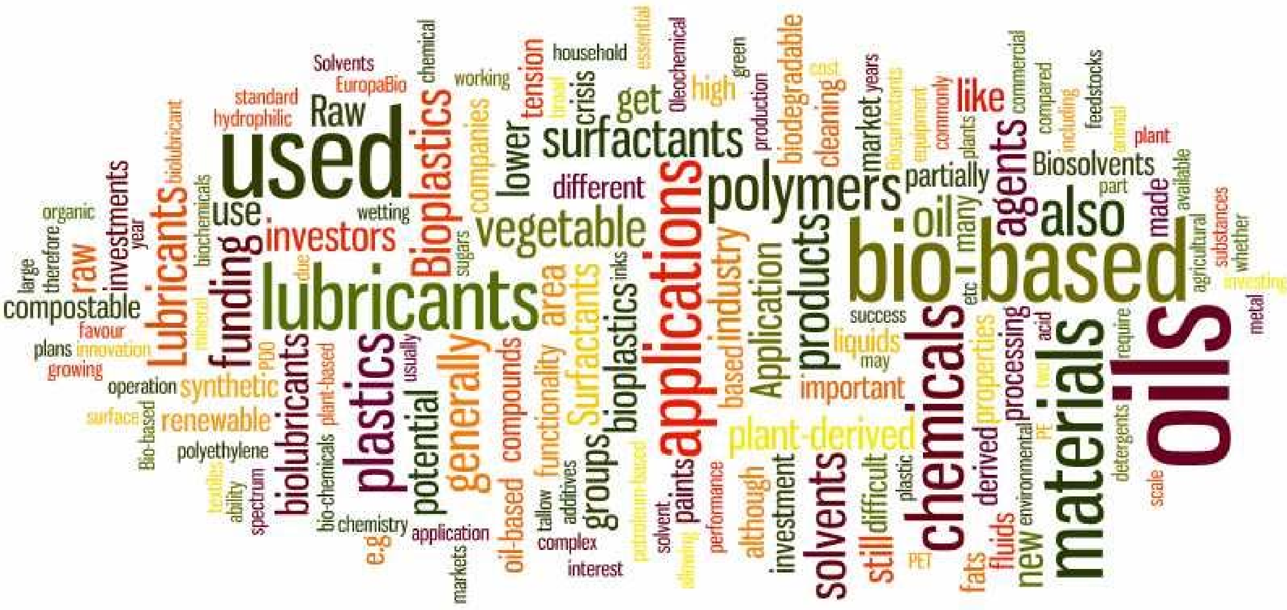
D2.3 - Report on the "Assessment of the Bio-based Products Market Potential for Innovation"



European Commission
Enterprise and Industry

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Contents

EXECUTIVE SUMMARY

This report, prepared by Pöyry Management Consulting, provides insight into the market potential of bio-based chemicals and into factors that may hinder the exploitation of this potential. The ultimate aim is to provide information to companies, particularly SMEs, to assist in decision-making and to support the development of new support tools within the context of the BIOCHEM project. In terms of scope, this report covers four product segments, namely bio-plastics, bio-lubricants, bio-solvents and bio-surfactants.

Chapter 2 of this report provides future growth estimates for bio-based products. The total volume growth of major bio-based chemical groups between 2008-2020 is estimated at 2.1 Mt (5.3% pa). Assuming similar market value growth, the market is estimated to grow from current (2008) 21 billion EUR to 40 billion EUR in 2020. This will increase the market share of bio-based products from 4% in 2008 to 6% in 2020, providing 43,600 new jobs within the biochemical industry only. Future growth will be affected by the cost of biomass feedstocks but also by fossil fuel prices and by the level of public support.

The volume of the European *bio-plastics* market totalled 0.13 Mt in 2008 and is estimated to grow to 0.9 Mt in 2020 (growth rate 16% pa). At the current state of technology, 5-10% of the plastics market could theoretically be bio-plastics and the long-term potential (2030 onwards) is significantly higher (70-100%). In the initial phase of market introduction, products are often used in niche markets, but some bio-based polymer applications have already gained an established position in the market. Recently, it has also become technically feasible to either partially or totally substitute fossil-based raw materials with renewable raw materials in standard and high-performance polymers.

Annual *bio-lubricant* consumption in the EU totalled 0.15 Mt in 2008 and is estimated to grow to 0.23 Mt in 2020 (growth rate 3.6% pa). The current market penetration of bio-lubricants varies considerably within the EU, and not all bio-lubricants are completely vegetable oil-based. Theoretically around 90% of lubricants currently used could be replaced by plant-derived chemicals.

The EU *bio-solvent* consumption totalled 0.63 Mt in 2008 and is estimated to grow annually by 4.8%, reaching 1.1 Mt in 2020.

The consumption of *bio-surfactants* totalled 1.52 Mt in the EU in 2008. Annual growth potential is estimated to be 3.5%, and bio-surfactant potential 2.3 Mt in 2020.

Chapter 3 gives an overview of the impact of bio-based products on the environment, society and economy. Most bio-based products consume less energy and emit less carbon dioxide than products produced from fossil resources. Vegetable solvents emit few or no volatile organic compounds; and bioproducts offer potential to reduce the generation of toxic wastes. The social impacts primarily relate to employment creation and the potential for rural development. The economic benefits derive from a growing bio-based products market and the macroeconomic savings of bio-based products when compared to petrochemical based.

Chapter 4 focuses on the identification of market and technology drivers, barriers and industry needs.

The expected rapid growth in *bio-plastics* is driven by concerns about oil prices, high technical substitution potential and superior product properties such as biodegradability. Major barriers to market uptake include economic barriers and competition with fossil fuel based plastics, for which the production and end use has been optimised for decades and which are well known in the entire supply chain. There are also challenges in scale-up and in the short term availability of bio-based feedstocks.

The *bio-lubricant* industry is growing based on environmental concerns as some countries have already banned the use of non-biodegradable lubricants in sensitive areas, at least in applications where oils are lost into the soil and surface water. Other motivations are concerns about oil prices and high technical substitution potential. Bio-lubricants are more expensive than conventional products, which is the major barrier to market uptake. However, the higher cost may be partly offset by the reduced need for replacement due to the longer lifespan of bio-lubricants.

The advantage of *bio-based solvents* is that the vast majority do not emit volatile organic compounds which are harmful to human health. However, bio-solvent production is not currently cost-effective enough to compete with traditional solvent manufacture. Research into the use of bio-solvents in chemical synthesis is advancing, with the successful replacement of organic and halogenated solvents demonstrated for a range of syntheses. The production of common organic solvents from biological feedstocks is also being investigated, allowing bio-solvent production at lower cost and higher purity. Similarly to other product segments, concern about future increases in the price of oil is also a driver for development.

The major drivers in the surfactant market are price, performance and product safety. Advantages of *bio-derived surfactants* include biodegradability, low toxicity and raw material availability as they can be produced from industrial waste or by-products. Similarly to other product segments, concern about future increases in the price of oil is also a driver for development. The major barrier to market uptake is the higher production cost.

Chapter 5 summarises the relevance of biomass feedstocks and platform chemicals for the development of the bio-based chemicals sector. The main biochemical feedstock groups are energy crops form both agriculture and aquaculture and biomass residues from agriculture, forestry and industry. At the present time, bio-based production mainly utilises crop feedstocks, but the role of algae in the generation of bio-based feedstock is expected to increase in the future.

Most bioproducts of biotechnology are based on C_6-sugar. Sugar consumption for the production of biochemicals will increasingly compete with the food and biofuel industry. This may result in a rising cost of sugar and a societal discussion about land use for food and fuel[24]. Limited sugar availability is already a driver for the use of lignocellulosic carbon sources such as waste biomass from agriculture or forest biomass.

The concept of biorefineries is a combination of integrated plants addressing the processing and fractionation of renewable raw materials, transforming feedstocks ~~to~~ into various products. Sugars, oils and other compounds in biomass can be converted directly into platform chemicals or chemical building blocks or as by-products from fuel production processes analogous to the petrochemical industry today. New advanced biorefinery concepts are still mostly in the R&D, pilot or small-scale demonstration phase. It is expected that these new concepts will be implemented in the market in the medium term (2013-2020).

In the biofuel sector production is generally located where feedstock costs are lowest. This may have an impact on the geographical distribution of biochemical production.

Chapter 6 focuses on the mechanisms available for demonstrating the properties and environmental competitive advantages of the bio-based sector. These include life cycle assessment, environmental technology verification, standardisation, certification and eco-labels.

Chapter 7 presents examples of successful and innovative bio-based products in the form of selected case studies.

Chapter 8 includes the recommendations. They can be summarised as follows:

1. Attitudes
   - Public risk funding should actually take risks and expect a high failure ratio for every big success.
2. R&D, education and open innovation
   - IPR support (expertise and funding) for SMEs and matching of SME IPR by public/private agencies.
   - Establishment of European Bioacademies: Networks of universities, research institutes and companies including SMEs, where graduate schools with e.g. public/private funding would have students getting their doctorates and post-doctoral merits solving problems provided by groupings of SMEs.
   - Establishment of a Biochemical Open Innovation Forum to distribute ideas and innovation and make them available to those who may be able to turn them into world-class products and services.
3. Financing
   - Provision of a rich array of public, public/private and angel instruments for SMEs.
4. Networking and roles in the supply chain
   - Support for building cooperations networks and supply chains.
   - Establishment of biomaterials exchanges, where, with public/private sponsorship, biomaterial developers and end use sectors would meet.
5. Scalability and markets

- Improving access to specialist demonstration facilities for proof of principle.
- Creation of tools for management/financial evaluation and market assessment support at an early stage to SMEs.
- Implementation of policies related to measures reducing production costs (e.g. tax incentives) at an early market stage
- Support to accompanying policies (climate change, agriculture, forestry) at a mass market stage in order to guarantee the realisation of positive external effects and to avoid the risk of insufficient supply of raw materials.
- Development of tools and support for sustainability policies and sustainability argumentation: environmental, social, and economic.

6. Regulation and standardisation
    - Identifying key EU regulation in areas relevant to bio-based chemicals,
    - Identifying the elements that best promote SME success, and
    - Introducing consistency and clarity.

1 INTRODUCTION

This report (D2.3 - “Assessment of the Bio-based Products Market Potential for Innovation”) has been prepared by Pöyry Management Consulting. It is a deliverable of WP2 (Market Assessment and Needs Assessment) of the BIOCHEM project with the aim to provide insight into the market structure and stakeholders, including risks and barriers related to the development of the European bio-based industries. The ultimate purpose of this report is to support companies – particularly small and medium sized companies (SMEs) - in making decisions on the potential viability of investments to enter this market, and to provide input for the development of new support tools that will help overcome the main barriers to innovation. It will also serve as a reference document for stakeholders in the European Chemicals Industry involved in the development of the bio-based sector as the BIOCHEM project aims at accelerating the growth rate of transnational bio-based businesses.

This report has as its goal to summarise the current knowledge of the market structure and potential for innovation of the bio-based product sectors. It provides consolidated literature reviews of

- market potential of bio-based products (updated with a Pöyry interpretation of the effects of the world economic crisis) (Chapter 2)
- impacts of this market potential on the environment, on people and on the economy (Chapter 3)
- identified market and technology drivers and barriers (Chapter 4)
- opportunities for platform chemicals (Chapter 5)
- main environmental issues related to bio-based products (Chapter 6)

Moreover, case studies of successful innovation are presented (Chapter 7) and recommendations given to overcome barriers in the bio-based product supply chain (Chapter 8).

The time span of this report is short to medium term, i.e. up to 2020. *Bio-based products* refer here to non-food products derived from biomass (plants, algae, crops, trees, marine organisms and biological waste from households, animals and food production). Bio-based products may range from high-value added fine chemicals such as pharmaceuticals, cosmetics, food additives etc., to high volume materials such as general bio-polymers or chemical feedstocks. Within the context of the Lead Market Initiative (LMI) the segments chosen for the initial focus of the BIOCHEM project are bio-plastics, bio-lubricants, bio-surfactants, enzymes and pharmaceuticals. The concept excludes traditional bio-based products, such as pulp and paper, wood products, bio-fuels and biomass as an energy source.[1]

Due to limitations in market data availability, this report focuses on four product segments, namely bio-plastics, bio-lubricants, bio-solvents and bio-surfactants. For the purposes of this study, these product groups can be characterised as in the sections below.

1.1 Bio-plastics

Bio-plastics are plastics totally or partially produced on the basis of renewable resources. A large proportion of certified (EN13432) compostable plastic products available on the market contain a high portion of renewable raw materials. However, bio-based polymers are not in all cases biodegradable and compostable.[2]

Existing and emerging bio-based bulk plastics are starch plastics, cellulosic polymers, polylactid acid (PLA), polytrimethylene terephthalate (PTT) from bio-based 1,3-propanediol (PDO), bio-based polyamides (nylon), polyhydroxyalkanoates (PHAs), bio-based polyethylene (PE), polyvinyl chloride (PVC) from bio-based PE, other bio-based thermoplastics (polybutylene terephthalate (PBT), polyphenylene sulphide (PBS), polyethylene terephthalate (PET), polyethylene-co-isosorbide terephthalate polymer (PEIT), further polyesters based on PDO), polyurethane (PUR) from bio-based polyols and bio-based thermosets.

New bio-based polymers have been available on the market for approximately one decade and some applications have already gained an established position. Recently, it has also become technically feasible to totally or partially substitute fossil-based raw materials with renewable raw materials in standard polymers like PE, polypropylene, PVC or PET and in high-performance polymers like polyamide or polyester.

Application of bio-plastics
As with conventional plastics, bio-plastics have a very broad application spectrum. Commercial success occurs above all when the particular properties can be transformed into useful product functionality and added value. Environmental aspects are important, too, and many bio-plastics products are still being used in areas where compostability represents a significant benefit (e.g. collection bags for compost, agricultural foils, and graveyard or nursery products). Other applications such as packaging and technical applications are gaining importance. Bio-plastics tend to have a generally very high consumer acceptance.

Raw materials
The starting raw materials are usually sugars or starches, partially also recycled materials from food or wood processing. Algae based resin production has also been announced to be commercialised by the end of 2010[3].

1.2 Bio-lubricants

The term bio-lubricant refers to plant-derived lubricants, whether they are biodegradable or not, and whether they are blended with biodegradable mineral oils or not. Formulations are very complex and they are blends of different types of oils. The bio-lubricants group therefore covers a very broad commercial range, and is not limited to 100% plant-derived lubricants.

Application of bio-lubricants
Lubricants are used in e.g. automotive, industrial, marine and aviation applications. Plant-based lubricants are commonly used in cutting fluids, chainsaw lubricants, metal working fluids, hydraulic oils, 2-stroke engine oils, marine oils and drilling fluids. There is a renewed interest in bio-lubricants due to their distinct performance properties and environmental benefits (biodegradability, lower toxicity), which enable their use in sensitive environments and contributes to pollution prevention.

Raw Materials
A bio-lubricant can be either vegetable oil-based (e.g. rape-seed oils) or based on synthetic esters manufactured from modified oils from mineral oil-based products.

1.3 Bio-solvents

Solvents are liquids that possess the ability to dissolve, dilute or extract other substances without modifying the chemical composition of the extracted substances or of the solvent itself[4]. There are eight main solvent groups: aromatic hydrocarbons, petroleum-based solvents, alcohols, ketones, esters, ethers, glycol ethers, halogenated hydrocarbons and so-called special solvents[4].

Application of bio-solvents
Base on their properties, solvents are used as degreasing agents (cleaning of metals, textiles), additives and diluting compounds (paints, varnishes, inks, glues, pesticides), stripping agents (paint, varnish, glue removers) and extraction solvents (perfumes, pharmaceuticals). Bio-solvents have applications in cleaning, plant-protection oils and wetting agents and biofluxing agents. The vast majority of bio-based solvents do not emit volatile organic compounds (VOC) which are harmful to human health.

Raw materials
Biosolvents can be entirely or partially plant-based. Examples of bio-solvents are soy methyl ester (soy oil esterified with methanol), lactate esters (fermentation derived lactic acid reacted with methanol or ethanol) and D-Limonene (extracted from citrus rinds).

1.4 Bio-surfactants

Surfactants lower the surface tension of liquids, allowing chemicals to mix more easily. Surfactants are usually organic compounds that are amphiphilic, meaning they contain both hydrophobic groups (their tails) and hydrophilic groups (their heads). Bio-surfactants are surfactants in which at least one of the two groups (hydrophilic or hydrophobic) is obtained from plants: they are therefore not necessarily 100% plant-derived[5].

Application of bio-surfactants
Surfactants are used in many industries such as household detergents, personal care, industrial cleaners, food processing, oleofield chemicals, agricultural chemicals, textiles, emulsion polymerization, paints and coatings, lubricant and fuel additives, metal working, mining chemicals, pulp and paper production, leather processing, etc. The largest end use market for surfactants is household cleaning detergents[5].

Raw materials
Surfactants are made from oleochemical (bio-based) and/or petrochemical (synthetic) raw materials. Oleochemical surfactants are commonly derived from plant oils such as coconut and palm oils, from plant carbohydrates such as sorbitol, sucrose and glucose or from animal fats such as tallow. Oleochemical feedstock sourcing for surfactants has been changing in recent years as animal fats have lost ground in favour of vegetable oils.

2 THE WORLD ECONOMIC CRISIS AND ITS EFFECT ON THE STATE-OF-THE-MARKET: A SHORT TO MIDTERM PERSPECTIVE

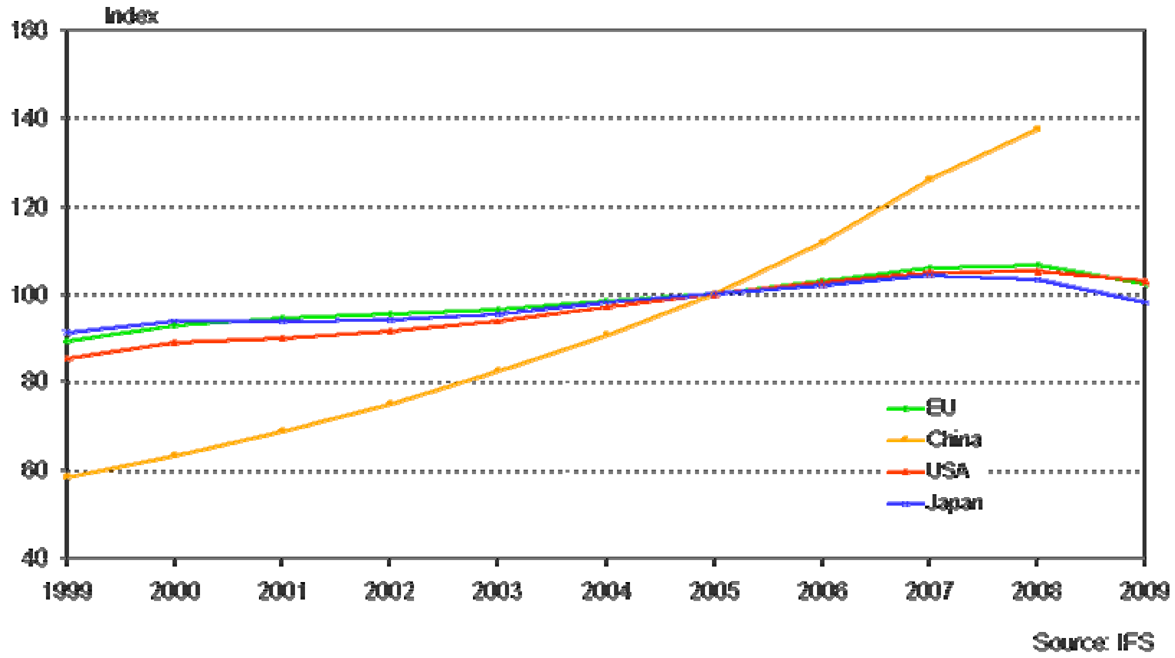
This chapter summarises the effects of the world economic crisis, focusing on observed effects on general economic indicators such as GDP, industrial production and confidence, and on their implications on the bio-based production (funding, raw material prices) and on the production volumes in the short to medium term, i.e. up to 2020.

2.1 Effects on economic indicators

It is obvious that any section on evolving reactions to a crisis becomes outdated very quickly. However, the following should be regarded as a basis; the reader will be aware of what is happening at the time of reading, and can place it relative to the development described here.

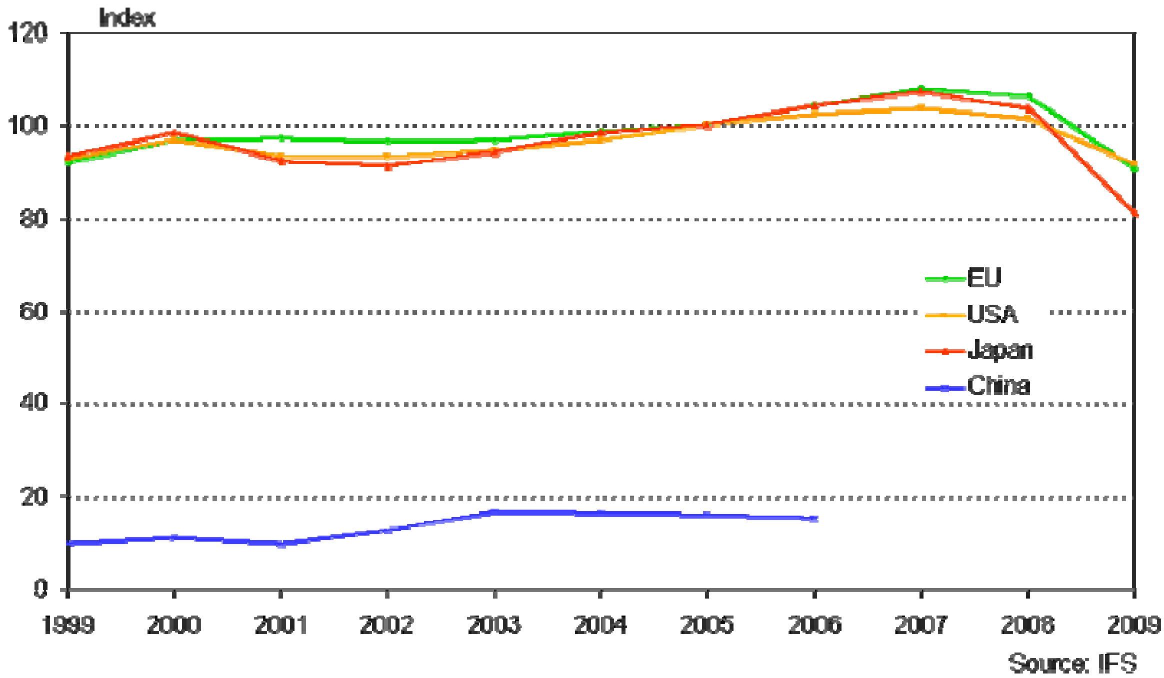
Based on International Financial Statistics (IFS)[6], the annual GDP index regularly grew between 1999 and 2008. Due to the economic crisis, GDP dropped in the EU, USA and Japan in 2009, but the 4th quarter of 2009 indicated a slight recovery. The 2009 GDP estimate for China was not available when writing this report.

Figure 1. Annual GDP development in the EU, USA, Japan and China



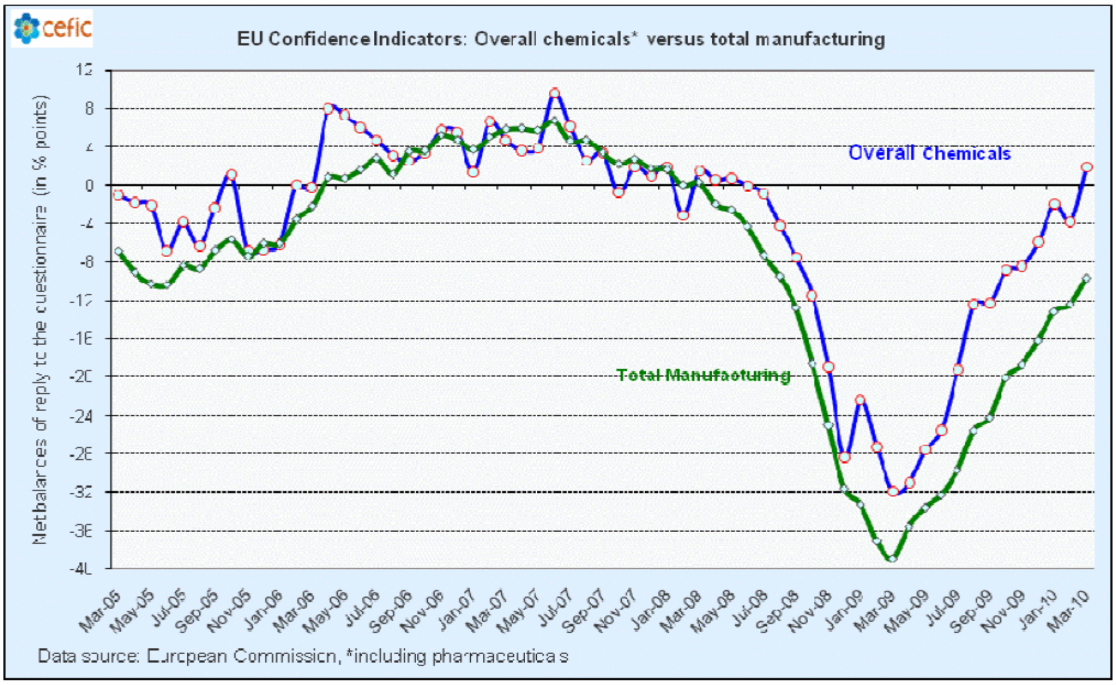
Similarly to GDP development, industrial production development dropped in the EU, USA and Japan in 2009. The 4th quarter in 2009 showed a slight increase in industrial production. Industrial production estimates for China (2007-2009) were not available when writing this report.

Figure 2. Annual industrial development in the EU, USA, Japan and China



The confidence diagram of the EU overall chemical production (including pharmaceuticals) shows a similar pattern to that of total manufacturing (**Figure 3).** After the 2008/2009 drop, the EU chemicals confidence improved from March 2009 to January 2010. In February 2010, however, confidence fell again but recovered in March when the confidence in the EU chemicals industry reached a positive value for the first time in twenty-one months (since May 2008). It can be concluded that the overall chemicals manufacturing has recovered quite well from the economic crisis and that the confidence of the EU chemicals industry is now higher than that in the manufacturing sector and above the long-term average indicated by the zero line.[7]

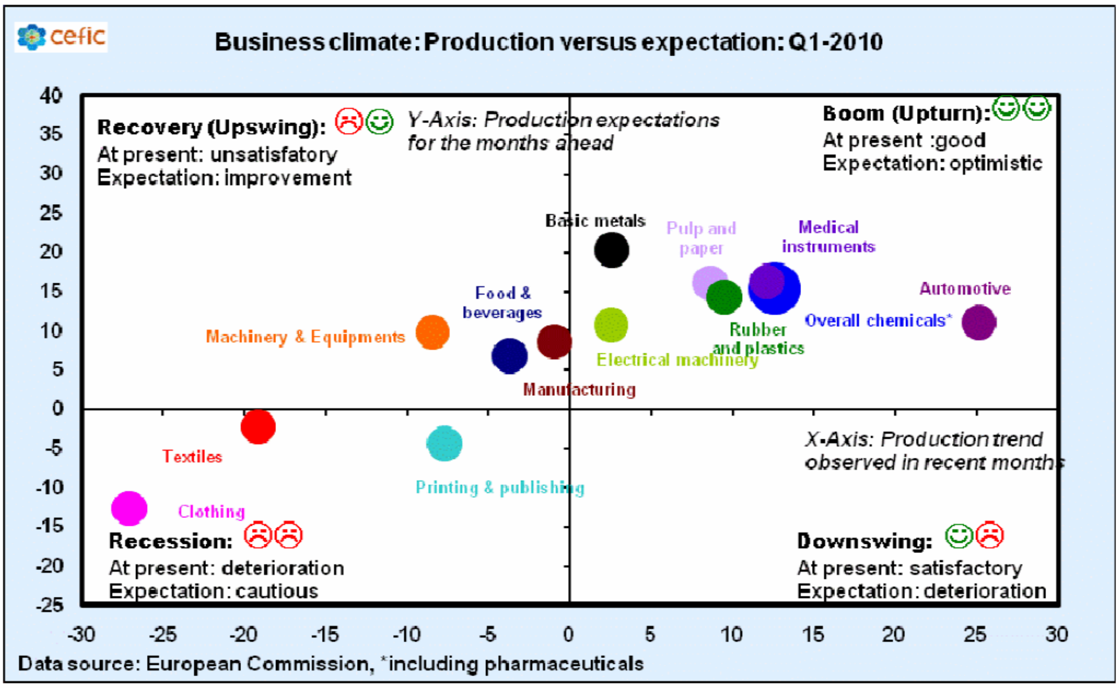
Figure 3. EU confidence indicators: overall chemicals vs. total manufacturing



Source: Cefic [7]

Sectoral data for the first quarter 2010 shows that "automotive", "medical instruments", "rubber and plastics", "pulp and paper" and overall chemicals (including pharmaceuticals) are well positioned compared to the other manufacturing sectors, and registered a positive appraisal of their production trends and production expectations. “Machinery and equipment”, and “foods and beverage” and the manufacturing sector as a whole are still registering a negative appraisal of their production trends but a positive change in product expectations for the months ahead [7].

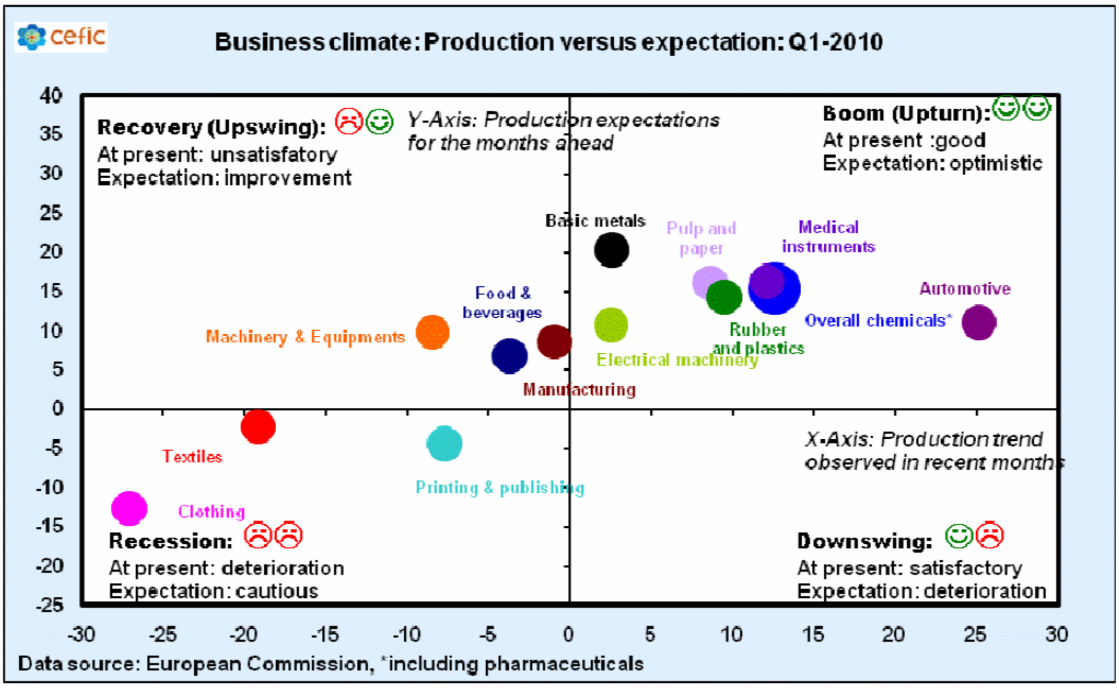
Figure 4. Business climate: production versus expectation, Q1/2010 (X-axis describes production trend observed in recent months and Y-axis production expectations for the months ahead)



Source: Cefic [7]

In March 2010, managers working for chemical companies (including pharmaceuticals) registered a decrease in the level of stocks and reported positive changes in the level of order books and in their prospects for production over the coming months.

Figure 5. EU chemicals industry confidence



Source: Cefic [7]

2.2 Effects on funding

It takes a lot of time, money and expertise to get a new bio-chemical from a laboratory scale innovation to a world scale commercial operation, which is why funding plays a key role in industrial breakthroughs. The economic crisis has reduced the relative importance of environmental aspects and affected the investment activity in general, making it more difficult to get funding also for investments in biochemicals. The decline in investment may have the effect of driving consolidation and reducing the ability of small companies to innovate[8]. Surveys conducted across Europe show that up to 78% of biotech SMEs have struggled and failed to find the investment they require to continue important R&D programmes[9]. The start-ups in the bio-based chemicals area are anyhow in general booming, although several have had to adjust their plans and some have even disappeared because of the difficult financing environment.

Despite the economic recession, most of the biochemical companies are still optimistic about their long-term plans and investing in new plants and in further innovation and cooperation. Many companies are confident that 2010 will see a higher revenue stream.[10, 11]

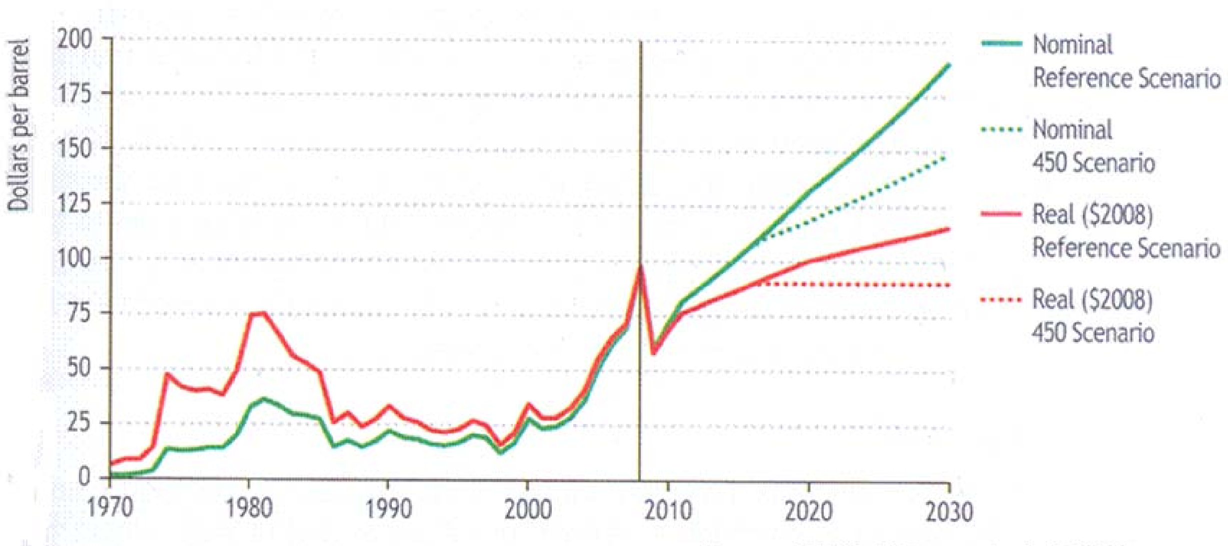
2.3 Effects on raw material prices

The future growth trajectory for bio-based products is affected by the cost of biomass feedstocks but also by fossil fuel prices and by the level of governmental support. The higher the oil price and government support level will be, the faster breakthroughs in bioproduct industry are foreseen. High oil price will also accelerate private research and development levels and improve investment profitability.

Fossil fuels

According to the International Energy Agency (IEA)[12], crude oil price will increase up to 100 dollars per barrel by 2020. In nominal terms, prices will roughly triple between 2009 and 2030, reaching almost 190 dollars per barrel. In the 450 scenario [a], prices are assumed to follow the same trajectory as in the reference scenario to 2015 and then grow with a lower level to 2030, due to weaker demand.

Figure 6. Average IEA crude oil import price (annual data).

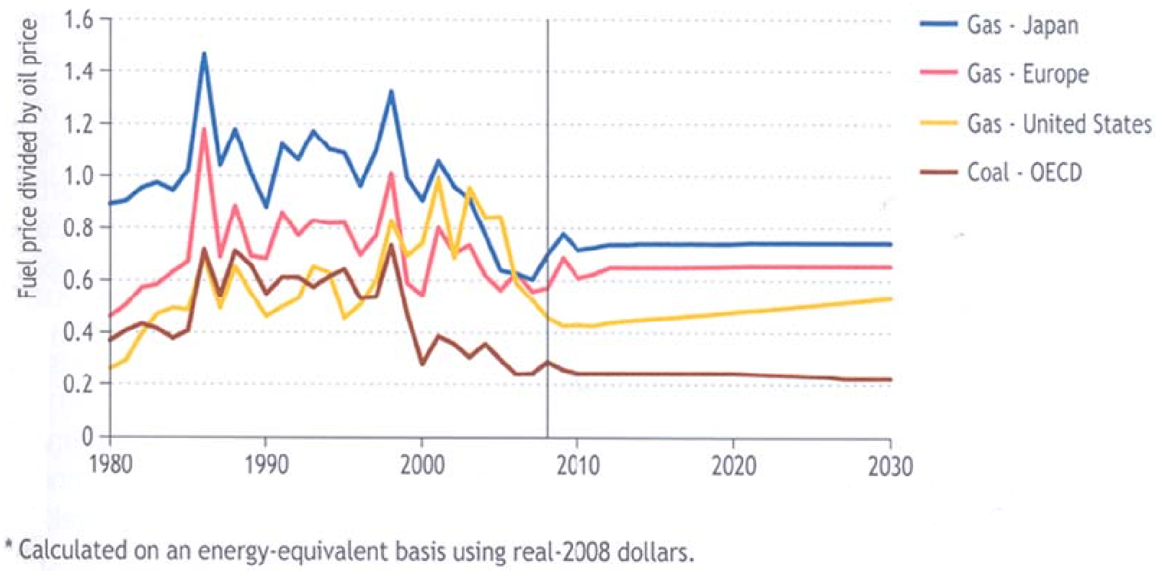


Source: IEA World Energy Outlook 2009

Instead of oil, some bioproducts are more dependent on natural gas and coal prices. According to IEA[12], natural gas and coal prices will follow the development of oil price **(Figure 7**). Natural gas prices have followed divergent paths in different parts of the world, largely according to the degree of contractual linkage to oil prices and of government price controls. In Europe and the Pacific region, where most gas is traded under long-term contracts with oil-price indexation, prices peaked in late 2008, reflecting the impact of high oil prices in the second quarter of the year (most contracts adjust gas prices with a lag of six to nine months). By contrast, in North America, gas prices are expected to follow a path much more independent from the oil price.

[a] 450 scenario: concentration of greenhouse gases in the atmosphere need to be stabilised at a level around 450 ppm CO_{2eq}

Figure 7. Ratio of natural gas and coal prices to crude oil

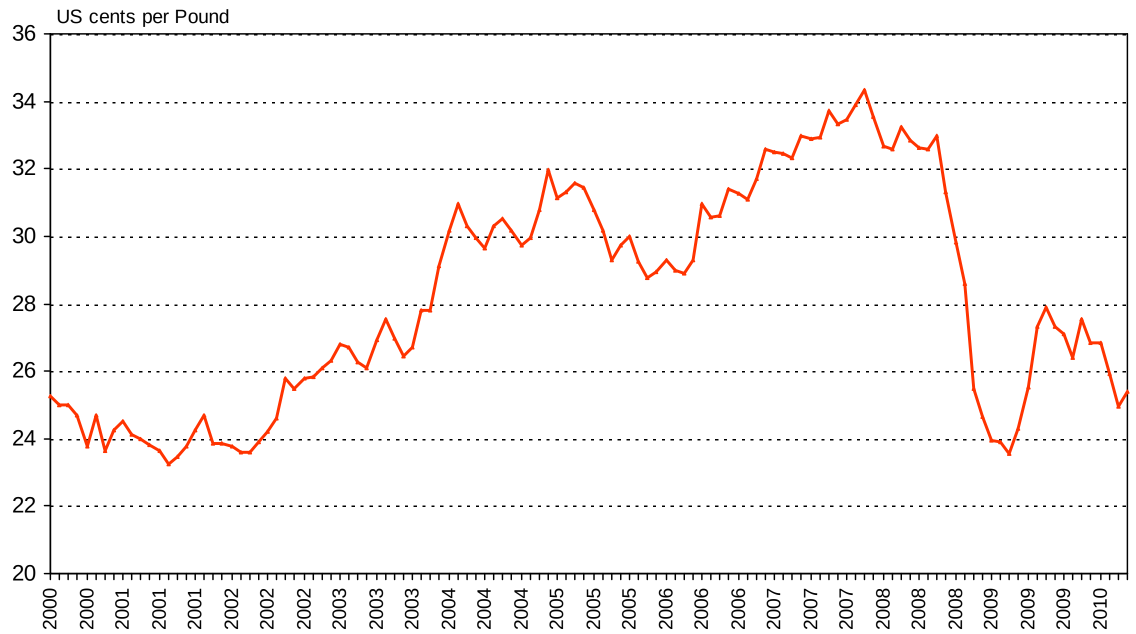


Source: IEA World Energy Outlook 2009

Bio-feedstock

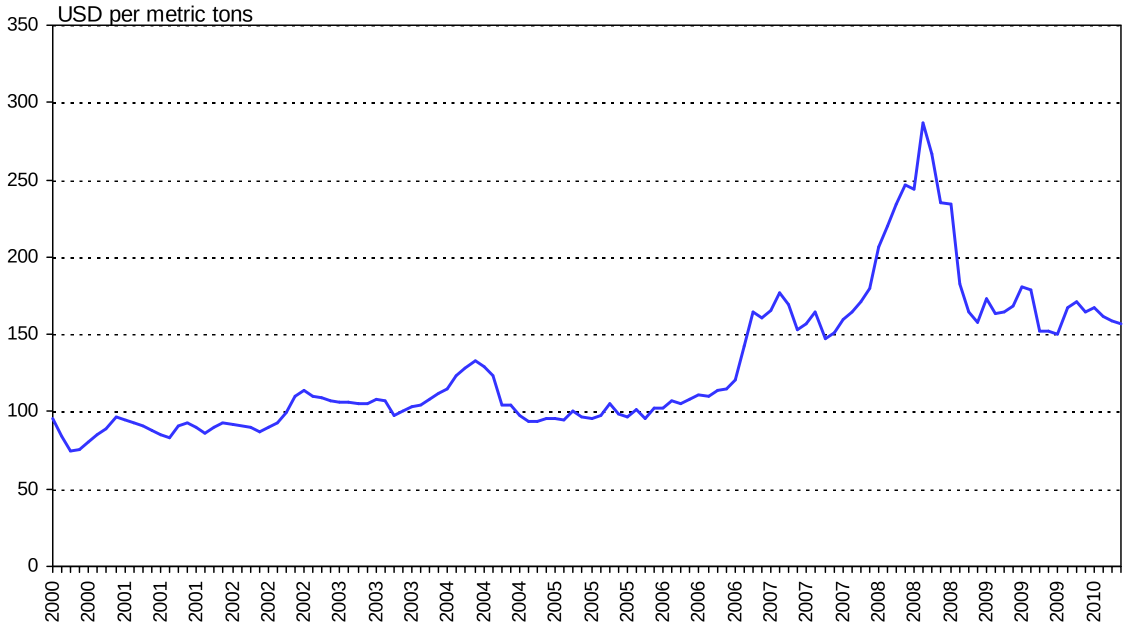
The feedstock cost is another important factor affecting the profitability of biochemical production and investment. Biomass feedstock prices follow general commodity price trends and the cost difference between fossil fuels and biomass is not significant. Naturally, crop yields vary from season to season due to growth conditions and crop damages. The price development of sugar, maize and soybean oil are shown in Figures 8 to 10. The costs of energy consumed during the production and collection of bio-based feedstock, and the amount of land required to produce it, need also to be considered.

Figure 8. Sugar, European import monthly price



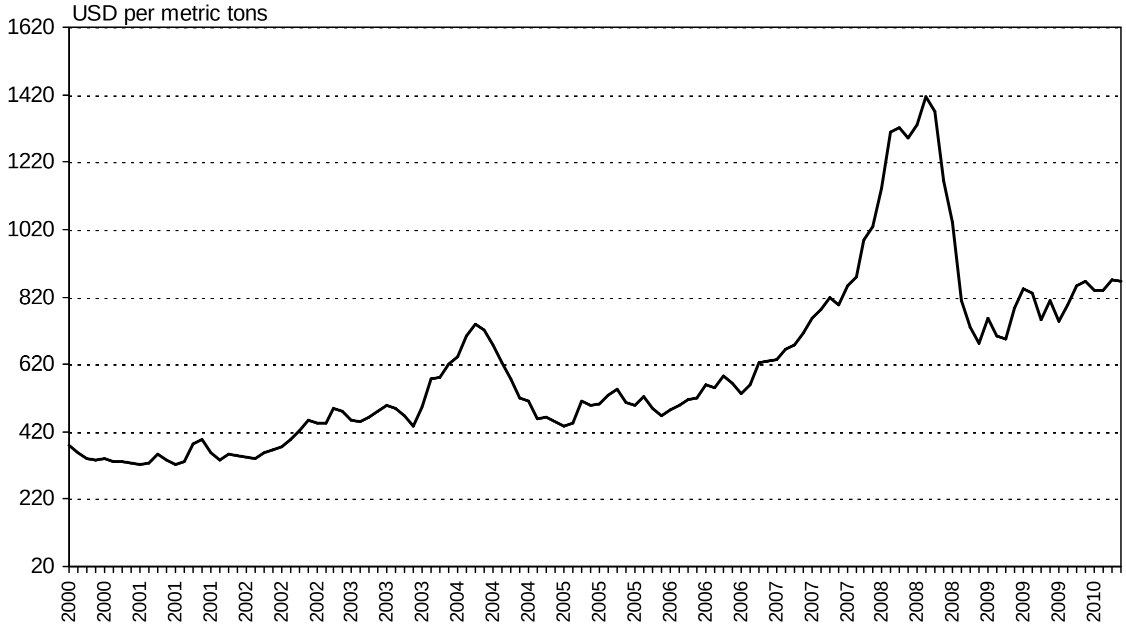
Source: Index Mundi

Figure 9. Maize monthly price



Source: Index Mundi

Figure 10. Soybean oil monthly price



Source: Index Mundi

2.4 Effects on market potential

Forecasting in a flock of black swans

The nature of market/financial forecasting is not always optimal for extraordinary conditions (which usually aren't that extraordinary, just less common). For discussion on this topic, one need only turn to e.g. Nassim Nicholas Taleb's "The Black Swan: The Impact of the Highly Improbable" (a new extended edition came out in May 2010).

So, let's enumerate the circumstances we are in
a) the task is to estimate the market potential for a group of products mostly new to the market, with very little business-as-usual
b) this group of products has to solve techno-econo-environmental problems
c) it is dependent on investments, i.e. belief in its viability
d) it is not the most risk-free investment on the market
e) we are in the grips of the strongest recession for decades, with uncertainty of how things will continue (Greece, Spain, Portugal? V,U,W,L-shaped recession?)

In short, not an easy situation for a forecast. Therefore, we have to be clear on what our market estimates are based on. An unexpectedly quick upswing or a painfully prolonged economic suffering will, obviously, have an impact on the forecast.

The process of updating the forecast can be summed up as follows
- collection of current (2008) and future (2020) production estimates based on various publicly available product group specific reports (Pöyry, European Bioplastics, European Solvents Industry Club, United States Department of Agriculture, United Soybean Board, Industry experts)
- making a synthesis of the various estimates and forecasts and combining them with our own industry expertise on recent technological and market development
- as the impact of the recession on investments remains to be seen, conservative estimates have been favoured instead of most optimistic ones. As stated above, the financial crisis has postponed some investments in biochemicals and some players have disappeared from the market. Despite that, investments in biochemicals are booming and the impact of the economic crisis on biochemicals has not been as dramatic as it was on many other manufacturing industries e.g. automotive and electronics. Therefore, we have not applied a general factor to scale down the future production estimates.
- reports describing the situation of the bio-based products sector before the crisis (for example European commission report[1]) can be used as a point of comparison to see the impacts of the crisis.

Based on several sources, estimations of market potential of major biochemical groups in the EU have been updated and are shown in Table 1. The total growth in production volumes is estimated at 2.1 Mt between 2008 and 2020 (5.3%/a). Assuming a similar development for the market value, the market value can be estimated to grow from current (2008) 21 billion EUR to 40 billion EUR in 2020. This increases the market share of bio-based products from 4% (2008) to 6% (2020) and provides 43,600 new jobs within the biochemical industry only (Table 2).

Table 1. **Estimated EU production volumes of bio-based polymers, lubricants, solvents and surfactants**

EU, million tons	Total consumption in 2008	Biobased consumption in 2008	Biobased potential in 2020	Growth potential,%/a
Plastics	48	0.13	0.9	16%/a
Lubricants	5.2	0.15	0.23	3.6%/a
Solvents	5.0	0.63	1.1	4.8%/a
Surfactants	2.7	1.52	2.3	3.5%/a

Sources: Pöyry, European Bioplastics, European Solvents Industry Club, United States Department of Agriculture, United Soybean Board, Industrial experts' views

Table 2. **Estimated EU market value and employment opportunities of bio-based polymers, lubricants, solvents and surfactants**

EU	2008	2020
Market value (billion EUR)	21	40
Share of biochemical value of total chemical value	4.0	6.0
Employment in biochemical production	50,200	93,700

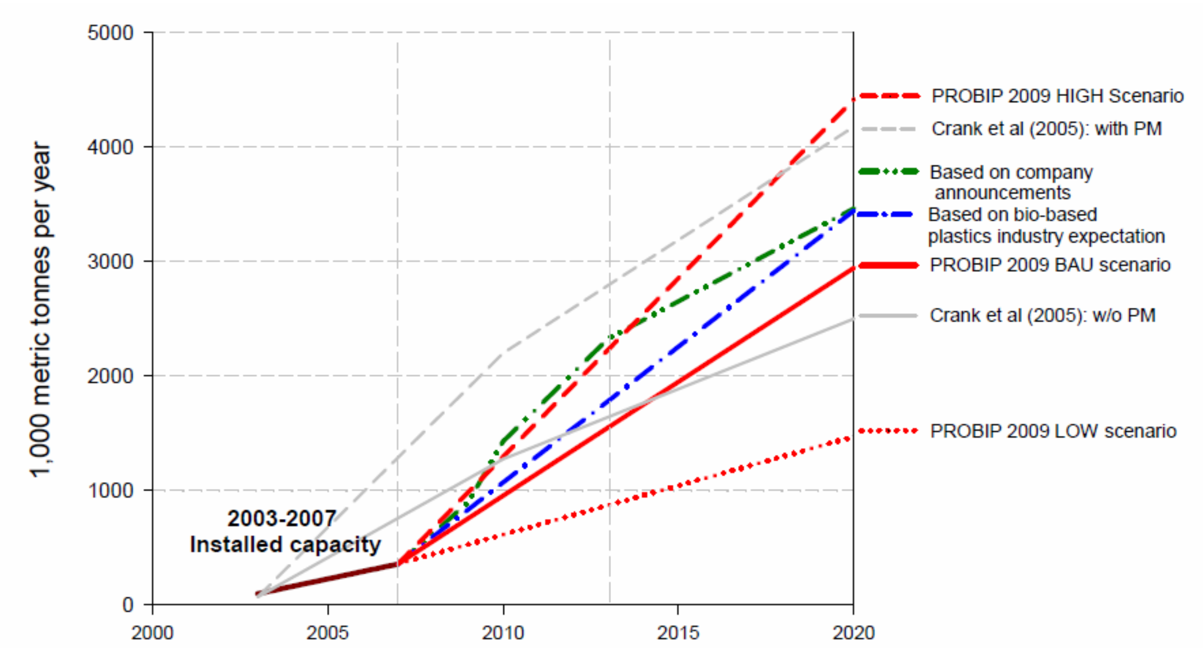
Bio-plastics

According to data collected by European Bioplastics[10], global bio-plastics production amounted to 0.75 -1.5 Mt tons in 2009 (3.5% of the global plastics market) and is estimated to grow to 1.5-4.5 Mt by 2020 (Figure 11).

Pöyry has estimated that the European bio-plastics market is at 0.13 Mt in 2008 and 0.9 in 2020. The current annual growth is estimated to be 16%. Most bio-plastics have only recently completed the basic development and are thus on the brink of broader market introduction. The EU countries with comparably advanced market development are the UK, Italy, the Netherlands and Germany, followed by Belgium, France, Austria, Switzerland and Scandinavia[10]. Europe is the second important region after USA for bio-based plastics. Asia is the third leading player and South America is an emerging area.

Theoretically the global market potential of bio-plastics could reach a magnitude of about 4.5 Mt by 2020 but the actual growth depends on various factors. In the following figure different future worldwide bio-plastic production scenarios are shown.

Figure 11. **Projection of the worldwide production capacity of bio-based plastics until 2020**



Source: European Bioplastics[10]

At the current state of technology, 5-10% of the plastics market could theoretically be bio-plastics today and the long-term potential (2030 onwards) is significantly higher (70-100%). This will not only involve replacing conventional plastics in individual application areas, but also development of completely new ones. The market penetration depends on multiple factors, such as environmental regulation, price development of raw materials and the general economic climate.

Whilst conventional plastics have experienced strong price increases of 30-80% in recent times as a result of high crude oil prices, bio-plastics prices have in some cases sank considerably. For the most part, the new materials remain more expensive than their crude oil based counterparts, however the relative price difference has clearly diminished [10].

The most important reason for companies not to shift to bio-based production on a large scale is the higher production cost.[13] There are also challenges related to capital availability, scale-up, short-term availability of bio-based feedstocks and to the ability of the plastics conversion sector to adapt to the new plastics.

Some important building blocks are not readily available from bio-based feedstocks. The single most important group of plastics precursors, for which bio-based alternatives are still missing, is aromatic compounds.[14] One possible source for aromatic compounds could be lignin derived from wood during pulp and paper production.

The recent technological development in new bio-based plastics has been fast. The first plants are being developed and set up for numerous types of plastics, although technological development is at an early state. Some of the plants are still rather small when compared to petrochemical plants but others are very sizable.[14]

The following applications or product segments are exhibiting high growth rates:

- Compostable waste bags to collect organic waste and carrier bags, which can also be used as organic waste bags. They can increase the volume of collected organic waste, therefore reduce landfill, and improve the composting process and compost quality. Such bags – most of them are bio-based too - are often regarded to be a key market for bio-plastics with regard to the sizeable market volume and valid arguments in favour of their use.
- Biodegradable mulch film which can be ploughed into the field once it has been used, offering the opportunity to reduce labour and disposal cost.
- Catering products for large events or service packaging for snack food sales. They can simply be composted after use along with any remaining food scraps. The available compostable product portfolio includes trays, cups, plates, cutlery and bags amongst others.
- Film packaging for foods with short shelf life which require attractive presentation, or to extend shelf life. These include compostable pouches, netting and (foam) trays for (organically produced) fruit and vegetables, and recently also fresh meat. The simple disposal and the fact that the sale period could in part be extended are beneficial to retailers. Spoiled foodstuffs can be recovered via composting with no need for separation of packaging and contents at point of sale.
- Rigid packaging such as containers and bottles. Bottles made from PLA are used for non-sparkling beverages and dairy products.
- Many other products make use of their specific functionalities, such as tyres with starch materials incorporated to reduce hysteresis and fuel consumption, diapers with silky softtouch back sheet, urns etc. [13] There is growing interest to source more renewable polymers as builders within personal (shampoo, cosmetics) and home care products, paints and other surface coatings, too.

In the initial phase of market introduction, products are often used in niche markets. The level of technical complexity of bio-plastics packaging is increasing: Co-extruded double or multiple layer film products have been commercialised recently. This involves an advantageous combination of bio-plastics such as starch-based materials, cellulose films and PLA films, which are already available on the market.

The development of durable products such as those in consumer electronics (laptop and mobile phone casings etc.), in leisure (sporting shoes, ski boots etc.), and in the automobile industry (interior trim, spare tyre covers) is in an early state of market penetration. Japan is currently the main centre for this development. The focus is equally on functionality, for example low electrostatic charging, and sustainability criteria such as reduction of CO_2 emissions. It is estimated that around 2030 it may become possible to imprint bio-plastics and thereby make extensive use of them in electronics.[15]

An appealing feature of bio-plastics is that they may serve a dual purpose: after use as for instance packaging material they may, by use of certain enzymes, be converted into biofuels. This opens up new markets and may for instance be promising for applications in the military sector. [15]

In the field of medical technology, special biodegradable plastics have been in use for some time as stitching materials and for decades for screws or implants (niche products with extremely high prices).

Major chemical companies are investing in the production of polymers from renewable sources. Strategies differ between replacement of conventional plastics and monomers using unconventional feedstocks to development of novel monomers using fermentation chemistries from other sectors. Several classes of bio-based polymers are becoming increasingly important: starch chemicals, polylactid acid (PLA), polyhydroxyalkanoates (PHAs), succinic acid, polyurethanes (PURs) and cellulosic polymers.

As examples of recent investments, Nature Works just doubled its production capacity of PLA and Brasem made a big investment for its start-up of bio-based PE. BASF introduced new biodegradable plastics for coating paper and shrink-film while Novamont launched the 2nd generation of Mater-Bi, and Purac, Sulzer and Synbra kicked off cooperation in the field of foamed PLA products. Several succinic acid production facilities have been started or announced to start in the near future, e.g. Bioamber's 2 kt/a plant in France started in 2010 and two other new large-scale plants are in the planning stage in North America and in Asia.

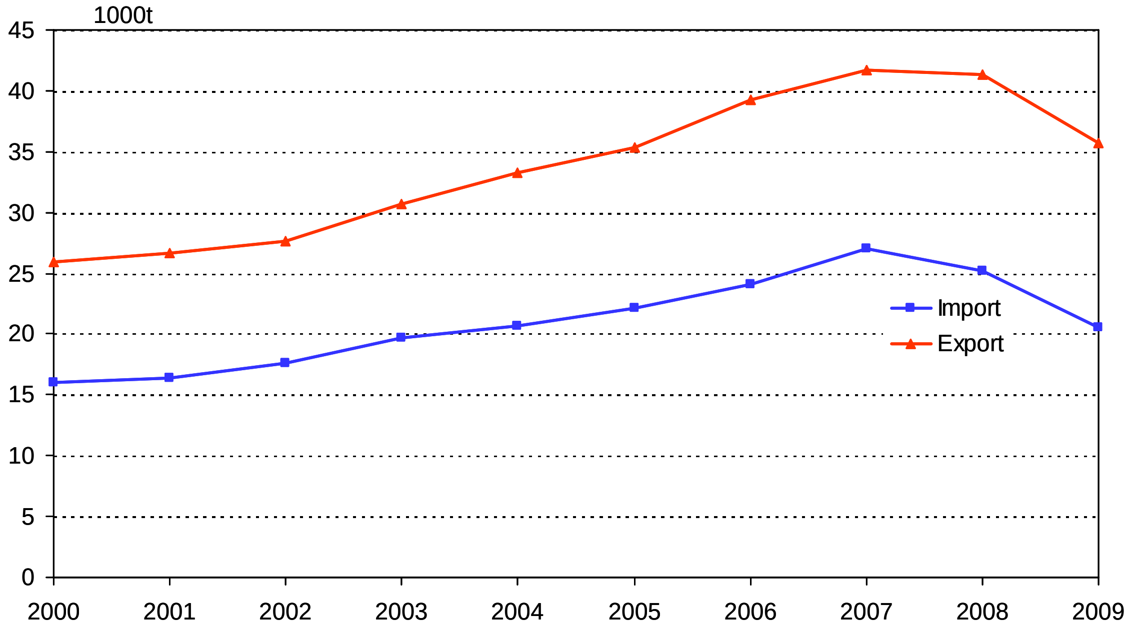
Coca-Cola has recently kicked off a marketing campaign in selected countries introducing its PET PlantBottle^{TM}, 30% of which consists of plant based material, and Samsung introduced a cell phone partly made of biodegradable plastics. Aldi, one of Germany's largest discounters, introduced biodegradable shopping bags. Hyundai draws on PLA for parts of the interior of their next generation hybrid car, and Frito-lay announced the use of bio-plastics in their SunChips packaging.

Different raw material bases have also been studied and e.g. Cereplast has announced the possibility to convert algae biomass into viable monomers for further conversion into potential biopolymers.

Bio-lubricants

Trade in lubricants has declined during the past two years (Figure 12). At the same time, lubricant demand has decreased in the EU. This trend is a consequence of a lower level of activity during the financial crisis, but improvements in engine technology have also diminished the consumption of lubricants.

Figure 12. Trade in lubricants (the EU, 2000-2009)



Source: Eurostat

Annual lubricant consumption in the EU was estimated at 5.2 Mt in 2008 and the share of bio-lubricants at 0.15 Mt (2.9%). It is estimated that bio-lubricant consumption will grow up to 0.23 million tons by 2020 which represents the growth rate potential of 3.6 %/a.

The market penetration of bio-lubricants varies considerably within the EU. It is estimated that their market share is about 15% in Germany and 11% in Scandinavia, but below 1% in France, Spain and the UK. The major vegetable oil in use in Europe for industrial products is rapeseed. However, not all the bio-lubricants are completely vegetable oil-based. In some countries, to get a label only requires that 50% of the oil is renewable. Thus, synthetic esters or even petroleum oils can be used in the formulation.[16] Theoretically around 90% of lubricants currently used could be replaced by plant-derived chemicals.

The bio-lubricant industry is growing based on environmental concerns and some countries have already banned the use of non-biodegradable lubricants in sensitive areas at least in applications where oils are lost into soil and surface waters. Several studies show that bio-lubricants also have a longer lifespan than mineral lubricants. Other benefits of bio-lubricants include lower toxicity, good lubricating properties, high viscosity index, high ignition temperature and increased equipment service life.

Bio-lubricants are more expensive than conventional products, which is the major barrier to market uptake, particularly during the economic recession. The higher cost may be partly offset by reduced need for replacement due to the longer lifespan of bio-lubricants.

The oxidative instability of soybean oil as well as rapeseed oil and other vegetable oils is due to the presence of polyunsaturated fatty acids, as in linoleic acid and linolenic acid. Efforts have been made to modify the soybean oil to moderate the effects of these materials to provide a more stable material, and also a product more competitive in performance compared to mineral oil-based lubricants. Recent development areas include e.g. additive technology, chemical transformation and polymerisation, transesterification and genetic modification.

Cognis has developed next-generation axle lubricant which is said to be the first of its kind to offer proven fuel efficiency without compromising performance. It is further claimed to reduce fuel consumption by 15%, resulting in lower CO_2 emissions and making significant cost savings for truck owners.

Bio-solvents

Trade in solvents is rather low compared to the consumption of solvents in the EU (Figure 13, Table 1) and import and export volumes have been in decline.

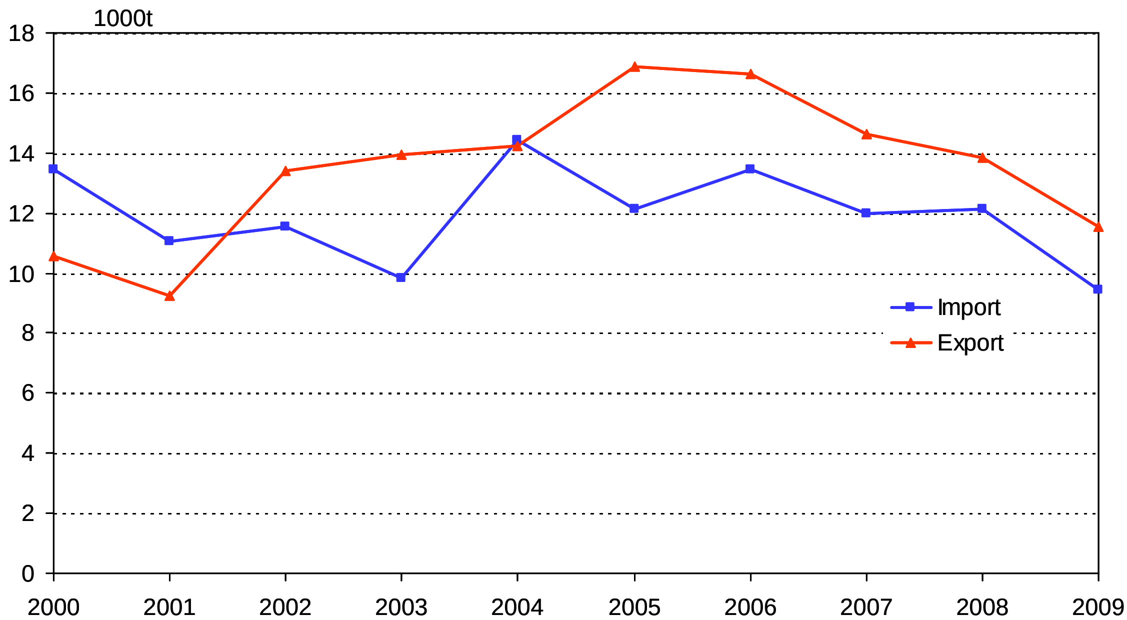
The EU solvent market totalled 5.0 Mt in 2008 of which bio-based solvent consumption was 0.63 Mt (12.6%). The consumption of bio-solvents is estimated to grow annually 4.8% up to 1.1 million tons by 2020 (Table 1).

The advantage of bio-based solvents is that the vast majority do not emit volatile organic compounds (VOCs) which are harmful to human health. Moreover, they offer the potential to reduce the dependency on crude oil feedstocks. However, bio-solvent production is not currently cost-effective enough to compete with traditional solvents.

There are a growing number of companies that supply bio-solvents to the printing industry (Hydro-Dynamic Products, Varn International, Akzo Nobel). These solvents are used to dissolve the pigments themselves, as well as to clean printer rollers, plates and other machinery parts. Such solvents can also be used to de-ink paper so that both the ink and the paper can be recycled. Some bio-solvent based paints and varnishes are now also available. A handful of companies supply them (Livos, EcoDesign) but the main barrier to widespread commercialisation is their cost. Bio-based paint strippers and brush cleaning solvents are also available from other chemical companies, but again the costs are high. As production costs fall and demand grows prices are likely to decrease.

Bio-solvents for the home are also growing in number, with a small selection of companies offering cleaning and degreasing products for household and office use (Vindotco, Lord and Partners). These products tend to use citrus oils to cut grease but, even though they are billed as environmentally friendly, they often still include fossil-based additives such as ethylene glycol or amines.

Figure 13. Trade in solvents (the EU, 2000-2009)



Source: Eurostat

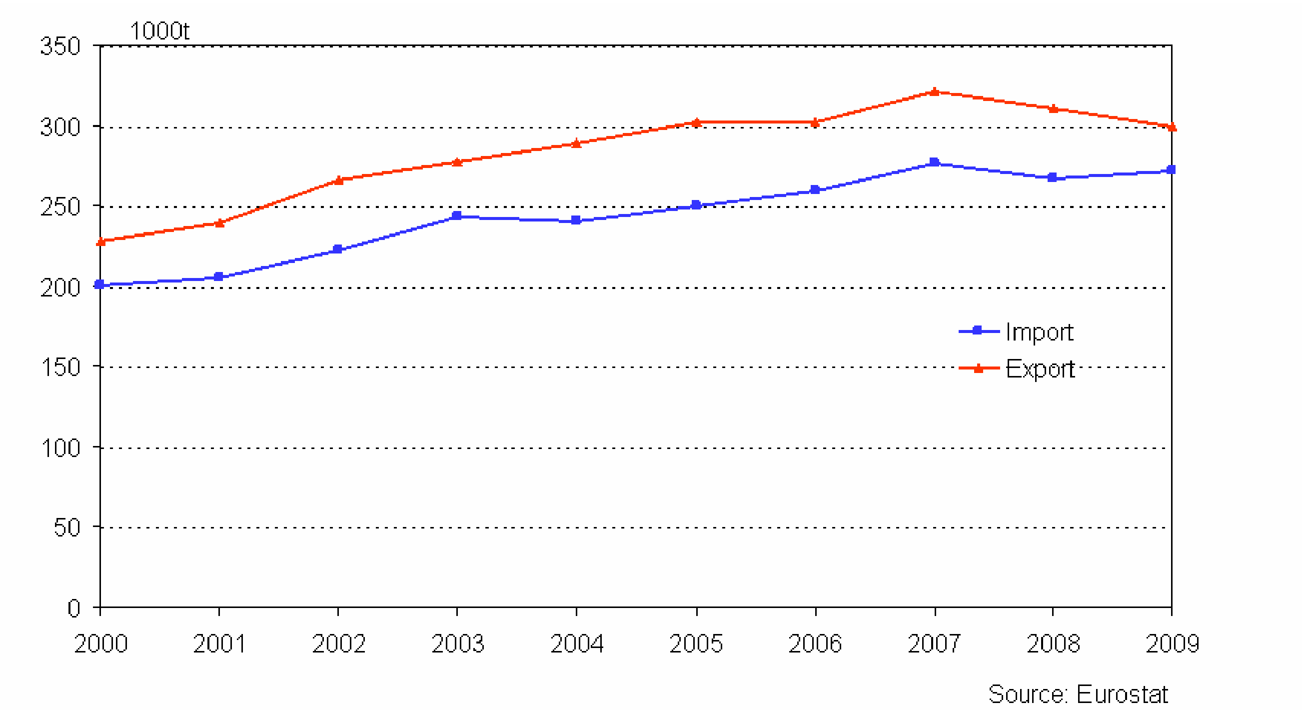
Research into the use of bio-solvents in chemical synthesis is advancing, with the successful replacement of organic and halogenated solvents demonstrated for a range of syntheses. Another area of investigation is the production of common organic solvents from biological feedstocks. An example of this is the conversion of succinic acid into tetrahydrofuran (THF). Such research is advantageous, as the production of the solvent would become sustainable and allow established chemistry using THF to continue in a more environmental way. Described production would not reduce VOC emissions.

The evaluation and refining of production methods for bio-solvents is under investigation, with new methods using biological feedstocks being discovered that allow bio-solvent production at lower cost and higher purity. An example of such research is work where using a technique called pervaporation, lactate esters can be produced with cheaper price and using 90% less energy than previously.

Bio-surfactants

The EU trade in surfactants has been only slightly affected by the financial crisis. A minor dip in imports was recovered already in 2009, but export volumes decreased also in 2009 (Figure 14).

Figure 14. Trade in surfactants (the EU, 2000-2009)



The consumption of surfactants totalled 2.7 Mt in the EU in 2008. At the same, time, the bio-based surfactant market was estimated at 1.52 Mt, representing 56% of the total surfactant market. Annual surfactant growth potential is estimated to be 3.5 %/a, and bio-surfactant potential 2.3 Mt in 2020 (Table 1).

The major drivers in the surfactant market are price, performance and product safety. Environmental drivers can increase the demand for plant-derived surfactants. Several large manufacturers are in operation, for example Huish Detergents Inc., based in Houston, USA, manufacture Methyl Ester Sulphonate from renewable resources. The plant's capacity is large at around 70,000 tonnes.

Advantages of naturally-derived surfactants include biodegradability, low toxicity and raw material availability as they can be produced from industrial waste or by-products. The REACH regulations are estimated to lead towards increased use of bio-based surfactants. Biodegradability standards and their vegetal composition (in whole or in part) confer a distinct advantage to bio-surfactants. However, mineral oil based surfactants are significantly cheaper than plant-derived surfactants.

Activities in bio-surfactant market are increasing. Only in April 2010, several new surfactants appeared on the market.

- The first vegetable oil based sodium lauryl (SLS) was launched by specialty chemicals supplier Rhodia, for use in shampoos, liquid soaps and body washers. Rhodia also introduced Mackine®301, a vegetable oil-based non quaternized amidoamine surfactant for hair conditioners and masks. Mackine® 301 offers an alternative to conventional CTAC (Cetrimonium Chloride).
- Air Products launched two new surfactants for the architectural coatings market, Carbowet® 13-40, a VOC- and APE-free alternative to 30-40 mole ethoxylate surfactants; and EnviroGem® 2010, a solvent- and APE-free surfactant that contributes no VOCs to zero VOC coating formulations.
- Cognis launched its new Disponil® NG series of APEO-free, VOC-free, and FDA-approved surfactants, which are based on modified natural and renewable-based fatty alcohols.
- Cognis also announced in May 2010 that it had officially opened its new production facility for its APG® surfactants at its site in Jinshan, China. Cognis has two other APG facilities, one in Dusseldorf, Germany and the other in Cincinnati, US. APG® surfactant is made from vegetable oil or starch.

New surfactants are being developed using biotech processing. Sophorolipids and rhamnolipids are examples; both are glycolipids that can be used to produce bio-surfactants via a fermentation process [11].

3 IMPACTS OF THE POTENTIAL OF THE EUROPEAN BIO-BASED MARKET ON ENVIRONMENT, SOCIETY AND ECONOMY

Many documents outline the tremendous potential of the bio-based products to foster sustainable development. This chapter summarises current knowledge of the main environmental, social and economic impacts of changing the raw material base of existing production.

This chapter mainly looks at the bio-based sector as a whole, but product segment specific information is given where feasible. However, as pointed out below, any product specific claims on impacts should always be based on sound and transparent life cycle analyses (LCAs). The LCA concept is discussed in Chapter 6.

3.1 Environmental impacts

An international level comparison of results of available research, namely LCA studies[b] evaluating the environmental performance of bio-based products compared to petroleum-based products, indicates that bioproducts (other than bacterial polymers) consume less energy and emit less carbon dioxide than products from fossil resources 13,[17] vegetable solvents emit few or no volatile organic compounds17; and bioproducts offer the potential to reduce the generation of toxic wastes [18].

On the other hand, there may be adverse environmental effects that are related to use of fertilizers and agricultural chemicals (excluding by-product streams) 17,18 and particulate emissions from feedstock preparation 18.

The overall environmental effects of bio-based production are seen as positive (Figure 16). However, the effects can vary considerably from one production chain to another, which calls for reliable LCA-based environmental assessments on a product level.

Non-renewable energy consumption and GHGs

Since many bioconversion processes occur at or near room temperature, atmospheric pressures, and neutral conditions, there are often lower combustion energy requirements and fewer associated emissions than in conventional chemical processing. However, energy used for feed preparation, drying and product separations can be a significant source of combustion emissions, which can be partially offset by the use of renewable fuels to meet processing energy demand. Thus substituting plant resources for fossil feedstocks results in lower non-renewable primary energy consumption and mitigates the greenhouse effect, except in the case of bacterial polymers and certain biopolymer applications[17]. According to Ademe [17], bioproducts can create savings in non-renewable energy consumption (that are of the order of magnitude of 40-80%) and in GHG emissions (at least 50% lower CO_2 emissions, with the exception of bacterial polymers) (Figure 15). In another review by University of Utrecht et al. [13], the non-renewable energy savings of bio-based production are estimated at 30%. Larger savings are achieved if lignocellulosic feedstocks (up to 75% non-renewable energy savings) or fermentable sugar from sugar cane (up to 85% non-renewable energy savings) can be used in the future.

[b] E.g. Ademe [17] included an analysis of 67 products and University of Utrecht et al.[13] of 21 products

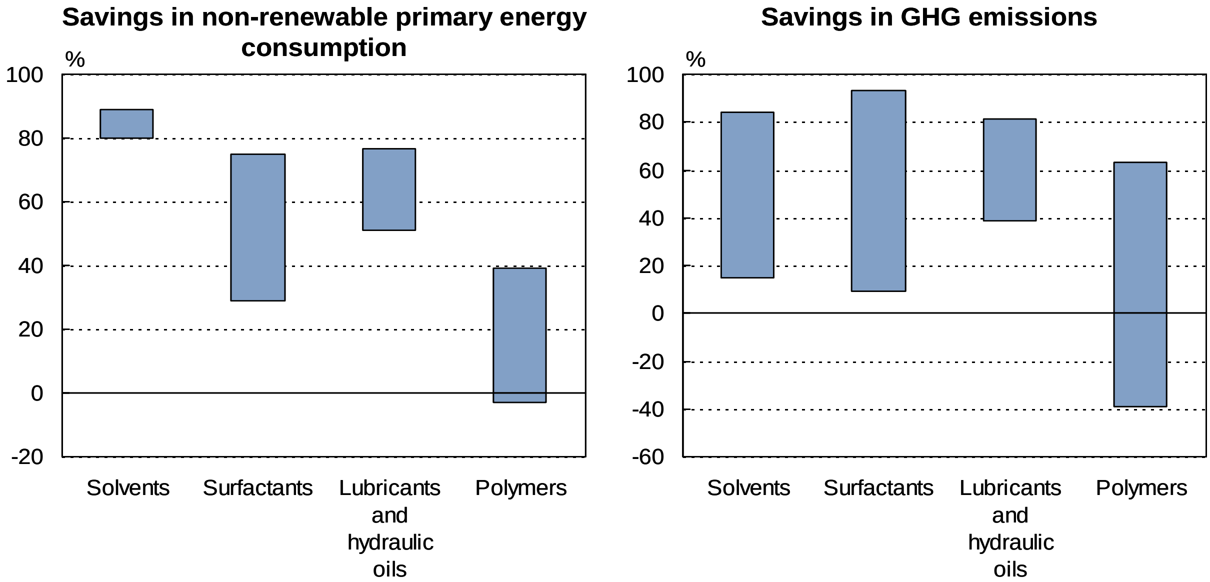
Figure 15. Impacts of bio-based vs fossil-based value chains

(+) Positive impact
(−) Negative impact or risk

	Raw material sourcing	Chemical production	Product use and end-of-life options
Environmental effects	(+) No hazards in raw material sourcing (+) Decrease in the consumption of non-renewable resources (+) Reduction in biomass-related waste (−) Risk of eutrophication due to use of fertilizers and plant protection products (not applicable to by-product streams) (−) Potential contribution of imported biomass to biodiversity losses	(+) Reduction in non-renewable energy consumption (+) Reduction in GHG emissions (+) Modernisation of process technology and energy concepts (−) Increase in water consumption (−) Increase in particulate emissions from feedstock preparation	(+) Less toxic waste (+) Less GHG emissions from waste incineration (+) Biodegradability offers opportunities for composting (+) Recycling possibilities of biobased products
Social effects	(+) Contribution to rural development (−) Risk of involvement in the GMO controversy (−) Potential contribution of imported biomass to food insecurity	(+) Contribution to rural development (+) Increasing sustainability and greening of chemical industry image (+) Reduction in VOC emissions improves workforce health and safety (−) Risk of involvement in the GMO controversy	(+) Decrease in human toxicity (+) Contribution to sustainable development (−) Risk of involvement in the GMO controversy
Economic effects	(+) Utilisation of wastes and by-product streams (+) Contribution to rural development (−) Competitiveness of raw materials compared to fossil fuels; possible need for subsidies (−) Need to develop the logistics of raw material sourcing	(+) Contribution to innovations and European competitiveness (+) Creation of jobs and maintaining production in Europe (+) In some products, savings in production costs (−) Investment costs (−) Risks of up-scaling	(+) Possible green premiums (+) Market entry in environmentally sensitive markets (+) Reacting on increasing consumer awareness (+) New innovations and products with superior functionality (+) Savings in waste charges

Source: Pöyry

Figure 16. Benefits of bio-based products compared to fossil-based products: Savings in non-renewable primary energy consumption and GHG emissions per functional unit



Source: Ademe [17]

Given the market penetration estimates of bio-based products by 2020 - 4 and 6 percent of sales within the EU chemical industry in 2008 and 2020 (Table 2) - the resulting savings in non-renewable primary energy consumption and GHG emissions will still be modest in the short and medium term. However, University of Utrecht et al. [13] have produced estimates reaching up to 2050. According to them, bio-based products result in up to a 32% overall reduction of non-renewable energy use in the production of all organic chemicals (not just those selected for the study) in 2050. The results vary from 3-5% for a low scenario (with rather unfavourable conditions for bio-based chemicals development) to 9-14% in a medium scenario or to 18-32% in a high scenario (with favourable conditions for bio-based chemicals development). (The scenarios are based on various assumptions about future production volumes and feedstock price levels. E.g. the total production of organic chemicals in Europe in 2050 reaches 70 Mt, 150 Mt and 300 Mt in the low, medium and high scenarios, respectively.) Within each range, the lower value is for starch and the higher value for lignocellulosics. In other words, up to one third of the current non-renewable energy use for the production of all organic chemicals could be saved by 2050 if substantial progress is made in White Biotechnology and if the use of lignocellulosic feedstocks is successfully developed.

VOCs and waste

During chemical processing harmful volatile compounds may be released from point sources and as fugitive emissions from valves, vents and pipes in the manufacturing plant. While bioconversion processes are often more benign, they can also release fugitive emissions. [18]

Another attractive aspect of bioproducts is the potential to reduce the generation of hazardous and toxic wastes associated with the manufacture of fossil-based products. Many chemical processes require large quantities of aromatic solvents or strong inorganic acids and bases (e.g., sulphuric acid, sodium hydroxide) that can result in effluent streams that are harmful to the environment. These must be recycled or treated and disposed of. On the contrary, most biological processes require natural catalysts (e.g., enzymes) and solvents (water) and produce few or no toxic or hazardous by-products. In most cases, solid wastes and effluents from these processes are biodegradable or can be recycled or disposed of without excessive treatment processes. [18]

Bio-based production can also contribute to reducing waste by increasing utilisation of current agricultural and other biomass-related waste and by-product streams.[1]

Fertilizer and agricultural chemical application and particulate emissions

Life cycle analyses show eutrophication impacts related to fertilizer use and agricultural chemicals to be weak points in plant-based production chains, excepting chains that use by-products [17] [18] .

Bioprocesses may also cause an increase in particulate emissions, which are generated during grain crushing and grinding operations where the feedstock is prepared prior to conversion to products. Most of these particulates are controlled using baghouses or filtering systems. [18]

3.2 Social impacts

Jobs

It is estimated that the production of bio-based products would provide direct employment for 93,700 people by 2020 (an increase of 87% from the estimated 53,200 jobs in 2008) (Table 2 in chapter 2). A major share of these will be in bio-surfactants (47,600 jobs in 2020), followed by bio-solvents (22,800), bio-plastics (18,600), and bio-lubricants (4,800). Additional jobs will be created outside the chemical industry, e.g. in agriculture, transportation and other services, equipment manufacturing and R&D. The sector will replace existing jobs based on fossil resources - it can be predicted that bio-based products will account for 4 and 6 percent of sales within the EU chemical industry in 2008 and 2020 (see chapter 2 of this report).

The production of bio-based products can make a major contribution to agriculture and forestry by creating new markets for biomass. Over time, this could transform the farming and rural economies. The other transforming factor will be the need to develop bio-refineries in rural areas, to avoid transporting biomass long distances. This would also provide work opportunities in rural areas.[9]

Bio-based production will require new skills, and producing information about emerging needs related to research, training and skills is one of the aims of the BIOCHEM project.

Health and safety

Conventional risks to human health related to the production of bio-based chemicals are comparable to those of fossil-based chemicals[13]. Sometimes, the bio-based chemicals are less harmful to health in production and product use, e.g. vegetal solvents emit few or no volatile organic compounds.[17]

Intangible assets

The bio-based sector contributes to the creation of knowledge driven and attractive jobs as well as to the greening of the chemical industry image.

Although a great opportunity for the bio-based product sector, the use of genetically modified organisms has also been identified as a potential risk for the bio-based products. [13] GMOs are widely opposed by European consumers, which may reflect on sector image.

The total land use for bio-based chemical production is relatively low and land requirements are hence not likely to become a critical issue in the next few decades. [13] Land use is, however, a delicate issue because of its close links to food insecurity and loss of biodiversity in developing countries.

3.3 Economic impacts

The value of the EU bio-based product market is forecast to grow from 21 to 40 billion EUR between 2008 and 2020 (see chapter 2 of this report). This growth implies significant employment opportunities and reduced dependency on imported fossil fuels. The sector will also facilitate the creation of knowledge driven and attractive jobs and development of new innovations[1].
University of Utrecht et al.[13] estimated the macroeconomic savings of bio-based products by comparing the total of product values of 21 most promising bio-based chemicals to their reference petrochemicals. The achievable savings for the economy in Europe total -0.13, 6.7 and 74.8 billion EUR in 2050, depending on the scenario. (The scenarios are based on various assumptions about future production volumes and feedstock price levels. E.g. the total production of organic chemicals in

Europe in 2050 is 70 Mt, 150 Mt and 300 Mt in the low, medium and high scenarios, respectively.) The negative value of -0.13 represents a net loss, while the positive values represent net savings. These savings can also be interpreted as an indicator of improved competitiveness.

Bio-based products will have the potential to utilise waste and by-product streams which currently have no value. This could transform the lives of farmers by making their business more profitable and creating new job opportunities[9].

4 IDENTIFICATION OF MARKET AND TECHNOLOGY DRIVERS AND BARRIERS AND INDUSTRY NEEDS

In this chapter, the main drivers contributing to the development of the bio-based chemicals sector are presented. Moreover, crucial factors for the exploitation of the identified market potential and for the development of the sector are discussed. The time scale is short to medium term, i.e. up to 2020.

On the driver perspectives used

The approach we have used is the following: Drivers can be seen as a branching tree.

At the root level, as a common ground for enterprise, is the **societal level**. Here reside drivers which derive from society as a whole and affect society as a whole. Obviously, all commercial actors live in this business environment.

On the next, the **company** level, appear drivers specific to enterprises with a commercial purpose. Since BIOCHEM has a focus on SMEs, we have attempted to write from a SME perspective, noting where there might be a difference between small and larger actors.

Finally, on the **segment** level, we note differences in drivers between the four foci of this report: bio-plastics, bio-lubricants, bio-solvents and bio-surfactants. It should be said that the differences are mostly not very significant, sometimes non-existent, and that the previous levels are the key determinants.

Moreover, out of a myriad of drivers, we have tried to **prioritise** the most significant ones. This means that it is certainly possible to find drivers not included here, but our intention is not to cloud the issue with a lack of focus.

What is a SME perspective?

Since SMEs are in the main role in this report, it is useful to enumerate some key characteristics we have ascribed to the SME perspective. That is

- our SMEs, obviously, fit the official Commission definition in size and scale,
- are not assumed to have special relationships that aid them (e.g. being a spinoff or already closely allied to a larger player, with e.g. a fixed long-term supply contract),
- are not assumed to be financially independent and in no need of funding.

In short, our SMEs are out on the markets, with no special helping hand, fighting to survive and make breakthroughs, and deserving of every reasonable aid that other actors such as the Commission can provide.

4.1 Market and technological drivers

Societal level

On a societal level, a transition towards bio-based products is motivated by

- reductions in greenhouse gas (GHG) emissions,
- reduced dependency on fossil fuels and their exporting countries,
- increasing scarcity of inorganic resources (especially rare metals),
- emerging options for rural development, and
- improved competitiveness.

In many countries, the promotion of biomass production for industrial uses to move away from petrochemical resources has been and will be a significant part of combating climate change. Biomass raw materials offer the opportunity to replace petrochemical resources for a large variety of bioproducts, but so far market penetration has been significant for transport biofuels only. Increasing consumer awareness about the impacts of consumption and thus larger scale sustainability issues are also likely to favour bio-based products. [19]

Reduced dependency on fossil fuels and their exporting countries refers to the wish to avoid risks related to limited fossil fuel reserves, with the view of diversifying the energy and raw material sources. Some importing countries of fossil fuels see risks related to the power of the OPEC cartel in controlling fossil fuel prices and to the location of many exporting countries in the Middle East.[19]

Moreover, natural catastrophes such as the oil spill in the Gulf of Mexico in 2010 are likely to shift consumer attitudes in favour of bio-based products.

Bio-based materials are also being developed with the view of replacing strategic or scarce raw materials such as platinum group metals and rare earth metals. *This should not be underestimated.* At the time of this writing, September 2010, a probable precursor of things to come is on the agenda, with an interchange of views on a possible threat from China to suspend the export of rare earth metals to Japan. This would have an impact on e.g. the production of hybrid cars and consumer electronics.

Furthermore, it has been recognised by many countries, both in developed and developing areas, that the production of biofuels and raw materials for bio-based products has the potential to contribute to regional and rural development and could open interesting opportunities for local players (e.g. supporting agricultural business). [19] Opportunities for employment in the manufacturing industry and for development of new innovations have also been recognised, and the European and US chemical industry see the potential of industrial biotech processes in sustaining competitiveness especially with regard to Asian challenges[20].

Company level

From a company point of view, the main drivers for creating bio-based businesses are

- Environmental advantages,
- Opportunities for new product properties and product differentiation,
- The potential for cost reductions,
- Uncertainty about oil price development,
- The benevolent and supportive attitude of authorities and society,
- Increasing consumer awareness including sensitivity to health and safety, and
- Pressure from flagship companies wanting to improve the environmental performance of their supply chain.

Apart from these drivers, there is a "technology pull" meaning fast technological development facilitating the transition to bio-based production by the substitution of existing products and by the development of new products.

As discussed in Chapter 3, most bio-based products consume less energy and emit less carbon dioxide than products from fossil resources, vegetable solvents emit few or no volatile organic compounds; and bioproducts offer potential to reduce the generation of toxic wastes. The bio-based products also offer potential for product differentiation, e.g. in cosmetics, and development of new properties and functionalities.

Improvements in product sustainability are also increasingly demanded by customers. An interesting issue is the increasing role of large retailer chains in reducing GHG emissions in their supply chains and in providing their customers with information on the carbon load of their purchases. E.g. Walmart announced in February 2010 its goal to eliminate 20 Mt of GHG emissions from its global supply chain by the end of 2015. Walmart will be collaborating with various groups to achieve the goal, including chemical companies such as Dow Chemical and BASF. It is believed that the Walmart programme is an important element driving for renewable and environmentally friendly solutions[21]. Carbon labelling pilots have been carried out by e.g. Tesco and E.Leclerc. These kinds of initiatives push suppliers to improve their knowledge of the carbon load of their product portfolio and call for product specific LCA data.

Chemical producers have concerns about future oil price development. The lower price of renewable feedstock has been the main driver for large-scale production of e.g. bio-based epoxy resin and bio-based PUR. For some bio-based plastics cost reductions have been achieved by using cheaper feedstocks, by scaling up the production or both. Financial incentives given by numerous governmental programmes encourage R&D and investments even if production methods and costs are currently not competitive with traditional production methods. The development of biorefineries and incentives for investment in biofuels production are also likely to encourage investments in industrial biotechnology. [22].

Technological development has been fast during the past few years in biochemicals. Separation technologies have improved substantially and scale-ups have succeeded. There is also a great deal of research going on. These together provide new opportunities for numerous breakthroughs if funding and experienced people are able to find each other.

Segment level

The above societal and company-related drivers apply to all product segments of this report and form a common ground for the rise in market potential of bio-based products. In addition, most significantly, degradability and high technical substitution potential are drivers for the development of bio-plastics and bio-lubricants, a reduction in volatile organic compounds (VOCs) emissions for the development of bio-solvents and degradability, safety and raw material availability for the development of bio-surfactants.

4.2 Market and technological barriers

Market and technological barriers refer here to factors that prevent the production and market entry of bio-based products. The bio-based market is largely overlapping/parallel to existing markets; only in niche areas can completely new markets emerge. This means that bio-based products must gain entry to existing markets, where companies already have a foothold with non-bio alternatives.

Company and product segment level

The key challenges for a bio-based company include

- Measurement and communication of environmental benefits and product properties,
- Development of the raw material supply,
- Scaling up from pilot scale to industrial scale production,
- Availability, reliability and cost of new technologies,
- Securing profitability and competitiveness, and
- Ability to participate in transfer of knowhow and technology through networking of product and equipment manufacturers, service providers and researchers.

The social acceptance of bio-based chemicals is normally high but the uncertainty about environmental benefits and product properties as well as weak market transparency sometimes restrict market penetration. Consequently, the acceptance and commercial adaptation of bio-based chemicals can be improved by communication, standardisation and labelling. Here, SMEs are at a disadvantage compared to larger companies, as their resources rarely stretch to extensive communications campaigns or even dedicated environmental marketing.

Raw material availability and its continuous supply are crucial to secure an undisturbed chemical production. Uniform quality of raw material is also required for efficient production. The profitability of biochemicals is often based on cheap renewable raw materials, and potential future increases/strong cyclicality in the raw material price can make production unprofitable. Price increases may materialise due to the increasing demand of biomass for biofuels. On the other hand, however, the biofuel targets benefit the bio-based chemicals sector by growing attention and fostering R&D in biorefineries. In this area, SMEs have smaller chances than large companies of establishing e.g. long-term fixed price contracts, using price hedging instruments and similar tools.

There are often challenges in scaling up from pilot scale to industrial scale production. In many cases, there are still some technical barriers to be overcome before large-scale production is feasible: E.g. for bio-based PE, PA11 and cellulose films, the technologies are relatively mature and therefore relatively little technical challenges need to be encountered. For PLA, important remaining challenges include downstream processing of lactic acid, alternative raw materials, plastic processing and material property improvements. For starch plastics, some material types such as starch acetate may require extra development. However, the processing of native starch blend extruded with other compounds is nowadays well understood. For PHA, the first-in-kind large-scale plant is currently being built. The time and effort required to overcome the technical challenges, the market price and the material properties will strongly determine the market uptake of PHA. Being the first large-scale plant of its type, the risks are still relatively high. The first-in-kind large-scale glycerol-to-epichlorohydrin plants are being built. For bio-based plastics which are still at the lab and/or pilot stage, the technical barriers are the most important issue. For example, bio-based PA 6 and PA 66 are still at the laboratory stage; and bio-based PP is still at the pilot stage.[14] SMEs, obviously, have smaller resources to take risks, and also smaller chances of securing financing than larger companies.

The reliability of new technology needs to be at very high level and possible downtimes must be diminished to achieve profitable production. Technical barriers include not only the conversion technologies and downstream processing technology, but also the availability of technology. Some technologies (e.g. lactic acid technology) are only mastered by a few companies and therefore the future development of the related polymers and plastics (e.g. PLA) strongly depends on the decisions of these know-how companies including their licensing policies. Moreover, the patent position and the success in patent litigation play a role. In this area, few SMEs have the resources to fight extended patent battles or even research and secure their IPR position – even the knowhow and awareness may be limited.

The economics of the biomaterial sector are not yet well understood given the wide range of variables in the rather new value and production chains. Larger players have a better chance of understanding the value chain and positioning themselves than SMEs.

In theory, biotech routes have substantially lower capital and manufacturing costs and allow greater flexibility because the economies of scale-effects are less significant. In some industrial segments, such as the food industry, biotechnological products can offer economic benefits compared to their chemically produced counterparts. In many cases, however, there are clear restrictions for biotechnological production processes on the economic side, e.g. operative costs, R&D costs and investments. For some products, the technology does not even exist yet (or has not yet been commercialised) or the development of a biotechnological production process is not cost efficient due to the low costs associated with the traditional production. For others, existing production facilities for chemical syntheses cannot be changed to biotechnological production without significant investments.

A considerable amount of time and resources needs to be invested in product development and commercialisation. E.g. sustained financing is needed for products that need to pass a regulatory approval process, e.g. food and cosmetics. Here, SMEs may lack the financial stamina to withstand the long process, however good their case and argumentation.

The competition with oil based substitutes can be very tight. E.g. surfactants have a relatively well structured industrial chain, with fewer than ten producers of the intermediate chemicals that are now entering into the composition of bio-surfactants (fatty acids, methyl esters, fatty alcohols and fatty amines). Entering into a well structured industry with major key players can be challenging to a totally new industry player. Here, everything that promotes partnering and understanding of mutual benefits is of key importance to SMEs.

Transfer of knowhow and technology forms an increasingly important form of growth and development in modern business. This stretches from the very large scale agreements between global players on mutual patent portfolio utilisation to small-scale cooperation. On the larger scale, extensive legal operations form a major part of the modus operandi. On a SME scale, it is a matter of both protecting the smaller player’s interest and of finding the alliances/groupings where e.g. a mutual pooling of knowhow is larger than the sum of its component parts.

4.3 Industry needs

Based on the indentified barriers, the industry needs can be grouped into the following six prioritised categories (on societal and, the last one, on company level):

- Access to funding,
- Technology transfer and strategic partnerships,
- Improved communication of competitive advantages,
- Identification of needs for R&D, training and skills,
- Promotion of the bio-based sector, and
- Development of new business models.

Societal level

Access to funding
The availability of capital is crucial to the development of a highly R&D intensive sector [15,23]. The process from basic research to commercialised products is basically very long and needs a lot of resources as shown in Figure 17. There are also regulatory issues (e.g. safety tests) to overcome before commercialisation of the products may occur. This can delay the commercialisation of certain products, e.g. cosmetics and food, by several years.

Figure 17. Illustration of time and funds needed for product development from basic research to commercialised product

		Years	Cost (Mio. €)
	Basic Research	2-5	0,1 - 1
Akademia	Applied Research	3-5	0,3 - 3
Start-up; SME	Development & Prototype	3-5	5 - 10
Industry	Scale-up & Production	2-3	100 - 300
	Market Penetration	3-5	10 - 100

Source: DSTI/STP/BIO(2009)25[24]

The need for capital stresses the need to support companies in obtaining financing by e.g. bringing together venture capitalists and start-ups. As the success of obtaining capital is largely determined by expected profitability, coaching and help in business planning is also needed. Here. SMEs are in particular focus.

Technology transfer and strategic partnerships
Gaining entry to existing markets and competing with existing products that are made using petrochemical processes calls for focused R&D efforts, e.g. by making use of collaborations with other companies or research organisations[23]. Open innovation i.e. buying or licensing of inventions may also benefit a start-up or a SME. Creating the right fora for this is absolutely essential for SMEs.

Improved communication of competitive advantages
There is a clear need for LCA skills and data to prove economic, environmental and societal benefits of the bio-based products. Moreover, companies should be aware of mechanisms available for communicating the competitive advantages of their products. The often very limited resources available to SMEs necessitate measures of support.

Identification of needs for R&D, training and skills
Needs for R&D, training and skills need to be determined (this will be done in the context of the BIOCHEM project). Future research needs are related to further development of e.g. non-food production systems (e.g. forest biomass, algae), biocatalytic transformation, fermentation technologies, and separation techniques, as well as to solving logistic issues and to development of bio-based products with unique properties.

In particular, the sustainability of bio-based products needs to be studied on all levels, covering e.g. effects on food production, availability of land and water, biodiversity, and climate change – otherwise there is a great risk of accusations of greenwash. Currently, biotechnology applications enjoy strong support from the European public but genetically modified organisms provoke negative perceptions. The aspect of public acceptance has to be considered when e.g. developing company/product strategies or the European research policy. Early analysis of ethical, legal and social implications of biotechnology applications as well as public education, dialogue and communication play a significant role in improving public acceptance [25]. Here, the resources of SMEs in influencing public awareness are very limited.

The lack of an educated workforce may become an issue in Europe within a few years. This issue should be addressed by increasing the share of science courses in primary and secondary schools, by promoting the attractiveness of science as a career opportunity and by giving an adequate funding for European universities to prevent "brain drain"[23,25]. The knowledge base needed for biochemicals production is very wide. In addition to traditional chemical process knowledge, a deep understanding of biomass, biorefineries, separation methods, analysing and control equipments, entrepreneurship, regulation and IPR is required. One of the key challenges is to encourage interdisciplinary interaction in order to share knowledge and find new innovations and solutions. A SME has only a very limited possibility to influence national and European education policy.

Promotion of the bio-based sector
To encourage the development of the bio-based product industry it is essential that the risks during the industrial biotechnology innovation process should be reduced. In particular, there is a need for specialist demonstration facilities for proof of principle. Other public sector means to promote the sector include e.g. R&D funding, technology transfer, establishment of networks and centres of excellence, support aimed at reducing investment risks and other business support schemes for facilitating market access (giving of a preferred status in procurement, product standardisation, further development of bio-based logo/labelling) [26].

Other policy needs are related to measures reducing production costs (e.g. tax incentives) at an early market stage and support to accompanying policies (climate change, agriculture, forestry) at a mass market stage in order to guarantee the realisation of positive external effects and to avoid the risk of insufficient supply of raw materials. Since the biomass demand for the production of bio-based chemicals will remain relatively small compared to the other uses of biomass (food, feed and fuel), raw material availability is not likely to be a bottleneck at least for the next few decades. However, the competition with biofuels can be reflected in the raw material price.

Company level

Development of business models
In biopharmaceuticals, there has been a shift from fully integrated (involved in pre clinical and clinical R&D as well as marketing and sales) companies to business models that are less capital intensive and provide the companies with a shorter time-to-market. These models include developing and licensing out platform technology and commercialising services and thereby focusing on a limited, specific part of the value chain [15]. Other bio-based chemicals also need support in the development of business models in order to shorten the time line of returns on investment. Here. SMEs need support to both understand the value chains they are in as well as position themselves and optimise their business models.

In addition, on the company level, we can discern between

- Policy measures e.g. to support processes with minimal greenhouse gas emissions,
- Price level of biofeedstocks,
- Investment risk (especially first-of-its-kind plants),
- Availability of capital, interest rate,
- Reliability of technology, acceptable downtimes,
- Patent situation,
- Availability of trained personnel,
- Collaboration through the value chain,
- Availability of raw materials, and
- Certifications and labelling.

Product segment level

For bio-plastics, bio-lubricants, bio-solvents and bio-surfactants, the differences are more in degree of weighting between the above company-level needs. Thus:

- Policy measures e.g. to support processes with minimal greenhouse gas emissions
  Important to all segments; the closer to the consumer (e.g. bio-plastics), the greater the importance.

- Price level of biofeedstocks
  Important to all, but of course depending on the proportion of feedstock cost in product.

- Investment risk (especially first-of-its-kind plants)
  The more experimental the technology, the greater the risk. This varies inside all the product segments.

- Availability of capital, interest rate
  Common to all.

- Reliability of technology, acceptable downtimes
  The larger the volumes (e,g. bio-plastics for beverages), the greater the importance.

- Patent situation
  The newer the technology, the greater the importance.

- Availability of trained personnel
  Linked to e.g., pilot facilities.

- Collaboration through the value chain
  The longer the chain (and the closer to consumer), the greater the importance.

- Availability of raw materials
  Linked to volume.

- Certifications and labelling
  Linked to closeness to consumer and supplier pressure in the chain.

5 OPPORTUNITIES FOR PLATFORM CHEMICALS AVAILABLE FROM BIO-REFINING TO BE USED AS INGREDIENTS OR STARTING MATERIALS

Biomass as a renewable feedstock offers the opportunity to replace fossil feedstocks as a source of energy, materials and chemicals. Intermediate platform chemicals can be produced from various biomass feedstocks and they can be raw materials for all product segments assessed in this report (bio-polymers, bio-lubricants, bio-solvents and bio-surfactants). In order to win the competition with petrochemistry and expand the share of biochemical products through biotechnological processes, yield and final product concentration must be improved.[27]

5.1 Biomass feedstock

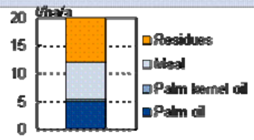
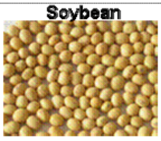
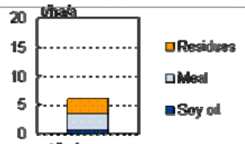
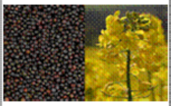
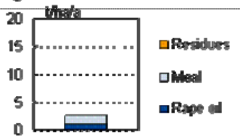
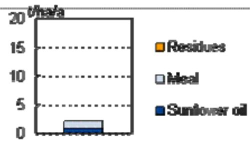
The main bio chemical feedstock groups are energy crops from both agriculture (e.g. starch crops, short rotation forestry) and aquaculture (algae, seaweeds) and biomass residues from agriculture, forestry, trade and industry (e.g. straw, bark, wood chips from forest residues, used cooking oils, waste streams from biomass processing). So far bio-based production is mainly utilising crop feedstocks, and this can be expected to remain the case at least for some time. In the future, algae in particular might be expected to play a much more important role in the generation of bio-based feedstock (for fuels, chemicals and other bioproducts).

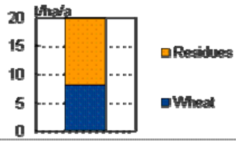
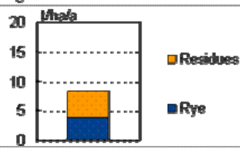
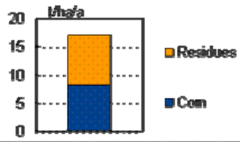
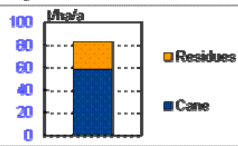
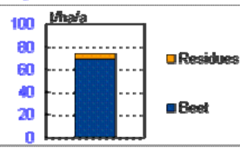
Crop production is determined by a combination of climatic and soil conditions on the other hand, and crop genetic constitution and crop management on the other hand. In the biofuel sector, production is located where feedstock costs are the lowest; e.g. Brazil leads in the global production of sugar cane, the US in maize, the EU in wheat and Indonesia in palm oil. This may have an impact on the geographical distribution of biochemical production, too.

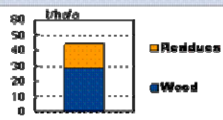
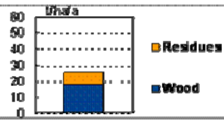
The genetic constitution of biomass feedstocks varies between different raw materials. Figure 18 illustrates the composition and yields (kg/ha/a) of selected biomass feedstocks. Palm oil has the highest yield of oil crops and sugars have the highest yields of cereals and sugars. Fast growing plantations and algae have also good potential in terms of yield.

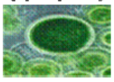
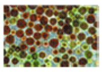
Ethanol and succinate as well as most other products of biotechnology are based on C_6-sugar. The prospects of growing sugar consumption for the production of biochemicals will compete with the food and increasingly the biofuel industry. As biofuel production grows, the biochemical industry will face the economical factor of the rising cost of sugar and the societal discussion about land use for food and fuel[24]. This potential limitation of sugar is already a driver for the use of lignocellulosic carbon sources such as waste biomass from agriculture (straw, corn husk), biomass from grass land, or forestry (wood).

Figure 18. Examples of composition of biomass for selected feedstocks

Feedstock	Crop yield kg/ha/a (fresh)	Oil yield kg/ha/a	Meal yield kg/ha/a	Residues kg/ha/a	Fractions
Palm oil 	Fruit 12000	Palm oil 5000 Palm kernel oil 320	Palm pulp meal 6000 Kernel seedcake 680	Empty bunches 8000	
Soybean 	Seed 3400	600	2800	2500	
Rapeseed 	Seed 2500	1000	1500		
Sunflower 	Seed 2000	800	1200		

Feedstock	Crop yield kg/ha/a (fresh)	Residues kg/ha/a	Fractions
Wheat 	8000	11800	
Rye 	3800	4400	
Corn 	8160	8700 Type / MC / Share d.w. Stalk / 70-75 / 50 Leaf / 20-25 / 20 Cob / 50-55 / 20 Husk / 45-50 / 10	
Sugar cane 	58000-88000	24000-37000	
Sugar beet 	69300	4700	

Feedstock	Wood yield kg/ha/a (fresh)	Residues m3/ha/a	Chemical composition (of dry matter)	Fractions
Eucalyptus ssp. 	14000-28000	8300-16400	Cellulose 40-50 % Hemicellulose 20-35 % Lignin 15-35 % Extracts 1-20 %	
Pine ssp. 	1800-17500	800-7600		

Feedstock	Yield kg/ha/a (dry)	Chemical composition (of dry matter)
Microalgae (open pond) 	1000-3000	Protein 6-79 % Carbohydrates 4-64% Lipids 1-40 % Nucleic acid 1-6 %
Microalgae (open photobioreactors) 	5000-6000	
Macroalgae 	45000	

Source: Pöyry

5.2 Biorefineries

The concept of biorefineries is a combination of integrated plants addressing the processing and fractionation of renewable raw materials, transforming feedstocks to various products from food, feed, fibres, bulk and fine chemicals up to biofuel and recycling the products after the use where possible. Many concepts deal with plant biomass including lignocellulosic carbon sources but also synthesis gas as the principal carbon source.[24]

Biorefining is not a new concept; production of vegetable oils, beer and wine requiring pretreatment, separation and conversion techniques developed thousands of years ago and a Chinese official started paper production around 100AD. New advanced biorefinery concepts are still mostly in the R&D, pilot or small-scale demonstration phase, with commercialisation being far away. It is expected that these new concepts will be implemented in the market in the medium term (2013-2020).[19]

Ongoing European research and pilot-scale projects funded under the 7th Framework Programme include e.g.

- European multilevel integrated biorefinery design for sustainable biomass processing (EUROBIOREF)
- Sustainable products from economic processing of biomass in highly integrated biorefineries (SUPRA-BIO)
- Integrated bioconversion of glycerine into value-added products and biogas at pilot plant scale (PROPANERGY)
- Sustainable and integrated production of liquid biofuels, bioenergy and green chemicals from glycerol in biorefineries (GLYFINERY)

In the classification system a differentiation is made between four main biomass conversion processes, including biochemical (e.g. fermentation, enzymatic conversion), thermochemical (e.g. gasification, pyrolysis), chemical (e.g. acid hydrolysis, synthesis, esterification) and mechanical processes (e.g. fractionation, pressing, size reduction). The biorefinery chains are classified by assessing the involved platforms, products, feedstocks and, if necessary, the processes.[19]

Whole crop biorefinery

In a whole crop biorefinery, grain and straw fractions are processed into a portfolio of end products. Abengoa Bioenergy is commissioning the first commercial-scale whole crop biorefiner plant in Spain, daily processing 70 tons of agricultural residues (wheat, barley straw) to produce annually over five million litres of fuel grade ethanol.

Oleochemical biorefinery

An oleochemical biorefinery can be considered as a special example of a whole crop biorefinery, which combines biodiesel production with that of high added-value vegetable oil-based products. It uses fatty acids, fatty esters and glycerol from oil crops to produce platform chemicals, functional monomers, lubricants and surfactants.

In the long run, oleochemical biorefining might produce renewable feedstocks for fossil-based chemical biorefineries. The success of a biorefinery will ultimately depend on its integration with its existing fossil counterparts, and building blocks of oleochemical biorefineries are offering a neat interface. The NexBTL-process of Neste Oil demonstrates how fossil platforms and biorefineries might interact.

Lignocellulosic feedstock biorefinery

Lignocellulosic feedstock biorefinery encompasses refining lignocellulosic biomass (wood, straw, etc.) into intermediate outputs (cellulose, hemicellulose, lignin) to be processed into a spectrum of products and bioenergy. Lignocellulosic biomass is expected to become a highly significant source of biomass in the future and be widely available at moderate costs, showing less competition with food and feed production. A forest-based biorefinery is an example of lignocellulosic feedstock biorefinery.

Green biorefinery

The use of grassland for cattle production in Europe is on the decline; however, it is felt that continued grass cultivation is essential to preserve valuable grassland landscapes. Green biorefineries, feeding grass to a cascade of processing stages, offer an innovative alternative. Essential is the mechanical grass fractionation into a liquid phase containing water-soluble compounds (lactic acid, amino acids) and a solid phase mainly consisting fibres. Overall economic efficiency of the biorefinery is mainly determined by the economic return of the fibres.

Marine biorefinery

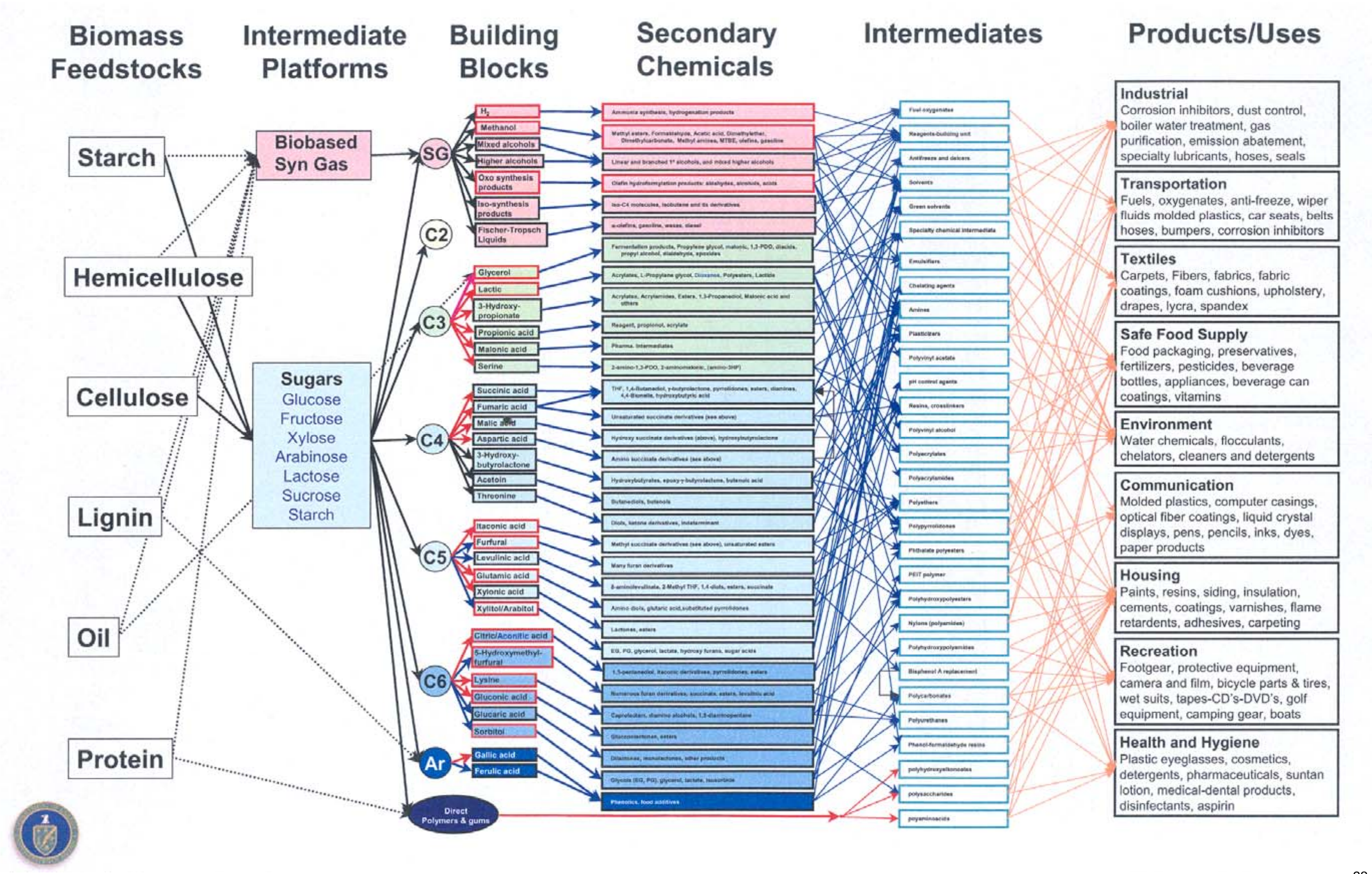
The global primary biomass production is equally divided between terrestrial and aquatic systems. So far, policies have focused mainly on terrestrial biomass, little attention being devoted to marine sources like microalgae and macroalgae and their derivatives. Algae can, depending on species and growing conditions, accumulate significant amounts of oils, carbohydrates, starch and vitamins.

(Source: Langeveld et al.[19])

5.3 Platform chemicals

Sugars, oils and other compounds in biomass can be converted into platform chemicals or building blocks directly or as by-products from fuel production processes analogous to the petrochemical industry today.

Figure 19. Illustration of platform chemicals



Source: Werby and Petersen[28]

From sugars
Over 300 possible platform chemicals have been identified[28]. Different surveys have tried to identify the most promising platform chemicals. Werby and Petersen[28] identified twelve viable platform chemicals that can be produced from sugars via biological or chemical conversions. The twelve building blocks can be subsequently converted to a number of high-value bio-based chemicals intermediates. The twelve sugar-based building blocks are: 1,4-succinic, fumaric and malic acids, 2,5-furan dicarboxylic acid, 3-hydroxy propionic acid, aspartic acid, glucaric acid, glutamic acid, itaconic acid, levulinic acid, 3-hydroxybutyrolactone, glycerol, sorbitol and xylitol/arabinitol. The list was derived by examining the potential markets for the building blocks and their derivatives and the technical complexity of the synthesis pathways. Utrecht University et al [13] report and the FROPTOP program identified a larger list of viable bulk organic chemicals from biomass by application of 'white biotechnology', i.e. industrial biocatalysis.

From oils & fats
Oils and fats are already well established as biomass based chemicals in industry[29]. The oleochemical industry uses over 16 million tonnes of oils and fats worldwide. Its products range from food applications (e.g. emulsifiers), metal working (e.g. cutting oils) to electronics (e.g. wire insulation). A variety of chemical and enzymatic reactions are used to transform oils and fats into basic oleochemical substances like fatty acids, fatty acid methyl esters (FAME), fatty alcohols, fatty amines and glycerols, which can be further converted into chemical intermediates like alcohol ethoxylates, alcohol sulfates, alcohol ether sulfates, quaternary ammonium substances, monoacylglycerols (MAG), diacylglycerols (DAG), structured triacylglycerols (TAG) and sugar esters. (Chemistry Innovation)

From lignin
Another product from biomass based processes is lignin[18]. At the moment it is mainly used to produce process heat by combustion or in animal feeds although around 1 million tonnes of lignin polymers are traded as chemicals. However, lignin also has the potential to be a chemical feedstock [18]. Lignin can be used as a carbon source by gasification producing syngas (carbon monoxide/ hydrogen), which can be transformed into methanol, dimethyl ether, olefins and mixed alcohols (ethanol and higher value alcohol chemicals). In addition lignin can be converted into aromatic hydrocarbon products that can be used commercially (e.g. phenol or vanillin)[27]. The single most important group of plastic precursors, for which bio-based alternatives are still missing, are aromatic compounds. Lignin could be an answer to this need even though it is structurally very complex and diverse, making the production of aromatic compounds from biomass a major challenge. [13]

5.4 Examples of recent activities in platform chemicals

Development of many platform chemicals has reached pilot or small-scale demonstration phase or even commercial scale production has started. To demonstrate the current state of the development, some examples of recent activities in this field are shown below.

1,4 –Butanediol (BDO)
Genomatica has developed a sugar-based 1,4 butanediol (BDO), a key feedstock in the manufacturing of hundreds of industrial chemicals for making plastics, rubber and fiber products. Genomatica has succeeded in creating strains of bacteria that have the potential to produce BDO via fermentation in a global-scale manufacturing plant. Genomatica first produced sugar-based BDO in February 2009, and is currently scaling its manufacturing output to meet the demands of large bioreactors. [21]

1,3-Propanediol (PDO)
DuPont's joint venture, DuPont Tate & Lyle Bio Products, LLC, announced in May 2010 that it is expanding production of bio-based 1,3 propanediol (Bio-PDO™) by 35% at its Loudon, Tennessee, facility (expected completion by 2Q/2011). DuPont's current bio-PDO capacity is around 45,000 t/a. The expansion is being driven by strong demand. Their corn-based bio-PDO is used as an ingredient ranging from cosmetics and personal care formulations to fluids and polymers including DuPont's Sorona® renewably sourced polymer. [21]

METabolic Explorer has started operating its bio-PDO pilot plant in Clermont Ferrand, France, in December 2009.

Succinic acid
DNP has started its 2,000 t/a bio-based succinic acid plant in Pomacle, France, through its joint venture company Bioamber. Sinoven will use the biosuccinic acid for its PBS plastic. Applications for the plastic include coffee cup lids, cutlery, stirrers, disposable razors, cosmetic packaging, etc. DNP's bio-succinic currently uses wheat-based glucose for feedstock. The acquisition will also give DNP a presence in China. [21]

Acetic acid
Zeachem have succeeded in the scaling-up of their fermentation-based acetic acid production from 0.5 litre to 5,000 litres. The company uses their proprietary acetogen bacteria for the process. Zeachem's next step is to concentrate and purify the bio-acetic acid into a saleable product, using energy efficient, non-distillation based process. [21]

Acrylic acid
OPX Biotechnologies is currently constructing a pilot scale bioacrylic process which will be completed later in 2010. A demonstration facility is expected in 2011 while a commercial plant will be on stream in 2013. Arkema has announced that it has partnered with the Lorraine Regional Council and two university laboratories in France for the development of bio-based acrylic acid and derivatives. The joint research program aims to develop an industrial process for the synthesis of glycerol - a byproduct of the processing of rapeseed into bio-diesel - into acrylic acid. [21]

Butanol
UK-based bio-butanol developer Green Biologics has announced its technology and commercialisation plans. The company plans to provide customers with retrofit packages to convert ethanol plants to bio-butanol.[11]

German specialty chemical company Lanxess has invested in bio-butanol developer Gevo, which is based in Denver, Colorado. Gevo and Lanxess plan to jointly develop and produce renewable-based isobutene, a key raw material in the manufacturing of butyl rubber. The companies intend to produce the chemical by dehydrating isobutanol. Gevo is already developing isobutanol via fermentation of corn and biomass. Isobutanol is a building block for making biodiesel, jet fuel, as well as plastics, rubber and fibers.[11]

DuPont and its joint venture company Butamax Advanced Biofuels LLC in partnership with BP have confirmed that their biobutanol demonstration facility in Hull, UK, will start up in 3Q/2010. Commercial production is expected in mid-2012. The JV plans to commercially produce the fuel in the US market in late 2012 to early 2013 by retrofitting ethanol plants to biobutanol. License to retrofit ethanol plants will also be available. DuPont is also looking to produce sugar-based biobutanol from Brazil, which will then be exported to strategic markets, including US and Europe.[11]

Isoprene
Genecor and Goodyear have announced a co-development programme to produce Bioisoprene™ entering large-scale manufacture by 2012. The isoprene will come from renewable materials and be used in vehicle tyres. Commercialisation of renewable-based tyres is expected within the next five years.

Houston-based Glycos Biotechnologies has announced that it is building a biochemical plant as well as a biotech R&D facility in Malaysia together with the Malaysian biotech company Bio-XCell. Malaysia is a good base for their new facility due to availability of palm oil-based glycerine. With their new 20,000 - 40,000 t/a facility, GlycosBio plans to produce bio-based acetone, technical grade ethanol and isoprene. Construction of the plant will begin in 3Q/2010 with an expected completion date in early 2012.[11]

6 KEY INFORMATION ON ENVIRONMENTAL ISSUES

Environmental issues are a potential competitive advantage for the bio-based sector. Companies wanting to exploit emerging green markets need to:

- be aware of customers' and ultimately consumers' environmental needs and develop products to address these needs, and
- communicate their product properties in a reliable way.

This chapter provides a snapshot of selected environmental issues. The applicability of these issues to companies operating in the bio-based sector (irrespective of a product segment) can be characterised as follows:

- Tools such as the Life Cycle Assessment (LCA) are essential in analysing the performance of products or processes. This type of information can be utilised in eco-design of a product or in making environmental claims (of a product/process as such, or in comparison to fossil-based products).
- Standards or (where standards do not exist) voluntary measures such as certification and labelling can simplify the communication of product or raw material characteristics and contribute to the access to market of bio-based products. They are also ways to prove compatibility with sustainability requirements established by e.g. guidelines for public procurement.

Proof of sustainability is also a lifeline to existence, as biomass-based sectors are often scrutinised for their possibly adverse environmental or social impacts. These include biodiversity, food security and greenhouse gas emissions.

6.1 Analysing the performance of products and processes

LCA

The renewable raw material content of a bio-based product does not necessarily make it more sustainable than a fossil-based counterpart. Additional information is needed in order to justify the sustainability of a bio-based product.

One key measurement tool for assessing environmental impact is Life Cycle Assessment (LCA). LCA can be applied for products or services, and it is not limited to specific product segments. LCA covers all stages of a product or a service, from cradle to crave. By carrying out a LCA it is possible to assess all the environmental impacts associated with a product or service. LCA allows measurement of and reporting on current impacts, alternative scenarios and improvements.

LCA is a supporting tool for decision making. It is too complex for direct communication for final consumers, but it provides valuable information to substantiate environmental and economical decisions concerning e.g. process and products improvements. There is an ISO standard for LCA (ISO 14040:2006 and ISO 14044:2006), but the number of degrees of freedom for conducting a LCA remain significant. LCA has also a clear subjective dimension, so when using it as a basis for decisions, it has to be remembered that the results are limited and they have a partly subjective character. Despite the limitations, LCA is one of the most comprehensive tools available at the moment to assess the environmental performance of products or services.

Eco-design

All products have some kind of environmental impact during their life-cycle and more than 80% of the impacts are determined at the design phase. Eco-design aims at taking into account all the environmental impacts of a product right from the earliest stage of design. This approach avoids uncoordinated product planning and making unfavourable tradeoffs, like eliminating a toxic substance should not lead to increased water consumption. The Eco-design approach can be used in any product development but so far both regulation and the development of supporting Eco-design tools have focused on electrical and electronic equipment. General information about Eco-design can be found e.g. from Eco-design Pilot, which is a qualitative tool enabling the user to identify appropriate eco-design measures for the improvement of the product [30].

Environmental Technology Verification

The European Commission is planning to set up a voluntary European "Environmental Technology Verification" (ETV) system in order to improve the competitiveness of European technologies in domestic and international markets. Building on the experience of existing ETV schemes in Canada and the US, the Commission has launched a pre-programme that is expected to become operational by mid 2011.

The EU ETV will assess the credibility of a given environmental performance claim, based on the data provided by the applicant company. The value added for the technology developer will be the proof of credibility of the claim and thus subsequent recognition of the product across the EU. [31]

Environmental technologies are defined in this context as all technologies (products, processes and services) whose use reduces environmentally harmful impacts, when compared with alternatives.[31] Given the technology areas selected for the pre-programme (Water treatment and monitoring techniques; Clean technologies including waste and resource recycling; Air pollution monitoring and abatement; and Energy technologies and energy efficiency), it can be assumed that at least the following applications may deal with bio-based products:

- Cleaner or low-carbon industrial processes, coating equipment,
- Recycling techniques for chemicals, and
- Energy efficiency in industrial processes.

An ETV system is expected to improve the market competitiveness of SMEs who will have access to affordable third party performance assessment through this tool. With available funding from public bodies, the Commission's objective is to limit the applicant's actual cost of verification to about €20,000 per verified technology. [31]

Verification is not the same as certification. Verification means an independent third party assessment of a vendor's claims regarding the environmental performance of their technology whereas certification usually implies a guarantee that specific standards - a pre-defined set of criteria - are met. That is why verification is most useful in areas where standards do not exist yet or in areas where standards are normally not applied. [32] The ETV system does not give a pass-or-fail judgement on the overall performance of technologies - it merely focuses on some environmental characteristics - and it does not compare technologies, but the information given by ETV should assist the purchasers' in their decision making process. [31]

The system will not change the obligations imposed on technologies by legislation or standards, but it should facilitate the proof of compliance with these obligations by providing objective evidence on the technology performance. [31]

Eventual establishment of an EU ETV scheme is pending on the results of the pre-programme. The bio-based sector should follow carefully the development to realise its potential to bio-based products. Specifically, the BIOCHEM partners should observe the development of EU ETV in view of making recommendations as part of the project exit strategy.

6.2 Standardisation

The absence of standards concerning the quality, functionality and characteristics of bio-based products can hinder their market uptake both on consumer markets and in public procurement (public procurement is a sizeable customer group that is increasingly giving preference to sustainable products and services). E.g. the prefix "bio" can refer to a large spectrum of aspects from biomass raw material and biotechnology to biodegradability, and the lack of an agreement on its contents can lead to misunderstandings and even greenwashing accusations.

There are attempts to develop EU standards for biopolymers and bio-lubricants in relation to bio-based product aspects: CEN recently published a "Recommendation for terminology and characterisation of biopolymers and bioplastics" (CEN/TR 15932:2010). CEN/TC 19 deliverables for bio-lubricants are under drafting and expected in 2011. Moreover, a standardisation programme is under development to prepare a definition of the term "bio-based" (CEN/BT/WG 209).

It will be equally important to have available a horizontal standard for the methodology to calculate the renewable carbon content, with specific chapters or annexes if necessary for specific products/sectors.[33]

In addition to standards, there is a voluntary industry self-commitment for highlighting bio-based and biodegradable polymer products, acknowledged by DG Enterprise 2004. Members of ERRMA are also preparing a self-commitment concerning bio-hydraulic fluids, laying down requirements for technical, biodegradable, toxicological and minimum renewable raw material content standards.[33]

6.3 Certification and labelling

The recent challenges of food security related to the biofuels markets have led to a lively public debate on the sustainability of biofuels. Moreover, the environmental viability of biofuels has been questioned based on concern over indirect land use change. This means that biofuel production may drive new cropland conversion for food elsewhere, implicating significantly on the overall greenhouse gas balance. Because of these debates, producers have been pushed to prove the sustainability of their businesses and their raw material sourcing in particular. Biofuels serve as an example on how important sustainability issues are for the bio-based product industry. To ensure sustainable production and use of biomass, a large range of aspects need to be considered.

Apart from challenges related to biomass use, the renewable raw material base also offers possibilities for product differentiation with the help of e.g. bio-based product labels.

Biomass certification

The demand for biomass is expected to increase significantly due to e.g. the EC commitment to the development of renewable energies in the EU. The growing use of biomass also gives rise to international trade. For biomass produced within the EU, the current legal framework (notably related to agriculture and forest management) gives certain assurances for the sustainable management of forest and agriculture. The same is true for some third countries – but others lack such a framework. For this reason, concerns have been expressed that an expansion of international trade of biomass and increasing imports from third countries may lead to the unsustainable production of biomass [34].

This concern has resulted in the development of certification schemes in the agriculture, forestry and energy sectors. As the schemes and national/local support mechanisms for biomass are variable in their requirements, there have also been attempts to harmonise the evaluation framework of sustainability, notably in the liquid biofuels sector. However, the wide variety of biomass feedstocks has prevented the development of a harmonised scheme and binding criteria for all biomass at EU level.

Current mechanisms for assuring the sustainability of biomass include

- Agricultural certification schemes: For the agricultural sector, various certification systems have been developed to ensure that products are produced in an environmentally sustainable way and are safer or healthier for the consumer. The most established scheme is GLOBALG.A.P. In addition, there are smaller, mostly species specific systems that focus their effort on one crop and related end products (RSPO, RTRS, BSI).
- Forest certification schemes: There are two major forest certification systems operating globally, namely FSC and PEFC.
- Energy crop certification schemes (RSPO, RSB)

The various schemes are outlined in Figure 20. In addition, some energy companies have developed biomass certification standards mainly for their own use in order to make claims on green electricity.

Figure 20. Biomass certification schemes

Agricultural certification

GLOBALG.A.P. covers the process of the certified product from farm inputs like feed or seedlings to farming activities, until the product leaves the farm. It is a global certificate aimed mostly at B2B, the key area being Southern Europe. GLOBALG.A.P. certifies crops, livestock and aquacultures. The product list contains 300 products, fruit and vegetables being the most prominent products. Currently, more than 100,000 producers are certified against the scheme.

Roundtable on Sustainable Palm Oil (**RSPO**) certifies growers and supply chains covering some 325,000 ha of palm oil plantations. The RSPO criteria and indicators take into account national special characteristics and have many similarities with those in use in the forest sector. The system does not yet require calculation of a carbon balance. Green Palm and UTZ have been endorsed by RSPO and they certify palm oil producers using RSPO criteria.

Round Table on Responsible Soy (**RTRS**) is in the field testing phase. The RTRS test principles and criteria include a fossil fuel use monitoring, but no carbon balance calculation is required yet.

Better Sugarcane Initiative (**BSI**) certificate is not yet in operation but standards are being developed.

Forest certification

FSC (Forest Stewardship Council) operates based on 10 worldwide principles. At the moment, FSC certificates cover 130 million hectares of forest and the system is supported by environmental organisations. FSC certifies traditional timber products but also plant based processed products like oils or extracts.

PEFC (Programme for the Endorsement of Forest Certification schemes) is a global umbrella organisation for the assessment and mutual recognition of national forest certification schemes. There are currently 32 countries with national forest certification schemes accepted by PEFC, covering altogether 220 million hectares of forest. PEFC certifies all kinds of forest based products, which can be e.g. extracts, fibers, oils or molecules.

Both FSC and PEFC offer *forest management certificates* which focus on responsible forestry and *chain of custody certificates* which enable the labelling of final products.

Energy crop certification

Roundtable on Sustainable Palm Oil (**RSPO**, see “Agricultural certification”) is currently the only operational system for energy crops.

Roundtable on Sustainable Biofuels (**RSB**) is in the pilot phase. The scheme will address e.g. local stakeholder issues (land use rights, food security), greenhouse gas emissions and biodiversity issues.

Biomass certification ensures that the biomass used in processing has been managed sustainably. Benefits of certification include improved market access and potential (although not common) price premiums and competitive advantages (e.g. efficiency improvement by better management). Costs are related to various certification requirements, resulting e.g. in the loss of harvest, and to the maintenance of the system (e.g. auditing, verification).

Product certification

There are two labelling schemes, namely OK biobased and BioPreferred, focusing on bio-based products. Moreover, there are general ecolabels such as the EU Ecolabel that may be available for both bio- and fossil-based products. These schemes are outlined in the figure below.

Figure 21. Labelling schemes for bio-based products

Labels for bio-based products

Belgian company Vincotte launched a global certification programme **OK biobased** in 2009. The methodology for OK biobased is based on an American standard (ASTM D6866). Each certified product must have at least 30% of organic carbon and at least 20% carbon content of renewable raw material. The OK biobased label can include one to four stars according to the share of renewable carbon content of the product. The programme is open for all biobased products except biofuels. At the moment there are products of five companies certified through this programme.

In the US, the USDA launched a programme **BioPreferred** in the end of 2009 to increase the purchase and use of renewable, environmentally friendly biobased products. BioPreferred includes a preferred programme for US Federal agencies and their contractors, and a voluntary labelling programme for the consumer marketing of biobased products. The labelling programme is still in the development phase but it is expected to be finalised soon.

General ecolabels

The **EU Ecolabel** scheme encourages the production and consumption of products which are less harmful for the environment compared to other products of the same product group. Current product groups include e.g. lubricants, paints and varnishes, floor coverings and various detergents and cleaning products. Moreover, it has been suggested that biobased products would become a new product group category within the EU Ecolabel scheme. Many countries also have their own schemes such as **Blaue Engel** in Germany and **NF Environnement** in France.

Moreover, there are several national and global certification schemes for organic products. For example **ECOCERT** primarily certifies food and food products, but the scheme also covers cosmetics, detergents, perfumes, and textiles. ECOCERT was founded in France, but it operates globally. Like all organic production labels, ECOCERT does not certify genetically modified organisms (GMOs).

More information about international and national environmental labelling schemes can be found e.g. in Ecolabels (http://ecolabelling.org/) or Global Ecolabelling Network (http://www.gen.gr.jp/whats.html).

It is important to notice that the certification schemes consider to a varying degree the lifecycle of products and the tiers of sustainability. The schemes apply to different phases of the value chain, e.g. to the biomass production, to the production of intermediate products or to the final product at the consumer surface. However, certification does not deal e.g. with emissions from the manufacturing process or with the quality of the final product. Moreover, there are global, international and national schemes of standards, labels and certificates.

Existing schemes may provide suitable platforms for bio-based products when assuring their sustainability. For edible products such as food additives and some enzymes, schemes focusing on product quality and their health and safety aspects may be the most relevant. On the other hand, carbon balances may be the main issue for bio-lubricants and bio-plastics.

6.4 Environmental regulation

Tightening of environmental regulation would in many cases improve the position of bio-based products, e.g. in the cases of controlling VOC emissions or the use of lubricants in sensitive areas, or potential demands for recyclability of products, for eco-efficiency or for carbon labelling of products in order to curb climate change.

Besides regulations on industrial emissions, waste legislation [c] may play a role in the development of the bio-based product sector as it draws the borderlines between products, by-products and residues, and determines what is waste and what is not. E.g. both production residues from manufacturing processes and consumption residues are primarily considered as waste, thus potentially affecting raw material sourcing and manufacturing processes as transportation and processing of waste requires special permits/registrations. In this context, the criteria for “end-of-waste” are also important as they determine when a substance or object ceases to be waste.

Waste is specifically excluded from REACH. This means that the REACH requirements for substances, preparations, and articles (e.g. registration, authorisation, and communication of information along the supply chain) do not apply to waste. However, where waste is recovered back into substances that are placed on the market for further commercial use, REACH applies as it does to any other substance placed on the market from the point a recovered substance ceases to be waste and waste management controls no longer apply.

6.5 Future implications for bio-based products

As explained earlier, the assurance of biomass sustainability currently refers to biomass imports from outside the EU mainly and the main concerns are related to legality of biomass production and its implications on biodiversity, food security and greenhouse gas emissions. Sustainability risks relating to domestic biomass production originating from wastes and agricultural and forestry residues, where no land use change occurs, are currently considered to be low [34]. However, biomass certification can serve as an instrument to guarantee market access to environmentally sensitive markets.

It is probable that increasing consumer awareness will lead to growing attention to the sustainability of biomass sourcing. This is likely to be reflected in all uses of biomass, not only in energy use. In fact, some players are calling for the same sustainability criteria to apply to biomass use regardless of the final product – be it chemicals, paper, furniture, or energy. Moreover, there is a strong possibility that biomass-related verification of greenhouse gas emissions becomes important in the future in the EU too. This may lead to the development of new sustainability standards and labels based on harmonised life cycle assessments.

[c] Particularly the waste framework directive (2006/12/EC, available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:114:0009:0021:EN:PDF) and related guidance (COM(2007) 59 final on the Interpretative Communication on waste and by-products, available at http://ec.europa.eu/environment/waste/framework/by_products.htm)

7 PRESENTATION OF CASE STUDIES DEMONSTRATING SUCCESSFUL INNOVATION

This chapter presents examples of successful and innovative bio-based products, both upstream and downstream, in the form of selected case studies.

Company: NatureWorks LLC **Turnover:** NA **Employees:**120 **Geographical area:** USA, Europe

Innovation: Production of a family of commercially available polymers based on agricultural resources – bioplastics, with costs and performance competitive with petroleum-based packaging materials

Background: NatureWorks was born in 1997 as a joint venture of Cargill and Dow chemicals. Before the foundation of NatureWorks Cargill had developed new, more efficient and cheaper processes of producing PLA. To obtain good knowledge of final markets, Cargill decided to partner with Dow Chemicals and form a joint company Cargill Dow to ensure that bio-based PLA production would become a success. Cargill Dow then later became NatureWorks with an annual PLA production of 140,000 tons.

Why have they succeeded in the innovation?

- Strong strategic partnership: Partnership of two different players can result in a successful transfer of knowledge
- Environmental awareness of consumers: Market pickup, increasing sales and retailers' interest show how increasing environmental awareness has created a whole new market for the bio-based PLA
- Cost competitiveness: Development of a product which is able to compete both technically and cost wise with petroleum based plastics
- Close market contact: The experience of Dow on plastics contributed to the success
- Communication: The attractive story of replacing fossil-based plastics with renewable and recyclable products was utilised well from the beginning
- Clear leadership in the initial project phases in Cargill: In the early development phase there were strong minded champions to carry out the project

Sources: www.NatureWorksllc.com, Genoma España, June 2007. Success Cases of Biotechnology and Genomics in Medicine, Food, Agriculture and Industry Sectors

Company: Novozymes **Turnover:** 1,13 M€ **Employees:**5 500 **Geographical area:** Europe, Americas, Japan and China

Innovation: Lipopan F, a lipase enzyme that increases dough strengthening potential and replaces partly or completely the chemical emulsifiers usually used for strengthening the dough

Background: Novozymes was founded in 2000 when a Novo Nordisk separated their pharmaceutical and industrial enzyme businesses. Although industrial enzymes for detergents and textiles were the first to be developed back in the 1950's, cereal food enzymes have been profitable and successful. Identifying the market opportunities and the needs in the baking industry Novozymes developed new successful enzyme products for the industry.

Why have they succeeded in the innovation?

- Strong technological background: Novozymes had a long experience in the lipase technology
- Knowledge of the underlying mechanisms of action: Understanding the mechanisms and products that enable changes in the industry helps creating success
- Market knowledge: Understanding baking industry's needs, habits and operational environment
- Articulation of marketing and research: Identifying market opportunities where you can develop and offer a solution
- Product robustness: Assuring a robust and reproducible product to get satisfying final characteristics

Source: Genoma España, June 2007. Success Cases of Biotechnology and Genomics in Medicine, Food, Agriculture and Industry Sectors.

Company: Bioamber, a joint venture established between DNP Green Technology and ARD (Agro-Industrie Recherches et Développements) **Turnover:** NA **Employees:** 76 **Geographical area:** Europe and Americas

Innovation: Commercialisation of bio-based succinic acid by building an industrial scale plant using technology that is cost competitive with the petrochemical processes

Background: Succinic acid and succinate esters can be used as building blocks in a multitude of markets including biopolymers, plastics, polyesters, resins, runway deicers, non-toxic solvents and renewable fuels (as a diesel additive). Much of the research into bio-based succinic acid originates in government agencies, particularly the US Department of Energy.

Why have they succeeded in the innovation?

- Differentiation in technology: Bioamber has an exclusive licence for the technology of the US Department of Energy's proprietary *E. coli* bacterium which Bioamber has optimised
- Case in favour of sustainability: The process consumes CO_2 gas, which gives an additional advantage over petrochemical processes
- Strategic partnerships in many areas: Development of new applications assisted by the work with variety of industry partners. Partnerships also to support distribution, new plant building, and scientific research. The strategy of Bioamber is to be more a partner rather than a competitor with the main players in the chemical industry
- Value chain management: Bioamber also has made an acquisition of a plastic producer to move down the value chain
- In the future actions to shape the market: Bioamber plans to build market demand by negotiating the sale of technology platform licences for large scale succinic acid plants

Sources: Biomass Magazine 2007, "The Quest to Commercialize Biobased Succinic Acid", August 2007. Press releases by Bioamber, 16.12.2008, 20.1.2010, 4.2.2010

Company: Tecnaro GmbH **Turnover:** NA **Employees:**12 **Geographical area:** Europe

Innovation: ARBOFORM® produces "Liquid wood" from lignin. It is a thermoplastic material that can be produced at a competitive price compared to conventional thermoplastic materials

Background: Plastics used to be the only economically feasible material for designing geometries. Now wood can be used like a conventional thermoplastic material. Liquid wood is mainly used for injection moulded wood applications.

Why have they succeeded in the innovation?

- Superior functionalities: The product has a number of technological advantages over synthetic plastics compounds as a strong engineering material
- Strong case in favour of sustainability: Lignin is a by-product of the cellulose industry, i.e. its use does not compete with food production. The product is based on renewable resources and thus provides independence from petroleum based materials The product is also biodegradable and can be burnt without the release of fossil CO_2
- The product is easily applicable in various industries: Utilisation does not require investments in the clients' facilities as it can be processed by conventional plastic fabrication techniques. Products are already applied e.g. in packaging, furniture, toys, shoes, music instruments and automotive industries and there is significant potential in many other industries, too
- Strategic partnership: Tecnaro has formed a partnership with a plastics company

Sources:Tecnaro's homepage, www.tecnaro.de, Press release by Tecnaro, 4.5.2010, Tecnaro presentation in NWBC 2009, Helsinki

Company: The Coca-Cola Company **Net Operating Revenue:** 30 990 M$ **Employees:** 92 800 **Geographical area:** Global

Innovation: The “PlantBottle™”, a PET bottle that contains bioplastics made from sugar cane juice and/or molasses (a by-product of producing sugar). The share of plant based plastics varies from 15% (e.g. in Scandinavia, where bottles also contain 25-50% recycled material) to 30% (e.g. in North America, where no recycled material is added). Life-cycle analyses of the Nordic version of the “PlantBottle™” indicate a 43-46% reduction in CO_2 emissions compared to nafta-based plastic bottles.

Background: The Coca-Cola Company has a vision to create a more sustainable business. As packaging forms a major part of the company’s CO_2 footprint, efforts have been aimed at
1) collection rates
2) recycling
3) renewable resources

The Coca-Cola Company launched the “PlantBottleTM” concept in May 2009 and first established commercial production of bottles in Denmark in November 2009 (0.5 and 2.0 litre Coca-Cola bottles). Thereafter the “PlantBottleTM” has been introduced to water bottles in Canada and USA and to BonAqua bottles in Norway.
Many countries are interested in the “PlantBottleTM” concept, but the Coca-Cola Company is careful in entering new markets due to supply and demand of the plant based material.
The plant-based materials are approximately 30% more expensive compared to their nafta-based counterparts i.e. the shift to the plant based bottles does not bring any direct positive economic impacts to the company.

Why have they succeeded in the innovation?

- Strong R&D partnerships: The company aims at reaching the ultimate goal of developing 100% recyclable plastic bottles made from 100 percent renewable materials
- Capitalising on increasing environmental awareness: Taking consumer trend into practice
- Multiple environmental benefits of the new product: The “PlantBottleTM” is less dependent on non-renewable resources than nafta-based PET plastic bottles. It is 100% recyclable and contributes to reducing GHG emissions while having equal properties as the standard PET
- Compatibility with the company strategy: The innovation is in line with company policies for climate protection, “Growing the business, not the carbon emissions in the manufacturing operations”, and sustainable packaging, “To advance a packaging framework in which the packaging is no longer seen as waste, but as a valuable resource for future use”.
- Launching of "PlantBottles™" in Denmark before the Climate Summit and in Canada and USA before the Winter Olympics

Sources:
Bernt Skov Jensen, Technical Director, Coca-Cola Nordic Services, Interview
Press release by Coca-Cola Company, 14.5.2009
The Industry Features: Patenting at Coca-Cola,
http://www.yet2.com/app/insight/insight/20010401_landgraff

8 CONCLUSIONS AND RECOMMENDATIONS TO OVERCOME BARRIERS TOWARDS INNOVATION IN THE BIOCHEMICAL SUPPLY CHAIN

Based on the market opportunities, barriers and industry needs identified in this report, this chapter includes the conclusions and recommendations for action.

8.1 Conclusions

As the focus of this report is on promoting the success of SMEs in the bio-based products area, we can run a question checklist on what an SME would at the very least have to know.

Is there a market for the products?

There are numerous drivers encouraging the development of bio-based products and the most important ones are related to environmental advantages, product differentiation and savings in raw material costs. Estimates of market growth (up to 2020) vary from 3.5%/a for bio-surfactants and 3.6%/a for bio-lubricants to 4.8%/a for bio-solvents and 16%/a for bio-plastics. Moreover, research on feedstocks and biorefineries is advancing and there are several successful examples of innovative bio-based products.

For the four bio-product segments examined (bio-plastics, bio-lubricants, bio-solvents and bio-surfactants), our findings indicate that all would be growth sectors.

Is there a reliable and adequate supply of feedstock?

A generic answer is hard to give, since the feedstocks vary; within a segment, there are alternatives; and there are many sectors competing for feedstocks. However, since most of the bioproducts are high value added, fairly low volume goods compared to e.g. energy, this sector is at the very least in an advantageous competitive position for the feedstocks.

Is there access to the necessary technological knowhow?

Not necessarily, at the moment. This is something projects such as BIOCHEM must work to rectify.

Is there access to funding?

Again, not necessarily. Again an item for projects of the BIOCHEM type.

Is there a clear policy on sustainability, and access to the necessary tools such as LCAs?

The answer, for many SMEs, is no. Support is needed on many levels.

Thus, we conclude that the basis (*markets and feedstock*) appears sound, even though competition is hard. The key needs for companies (in particular SMEs) are primarily related to the following issues:

- Access to funding: Companies need help in developing a robust business plan which will have the potential to attract funding.
- Technology transfer and strategic partnerships: Companies have limited access to necessary technology.
- Improved communication of competitive advantages: Companies lack a clear policy on sustainable development and have limited access to the necessary tools, such as LCA, to demonstrate sustainable products.
- Identification of needs for R&D, training and skills: Companies' limited resources necessitate focus in this area.
- Promotion of the bio-based sector: The knowledge-based bio-economy doesn't happen by itself.
- Development of new business models: The innovative and risky components of the sector would benefit from new, non-traditional business models.

8.2 Six barriers and boundaries to cross

Based on our research, it is possible to group obstacles, barriers and boundaries into six groups. There is overlap between the six, and this is both unavoidable and advantageous: skilful use of linkages can swing the European bio-based sector a great leap forward.

1. Attitudes
2. R&D, education and open innovation
3. Financing
4. Networking and roles in the supply chain
5. Scalability and markets
6. Regulation and standardisation

We can traverse these groups one by one and give an SME perspective.

8.2.1 Attitudes

There is an attitude challenge on many levels which acts as a barrier against SME success in bio-based chemicals. It may be a natural phenomenon in a region with the world's most successful chemical industry, but it is potentially lethal nonetheless.

- In smaller companies, many studies have shown that the preparedness and confidence to take risks is far smaller than in e.g. US and Chinese enterprises. The entrepreneurial spirit is not something that can be commanded, but the preconditions can be improved.
- In larger companies, a cost-cutting mentality and focus and an obsession with e.g. Chinese labour costs will not lead to competitive advantage.
- In public funding, risk funding which actually takes risks and expects a high failure ratio for every big success instead of an evolutionary, "safe" approach is a necessity for breakthroughs.

A "fast risk track" instrument accelerating bio-based chemicals development is one possible solution.

Of course, an analogous attitude among financiers of all classes is likewise a decisive element.

For SMEs, a change in attitude from "Lone innovator" to networked innovator may be needed – and the best teacher is support in forming connections and understanding the markets.

8.2.2 R&D, education and Open Innovation

Interdisciplinarity

The foundations underlying biochemicals production are very wide. In addition to traditional chemical process knowledge, a deep understanding of biomass, biorefineries, separation methods, analysing and control equipments, entrepreneurship and regulation is required. One of the key challenges is to encourage interdisciplinary interaction in order to share knowledge and find new innovations and solutions.

Bio-based chemicals provide a perhaps unparalleled opportunity for interdisciplinary research and development. The overlap between the value chains of practically all key EU industries, from automotive to chemical, is here significant, and common bio-based chemical platforms can provide parallel value (and scale). The presence of chemists, biologists, mathematicians, medicine researchers and more is needed.

Future research needs, related to further development of e.g. non-food production systems (e.g. forest biomass, algae), biocatalytic transformation, fermentation technologies, and separation techniques, as well as to solving logistic issues and to development of bio-based products with unique properties, could be e.g. the focus of *European Bioacademies* - Networks of universities, research institutes and companies including SMEs, where graduate schools with e.g. public/private funding would have students getting their doctorates and post-doctoral merits solving problems provided by groupings of SMEs.

Schooling and education

The lack of an educated workforce may become an issue in Europe within a few years. This issue should be addressed by increasing the share of science courses in primary and secondary schools, by promoting the attractiveness of science as a career opportunity and by giving an adequate funding for European universities to prevent "brain drain". [25]

For SMEs, enjoyment of the fruits of larger players is the case: they themselves have small possibilities or resources to change schooling.

Open innovation

Open innovation is an overused and sometimes meaningless term. Illustrative of the confusion is that an extremely closed innovation system (Apple) that tries to make sure nothing of its intention leaks in any direction is sometimes used as an example to uphold of open innovation. Apple illustrates the problem: hypercompetition and the need for secrecy in the markets. For SMEs, the fear of having innovations stolen is often quite well grounded in reality – and even a flagrant theft by a larger or distant party may go unpunished due to the lack of resources of the SME to pursue the matter.

Example of Operation Model: What Finally Became "Innovation Mill"

As an example of a project of public private partnership, linking a large company with a public agency, with cities and smaller players, we can cite "Innovation Mill" [35]:

"The idea of Innovation Mills is to take ideas and innovation no longer required by Nokia and make them available to companies across Finland who may be able to turn them into world-class products and services. The idea is to match ideas with businesses that can make them happen. Working alongside Nokia on the initiative is Technopolis, one of Europe's largest science and technology park chains, and Tekes, the Finnish agency for funding technology and innovation.

The ideas come from the innovation spring that is Nokia R&D. With thousands of potential innovations created every year, only a fraction are chosen by Nokia to be taken forward. The Nokia Technopolis Innovation Mill will recycle those ideas, giving them a new lease of life and giving Finnish companies an opportunity to tap into world class product innovation.

The innovations will also receive funding to the tune of €8million, including €4.5million coming from public funding. Local cities in Finland are also involved and hope to drive ICT in their local regions. The end game is to help more Finnish businesses become competitive on the international stage."

Now, this open innovation model revolves around a source of ideas (Nokia) sowing them out for commercialisation by partners of mostly SME-caliber, with public support. Nokia receives no reimbursement for the ideas; its benefit is that gaps in its innovation ecosystem be filled. For SMEs, the benefit is having a ready-made position.

Could an "Innovation Mill" work in bio-based materials? Would large players such as BASF provide "excess ideas"? Or, could we reverse it, so that SMEs also offer ideas for realisation? Or, could we have a two-way Innovation Mill, with ideas and prototypes from large and small companies meeting, with public private partnership? The idea is, at least to the writers of this report, worth a consideration.

8.2.3 Financing

Financing

Financing here captures the whole edifice of support, direct or indirect, coming from private and public sources – or joint exercises.

To encourage the development of the bio-based product industry it is essential that the risks during the industrial biotechnology innovation process could be reduced by e.g. R&D funding, technology transfer, establishment of networks and centres of excellence, support aimed at reducing investment risks (investment subsidies for the realisation of demonstration projects, soft loans, fiscal measures) and other business support schemes for facilitating market access (giving of a preferred status in procurement, product standardisation, further development of bio-based logo/labelling).

The translation of knowledge into products and “culture of commercialisation of ideas” should be promoted e.g. by funding early-stage companies, harmonising IPR protection and affordable access to lawyer services. Financing is the sustenance for innovation, so it’s essential that the EU attracts capital from outside and keeps European venture capital here. Tax incentives, attractive exit options and matching private capital with public funds and loan guarantees are suggested solutions for keeping finance in the EU. [25]

Public private partnerships

Public-private partnership describes a government service or private business venture which is funded and operated through a partnership of government and one or more private companies. These partnerships are more and more established in the area of venture capital especially for seed and start-up financing of start-up companies. [22]

Founding Angel activities

As a rule, a gap exists between academic research and the commercialisation of the results of the research, which in innovation processes represents a serious barrier. This gap can be best overcome in that founding angels, together with appropriate partners from research, found start-up companies to further develop the research results and later, alone or together with an industrial partner, commercialise the technology. With the founding angel business model, support is given to interesting business concepts before the actual founding of the start-up, whereas Business Angels usually enter in already founded companies. This business model is already being successfully implemented in the UK and the US mainly in the field of nanotechnology by companies such as, Advance Nanotech, Arrowhead Research Corporation, Molecular Manufacturing Enterprises Incorporated, Precede Technologies, XL TechGroup. Meanwhile there are also some investments in Germany and Switzerland with a special focus on industrial biotechnology. [22]

For the three issues above (financing, public private partnerships and Founding Angel activities), for SMEs, key solutions are ***awareness*** and ***access***. Awareness applies both to SME awareness of sources of funding and to financier awareness of promising SMEs and technologies, both of which promote “information and innovation exchanges” between funding and SMEs. Access to funding is preceded by *access to sources of funding* – finding the right people and organisations. In all of this, innovation agencies, governments and the Commission have an important supporting and enabling role to play.

8.2.4 Networking and roles in the supply chain

Networks and clusters

Networks is a lately overused term, but it does have a very practical meaning. How does an SME acting alone find out e.g.

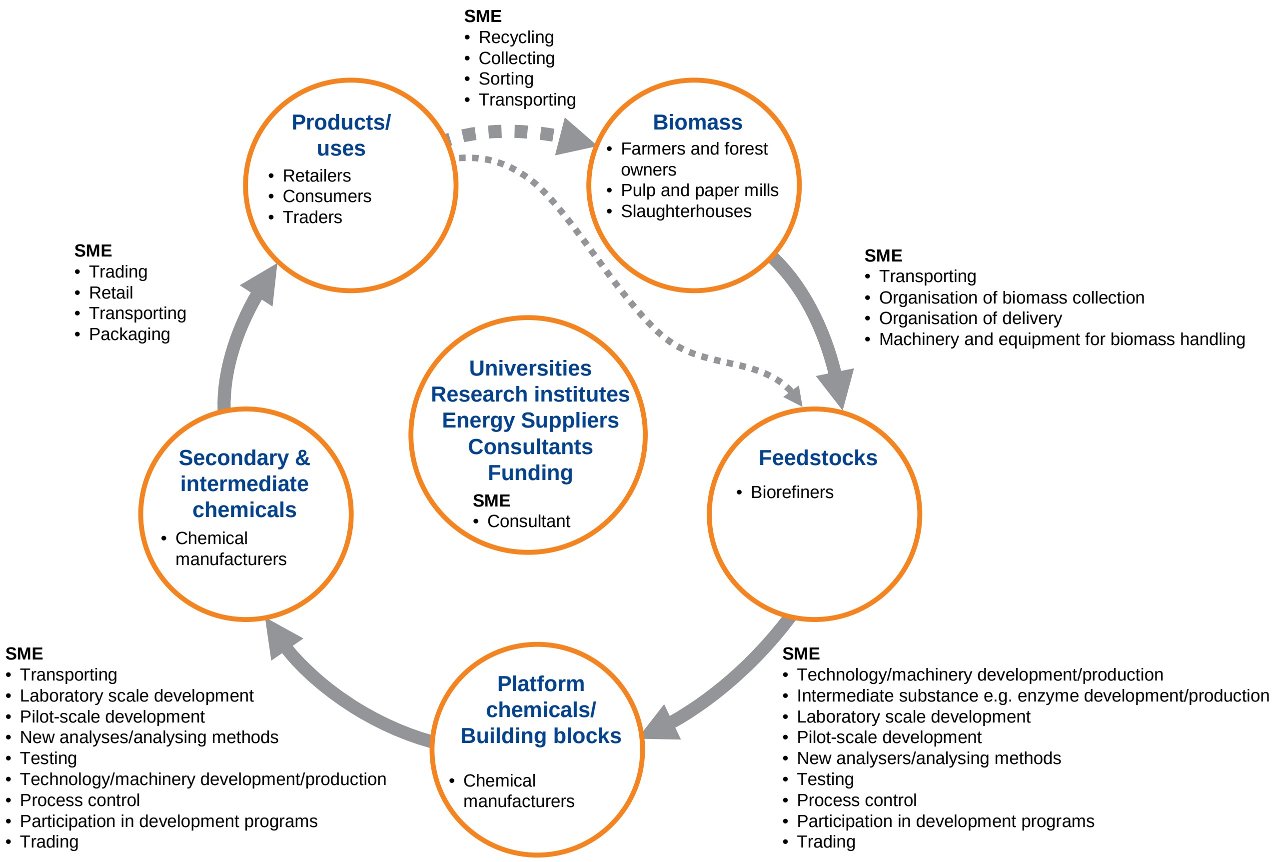
- whether it is reinventing the wheel, i.e. whether what it is focussing on has already been done – or whether e.g. there is a “submarine patent” or other patent in “hiding”, waiting for an innovation to come along for a lawsuit.
- whether it can be/become part of an existing supply chain of actors in different roles

- whether it can find a component its product/technology/service needs from a willing partner, or through licensing
- whether it can be/become part of a “swarm” of SMEs acting in the ecosystem around one or more larger companies
- whether it can find university/research partners with parallel interests
- whether it can obtain funding and other support?

The nature of a lone innovator often works against networking, but the R&D infrastructure in the EU has the potential to build cooperations networks and supply chains second to none.

Examples of roles of SMEs in such networks are given in Figure 22 below.

Figure 22. Examples of roles for SMEs in networks



For SMEs, the network issue translates to e.g. ***cluster awareness*** and ***connecting to information flow***. In many countries and on a European scale, cluster thinking is advanced. Biochemical products often lie in the borderland between several clusters (e.g. the chemical cluster, the pharmaceutical cluster, the forest cluster, the food and drink cluster, the equipment manufacturing clusters of various types) which is both an advantage and a disadvantage. It is an advantage in that a biochemical SME can in the best case connect to several established structures for information flow and connections; a disadvantage in that it may be hard to find a natural place or convince other players. In all cases, measures that both communicate existing structures to SMEs and help them find their place are of extreme importance.

The growth of services means that a *product and a service around it together are more than the sum of a separate service and product*. This means support for SMEs either in locating potential service providers around their products, or allies in together packaging a product and a service.

8.2.5 Scalability and markets

Scalability

The step from a laboratory/pilot scale installation to scaled-up production is almost always greater than anticipated and there is a need for access to specialist facilities to develop and trail new technologies using biomass feedstocks. How does one minimise the amount of dead ends, where a technology finally works, but is inherently (or within the relevant time horizon) unscalable? Here, the role of e.g. providing management/financial evaluation support at an early stage to SMEs, where the problems with scaling are identified and early-stage-assessed cannot be overstressed. A public/private partnership might be the optimal solution here.

Raw materials, their cost and availability are one factor worth mentioning here. If a technology presupposes the large-scale availability of cost-efficient raw material, and this availability is threatened by e.g. political measures, we have a fundamental flaw. This links us to other policy needs related to measures reducing production costs (e.g. tax incentives) at an early market stage and support to accompanying policies (climate change, agriculture, forestry) at a mass market stage in order to guarantee the realisation of positive external effects and to avoid the risk of insufficient supply of raw materials. Since the biomass demand for the production of bio-based chemicals will remain relatively small compared to the other uses of biomass (food, feed and fuel), raw material availability is not likely to be a bottleneck at least for the next few decades. However, the competition with biofuels can be reflected in the raw material price.

> For SMEs, scalability is such an issue that a larger partner is almost always needed. This larger partner can be a financier (providing the resources to acquire expertise and/or build pilots) or a larger player in the chain, providing facilities and missing knowhow and “adopting” the SME into its network. In any case, finding the larger partner is an issue where support is needed.

Product or Service

It should not be forgotten, that at the heart there is a product (or a service), built using materials, processes and technologies. A product needs to be responsive to market needs, attractive costwise, and available in required quantities.

> Especially the market linkage is often very far from innovative SMEs, and special aid in e.g. providing market evaluation support at an early stage to SMEs, for the purpose of e.g. seeking funding could be decisive.

Sustainability

The sustainability of bio-based products needs to be studied on all levels, covering e.g. effects on food production, availability of land and water, biodiversity, and climate change – otherwise there is a great risk of greenwashing accusations. Currently, biotechnology applications enjoy strong support from the European public but genetically modified organisms provoke negative perceptions. The aspect of public acceptance has to be considered when e.g. developing company/product strategies or the European research policy. Early analysis of ethical, legal and social implications of biotechnology applications as well as public education, dialogue and communication play a significant role in improving public acceptance[25].

> For SMEs lacking the resources to either conduct sustainability research on their own or commission such studies, support platforms are necessary. Even if bio-based products provide environmental benefits and economic and social opportunities, sustainability issues can add a tremendous burden on the bio-based product sector, particularly if they are not addressed at the very early stage of sector development.

Markets

The sprawling nature of the bio-based chemicals area makes it less likely that supply and demand meet – the needle in the haystack may be pretty well hidden. This makes it imperative that policies to support the more than serendipitous meeting of end use need (a renewable material e.g. for automotive textiles) and supply (e.g. agro-based fibres processed in innovative ways meet.

The lead market initiative has one possible application area here. On another level, a specialised form of networks could be *biomaterials exchanges*, where, with public/private sponsorship, biomaterial developers and end use sectors would meet, with SMEs enjoying special support.

8.2.6 Regulation and standardisation

Regulation

The policy frame surrounding bio-based chemicals is extremely complex – because the area covered is both wide and overlapping. The main needs are related to
- Identifying key EU regulation in areas relevant to bio-based chemicals
- Identifying the elements that best promote SME success and
- Introducing consistency is an exercise for the Commission, where companies can provide guidance by pointing out the greatest problems.

Specific recommendations on how to develop European legislation and standards have been given by an Advisory Group [26].

For SMEs, all aid in understanding the opportunities (and of course also limitations) given by regulations is of extreme importance, and support is needed.

Standardisation

Ensuring the quality of bio-based chemicals with a flexible yet reliable standardisation is an important instrument that can promote the market uptake of bio-based products.

For SMEs, standards can be a safety net; a provider of credibility and a protector against cheaper but substandard competition.

8.3 Recommendations to overcome the barriers

Summarising the above recommendations around overcoming barriers, we might use the analogy of an *obstacle course* for the biochemical SME. Unfortunately, this is not necessarily far from current reality – but we can and must improve the situation.

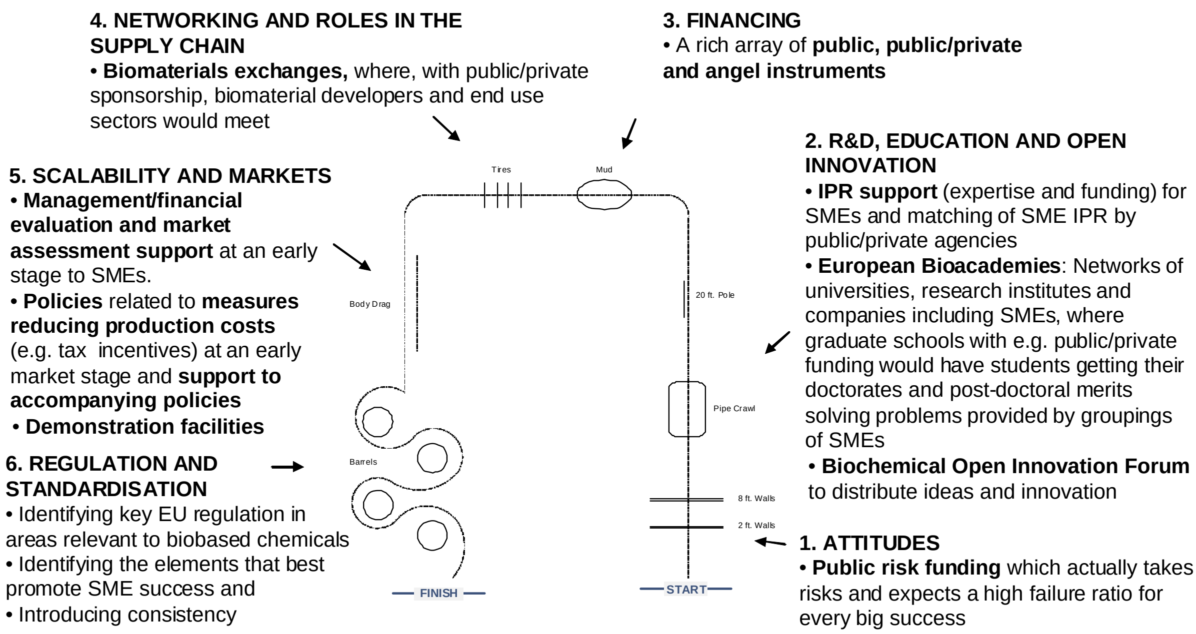
The “obstacle course” has six parts, and along them, selected key recommendations have been collected.

1. Attitudes
   – Public risk funding should actually take risks and expect a high failure ratio for every big success. Here, the role of actors such as the EU and the EIB is very significant.
2. R&D, education and open innovation
   – IPR support (expertise and funding) for SMEs and matching of SME IPR by public/private agencies.

- Establishment of European Bioacademies: Networks of universities, research institutes and companies including SMEs, where graduate schools with e.g. public/private funding would have students getting their doctorates and post-doctoral merits solving problems provided by groupings of SMEs.
- Establishment of a Biochemical Open Innovation Forum to distribute ideas and innovation and make them available to those who may be able to turn them into world-class products and services.

3. Financing
   - Provision of a rich array of public, public/private and angel instruments for SMEs. Here, the BIOCHEM project has a clear contributing role.
4. Networking and roles in the supply chain
   - Support for building cooperations networks and supply chains.
   - Establishment of biomaterials exchanges, where, with public/private sponsorship, biomaterial developers and end use sectors would meet.
5. Scalability and markets
   - Improving access to specialist demonstration facilities for proof of principle.
   - Creation of tools for management/financial evaluation and market assessment support at an early stage to SMEs.
   - Implementation of policies related to measures reducing production costs (e.g. tax incentives) at an early market stage
   - Support to accompanying policies (climate change, agriculture, forestry) at a mass market stage in order to guarantee the realisation of positive external effects and to avoid the risk of insufficient supply of raw materials.
   - Development of tools and support for sustainability policies and sustainability argumentation: environmental, social, and economic.
6. Regulation and standardisation
   - Identifying key EU regulation in areas relevant to bio-based chemicals,
   - Identifying the elements that best promote SME success, and
   - Introducing consistency and clarity.

Figure 23. "Obstacle course": Barriers and recommendations



Concrete example linking several drivers, needs and actions

We could link three of the recommendations above (European Bioacademies, European Biochemical Open Innovation Forum, and Biomaterials Exchanges). The key would be integrated planning. Not so that there is a separate agenda for each of these three, but so that they share a common platform, even a common declaration of goals and means.

To illustrate what we mean, let us take one possible scenario and where pieces of the puzzle already exist. The steps to this construction could be e.g. the following

1. Collect actors (the European Commission, financiers, larger players, researchers, SusChem, Forest Industry Technology Platform, SMEs) for a Biochemical Summit. The role of organising this could belong to the Commission, with input from all players in preparatory meetings.
2. The creation (using tools and platforms e.g. from social media) of a joint Declaration for the promotion of the European biochemical sector.
3. The joint working out of roles for
    - the commercial arm (the Biomaterials Exchanges)
    - the academic arm (the European Biomaterials Academy)
    - the open innovation arm (the European Biomaterials Innovation Forum)
4. Then, the actual establishment of pilot activity or merging of existing activity is a matter of negotiation between the partners.

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