Progress

Priorities for Addressing **O**pportunities and **G**aps of Industrial Biotechnology for an efficient use of funding **res**ource**s**

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About PROGRESS

PROGRESS is a coordination and support action for the European Commission and aims to support and accelerate the deployment of Industrial Biotechnology (IB) in the EU industry by identifying high-value opportunities for IB and proposing actions to address them successfully. For that purpose, we will first provide a comprehensive and dependable information base (including modelling and simulation approaches) which allows for plausible estimations on the future of IB in the EU in the short and medium-term. Second, in collaboration with stakeholders we will elaborate a future scenario and a common vision for IB in Europe containing the most promising value chains, related R&D&I needs and necessitated policies for IB in Europe. Based on these steps, we will provide strategic advice for research, industry and policy making regarding potential issues and topics for collaboration, future policy programmes, the required technological infrastructure, capabilities, and economic structures. A main focus will be to identify opportunities for collaboration between EU member states and proposed actions to increase awareness and incentives for those collaborations. For more information see www.progress-bio.eu

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Content

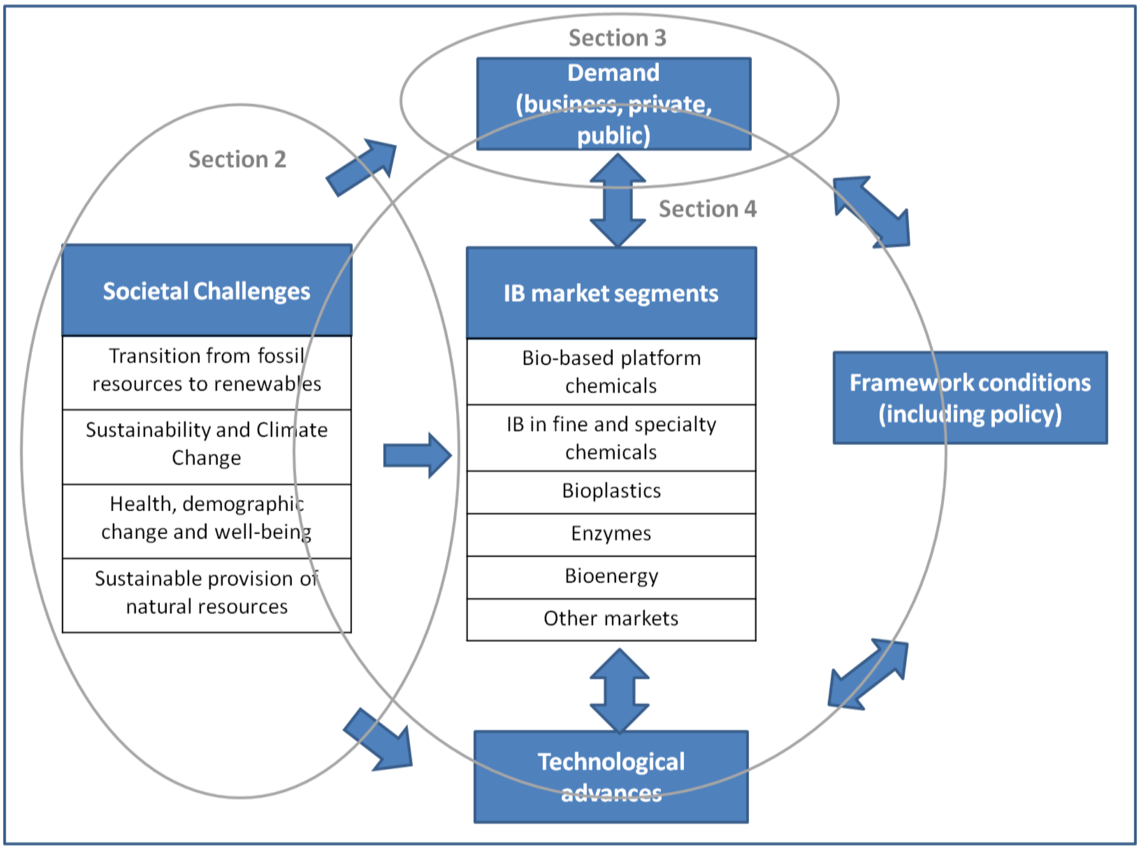
1 Introduction

To achieve a high deployment and to realize its full socio-economic potential, Industrial Biotechnology (IB) has to the address market demand and societal needs. Accordingly, it is essential to shift from a solutions-looking-for-problems (technology-push) view to a perspective that takes market demand and the grand challenges (e.g. climate change, food security, energy security) into the focus. Thus specific attention must be paid to the needs of the application sector, consumers and society as well as the acceptance and potential risk of IB technologies.

This Deliverable aims to cover the potential needs for IB solutions resulting from societal challenges, drivers and barriers on the demand side for different segments, as well as current and projected market developments in various application sectors for IB products and services. The goal is to assess, whether from a macro-meso demand perspective key opportunities (e.g. certain market segments) and requirements (e.g. certain performance characteristics) for IB arise and whether respective articulation of demand is happening on the market. Please notice, that IB markets are influenced by many factors which are closely intertwined (among others feedstock costs, policy and regulation, acceptance, technological advantages and hurdles). In this Deliverable we focus only on those factors which are closely related to demand and consumer needs. The full innovation ecosystem will be analyzed for selected value chains in forthcoming Work Packages of this CSA.

The Deliverable is structured as follows. First, we will shortly summarize the potential implications of the societal challenges for IB. Then we will set these challenges together with other demand drivers and barriers into the context of different segments regarding demand actors (consumer, business, public institutions). Finally we will review market trends and drivers for different segments of IB. The findings are summarized in section 4. Figure 1 summarizes the approach.

Figure 1: Summarization of approach



2 Societal challenges as drivers for Industrial Biotechnology

IB may contribute significantly to address societal challenges (Jiménez-Sánchez and Philp 2016). The other way round, the urgency to address the societal challenges can be regarded as potential key driver for IB. In the following, we summarize key societal challenges and the potential contributions by IB. However, these potentials and their realization cannot be taken as given, and uncertainties regarding the role of IB and future challenges have to be taken into account. These are analyzed as well.

Transition from fossil resources to renewables

The European economy relies heavily on fossil resources. Worldwide demand for this resource will grow in the future, while supply will hardly keep place and climate change is demanding for alternatives (Verbeek et al. 2012). Even in times of relatively low oil prices the urgency for a transition away from fossil resources exists. E.g. Jiménez-Sánchez/ Philp 2016, p.221) state: “There is no shortage of crude oil or natural gas, and replacing the oil barrel will take decades. However, increasing political pressure and societal awareness over climate change and energy security may necessitate its replacement long before crude oil becomes scarce.”

Modern IB is largely about replacing existing products and energy from fossil resources by using renewable feedstock and/or new functionalities and may play a significant role in the transition away from chemical feedstock (Jiménez-Sánchez/ Philp 2016).

This would enhance the energy independence of many western countries, such as the EU (NRC 2015). Biomass-derived energy based on biotechnology already accounts for an increasing share in energy consumption and mainly contributes to the achievement of the EU renewable targets (EEA 2016). This share may increase in the future. E.g., advanced chemical manufacturing or fuels based on biological sources such as plants, algae, bacteria, yeast, filamentous fungi, and other organisms can replace many chemicals now derived from petroleum or other fossil fuels. If properly designed, biotechnological production processes, can improve energy efficiency and, in some cases, reduce energy costs (NFC 2015; see also table 1). Moreover, IB enables to provide products that are amenable to re-use, recycling or biodegradation and contribute to cascade use and hence to circular economic concepts related to the bioeconomy, leading to lower material consumption

Much of the effect will depend on establishing efficient value chains and systems, e.g. regarding cascade use, decentralized solutions to use biomass, interaction with changing consumption patterns. Another key limitation in current bioconversions is that most industrial microbial production strains can only convert relatively pure and non-complex feedstock (SuSChem 2015). Thus, the conversion of alternative feedstock is still a challenge.

Table 1: Results of meta studies regarding energy and GHG balance of bio-based vs. fossil based chemicals/ materials

Study (year)	Field of analysis	Key messages
Patel et al. (2006)	Comparison of 21 **biotechnologically produced chemical bulk products** from biomass to traditional procedures	**Non-renewable energy savings** of bio-based production are estimated at **30%.** For 2050 it is possible to save up to 67% (high-scenario) of energy for the regarded chemicals (20-30% in the "medium" scenario).
Weiss et al. (2012)	Meta-analysis of 44 LCA-analysis for **bio-based materials** (Patel et al. results partly included)	One metric ton (t) of bio-based materials **saves**, relative to conventional materials, **55 ± 34 gigajoules of primary energy and 3 ± 1 t CO_2 equivalents.**
Raman Jegannathan and Nielsen (2013)	Review of 29 environmental assessments of **enzymatic** and conventional processes in various industries.	Implementing **enzymatic processes** in place of conventional processes generally results in a **reduced contribution to global warming** and also a **reduced contribution to energy use.**
ADEME (2004)	Meta-analysis of 67 studies for 10 **bio-based product groups**	Bio-based products can create **40-80% savings** in non-renewable energy consumption and at least **50% lower CO_2** emissions.
Bang et al. (2009)	Estimation of GHG emission reductions vs. baseline for food, material and energy applications of **IB**	The industrial bio-technology sector globally avoids the creation of 33 million tonnes of CO_2 each year (2009). The full climate change mitigation potential of industrial bio-technology ranges between 1 billion and 2.5 billion tonnes of CO_2 emissions per year by 2030.

Sustainability and Climate Change

Climate change and sustainability issues will challenge almost all human endeavours, and requires drastic action. Hence, the way of production and consumption has to change profoundly (OECD 2011; IDEA 2012).

IB provides a range of options for improving competitive industrial performance in selected sectors, while at the same time saving resources (OECD 2011). It offers new ways to produce goods and services, which reduce the release of toxic contaminants, use milder conditions (lower temperature and pressure) and yield products with superior purity compared to conventional chemical processes (SuSChem 2015). Waste reduction may be achieved through bio-based production processes and the resulting products' life cycle. Moreover, the development of bio-based chemicals may lead to increasing the number of products that are carbon neutral in terms of not producing any net increase in carbon dioxide or other greenhouse gases over their entire life cycle. While so far the focus has been on CO_2 emissions reductions in the energy industry and transport sector, it has to be reminded that the chemicals sector is the largest industrial energy user, accounting for one-tenth of global energy use and is the third largest industrial source of emissions after the iron and steel and cement sectors (Jiménez-Sánchez/ Philp 2016). IB is the key technology to reduce this impact in the chemical sectors.

Moreover, in the broader context of the bioeconomy clear linkages to a significant number of the Sustainable Development Goals (SDG) have been identified, with an explicit role of biotechnological methods[1] (Anand 2016; El-Chichakli et al. 2016).

The potential impacts of biotechnology and bio-based products on sustainability have been mainly analyzed on a meta-level regarding GHG-emissions (see Table 1). These studies point out substantial potential of IB to minimise CO_2 emissions.

However, IB products and processes are not necessarily sustainable per se. The effects depend on the individual products and production ecosystem as well as on the performance of the different products that may be substituted. Moreover, while IB reduces CO_2 emissions and the demand for energy according to many existing analyses, it reinforces negative environmental impacts caused by the large-scale cultivation of biomass in intensive agriculture, such as the pollution of water through the supply of nutrients, stratospheric ozone depletion or soil acidification (Schiller 2016; Patel et al.2006; Weiss et al. 2012). In addition, many IB processes require large amounts of water (SuSChem 2015). Hence, further improvement in the efficiency and other environmental impacts as well as methods to improve the measurement of sustainability of individual products and processes, and also on a system level, are required (Schiller 2016; Weiss et al. 2012). Finally, the overall effect may be limited because of rebound effects that may occur via higher consumption of products, e.g. increased washing of

[1] E.g. for SDG 11 (sustainable cities) and SDG 12 (sustainable consumption) (see El-Chichakli et al. 2016).

clothes offsetting enzymes enabled reductions in temperature and detergents. Hence, the combination of IB technology improvements together with sustainable consumption will be necessary.

Health, demographic change and well-being

Population growth and ageing, social changes as well as new ‘modern’ and emerging diseases will ask for further advancement in treatment concepts in health care (e.g. prevention) in combination with new kinds of diagnostics and therapeutics (Verbeek et al. 2012). Such developments are mostly related to medical / red biotechnology which is out of the scope of this CSA. Nevertheless, subsequent demand for biopharmaceuticals drives demand for manufacturing of new biotechnological pharma ingredients and related R&D and services. Moreover the need for new analytics and diagnostics will require advances in industrial bioprocessing. Another contribution may be the further development of nutritional ingredients with potential health benefits.

Future challenges for IB include the production of active and complex compounds at an affordable price in a society that has an increasing health care cost structure. For example, new analytics could contribute to this end by shortening time-to-market of new products through greater process knowledge. Moreover, higher flexibility of process methods and plants to produce small batches will be a key challenge (Deloitte 2015).

Sustainable provision of natural resources (agriculture, food, water management, forestry, biodiversity)

Increasing demand for food and the unequal distribution of food availability around the world as well as increasing industrial use of biomass lead to a growing demand for natural resources, while agricultural productivity cannot keep pace (Verbeek et al. 2012). Moreover, maintaining biodiversity as a natural resource has become an enormous challenge. The potential impact for IB is ambiguous. On the one hand, IB contributes to higher efficiency of resource use and to the transition to non-food feedstock via biomass treatment (e.g. more productive enzymes) or contribution in later value chain stages (conversion to product). IB also enables the development of nutraceuticals, proteins or food and feed additives and hence contributes to some extent to satisfy consumer demand for food.

On the other hand, IB products and process may require large amount of feedstock, in particular in mass markets (biofuels, bulk biochemicals, bioenergy), thereby reinforcing the discrepancy between a growing demand for natural resources and limited productivity of agricultural systems. While currently the discussions about land use conflicts are less intensive, a potential future hunger crisis may raise this issue prominently again (Verbeek et al. 2012). In consequence, public acceptance and potential policy support for IB may affected. Moreover, sustainable provision of natural resources is a decisive factor for deployment of IB in a considerable number of segments.

Summary

Overall it can be concluded that IB has indeed the potential to contribute to various societal goals. However, these contributions and in consequence the implications of societal goals for IB in many cases are not clear cut. Among other, this is due to the high heterogeneity of products, processes and applications, the different opposing effects (e.g. higher efficiency of use by IB but also higher demand for biomass) and the required improvements regarding new and existing products, processes and production system.

Moreover, different societal needs do not always go hand in hand, but some dilemmas arise. For example, while the demand for organic products (e.g. textiles) may be connected to the rejection of biotechnological processes (e.g. GMO-modified enzymes) by consumers, IB may be a solution to manufacture those products in a more sustainable way.

Moreover, a key issue is whether societal needs are aligned with market demands and/or supporting policies. Market demand is influenced by many economic factors, information availability and behavioural consumption patterns. This issue will be addressed in the following section.

3 Demand Drivers and Barriers

There have been plenty of studies and initiatives that assess the market demand for bio-based products in total or for certain bio-based materials. The insights can be useful for IB as it is usually the green basis or the functionality of the whole product that drives market behaviour (and not the kind of production process itself). But, it has to be reminded that not all products processed with IB rely on biological resources, so the results do not apply for all IB applications.

In the following, main results are summarized from literature with additional insights from stakeholder interviews: The different types of demand have to be distinguished in this discussion: commercial buyer (B-to-B market), private demand (consumer markets), public demand.

Commercial buyers (B-to-B market)

The interest from business customers in B-to-B markets for IB products has been increasing in the past decade, in particular for bio-based chemicals. In particular, more and more brand owners are showing interest in bio-based products regarding more sustainable supply chain. Overall, the main driver for the B-to-B market is the positive public image associated with bio-based product (Meeusen et al. 2014). E.g., in the market of bioplastics the decision of some brand-owners to use and promote bio-based packaging raises demand by far to another level. In relation to that, potential environmental advantages savings, e.g. in CO_2 emissions, are important drivers to purchase IB-processed bio-based products. Moreover, independence from fossil sources is a strategic goal of some business costumers.

The main barriers for the uptake of IB in the B-to-B market are connected to costs. First, IB products are quite often more expensive than their alternatives (Bio-Tic 2015b). Secondly, for those products that do not have identical properties to fossil-based counterparts (non drop-ins) – switching costs for users occur, such as reconfiguration of the processed products or the equipment for production, learning costs to use the product and sometimes costs for selling new processed product (Wydra et al. 2011). In addition, various uncertainties for business customers arise. This relates to the volatility of prices[2], the availability of the product (often only one supplier exists,

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2 While this is also the case for fossil-based product, it was pointed in expert interviews that to rely on a certain agricultural feedstock is more risky for a company, as most of the competitors still rely on fossil-based resources and wouldn't be affected in a situation of price shocks. In the alternative case that all the company itself relies on fossil-based feedstock, this individual risk wouldn't exist.

availability of feedstock is uncertain, etc.), the performance of products, the acceptance of end consumer as well as future regulation and policy support. In addition, the knowledge and awareness in the B-to-B market regarding bio-based products is still limited regarding visibility as well as characteristics and potential benefits of bio-based products. Moreover, the communication between customers and suppliers regarding needs is not trivial. E.g. according to expert interviews it is highly difficult to capture the real demands and needs: for example even if potential customers need new product functions, which might be addressed by IB, this is usually not communicated openly, but kept internally.

Private Demand (Consumer market)

The insights concerning consumer acceptance and willingness to pay are scattered. General surveys of consumers about bio-based products do hardly reflect actual purchasing behavior, while studies concerning specific products or product attributes are difficult to generalize. Moreover buying decisions for bio-based products are influenced by a myriad of factors, e.g. a study by Pelli and den Herder (2013) about foresight on future demand for forest-based products and services points out to different dimensions of consumer awareness. Accordingly, major factors for consumer choice include environmental awareness (nature first), price awareness (price decisive), quality awareness (quality first), sustainability awareness (incl. “balancing” of the environment, economy, social and cultural impacts), and health awareness (wellbeing first).

Generally, the consumer attitude to bio-based products is assumed to be mostly positive (BIOPOL 2009; Genencor 2011; Meeusen et al. 2014). However,

- potential land conflicts because of higher demand of biomass for industrial use and the use of GMO-based interim products lead to limited acceptance of some IB segments;
- the general positive attitude and the willingness of consumers to buy bio-based products and to pay a premium is limited (Carrez 2015; Bio-Tic 2015a). More likely, some kind of expectations toward big consumer brands to build up more sustainable value chains may create market pull.

Main reasons for their negative attitude are first the lack of awareness of the existence of bio-based products (Carrez 2016). Consumers often have limited understanding about the “term bio-based” as well as characteristics of bio-based products. Second, there is a lack of understanding of the benefits as well as unclearness regarding the actual impact of IB products (Wydra et al. 2012; see section 2). Here, the difficulty is to assess sustainability issues through all segments of the value chain of bio-based products (from biomass production to end-use). The lack of a widely-accepted mechanism to assess and confirm sustainability is an important barrier (OECD 2011).

Public Procurement

The demand for IB products also can be fostered by public institutions via public procurement: “Public procurement can shape production and consumption trends and a significant demand from public authorities for "greener" goods will create or enlarge markets for environmentally friendly products and services. By doing so, it will also provide incentives for companies to develop environmental technologies” (BIO-TIC 2015a, p.31). In the US, the so-called BioPreferred program sets regulations for Public Procurement for bio-based products. An European equivalent is not existing yet. The Commission Expert Group for Bio-based Products (Expert Group 2015) recently evaluated the implementation of the Lead Market Initiative (LMI) of bio-based products priority recommendations, which partly relate to the fostering of public procurement. The Expert Group points out that while in some countries, concrete pilot projects have been initiated to give preference to bio-based products in tender specifications, public procurement still takes place in a fragmented landscape in Europe.

The project Open-Bio (Meeusen et al. 2014) conducted a survey among experts in the field of (green) public procurement from 12 EU countries. The results revealed, that environmental impacts immediately related to the production, use and disposal of products (i.e. recyclability) are considered as more important than the environmental impacts which originate from the raw materials. Hence, the bio-based content alone is not sufficient.

4 IB markets – status quo and outlook

The IB market is expected to grow significantly in the future. Various market studies show strong signs of growth. However, the estimation and projections significantly differ from each other, especially in the medium-term. While there are plenty of market studies that analyze specific application sectors (see next sub-sections) there are very few overall studies covering all the different IB application markets, which have been conducted in the last five years. Table 1 summarizes a Frost & Sullivan study (2011) that aims to cover the whole IB market globally and the Bio-Tic (2015a) study for the European market. While the overall numbers may appear roughly consistent, significant differences in the expected growth rates have to be highlighted. While Frost & Sullivan expects an 8.5% compound annual growth rate (CAGR) between 2010 and 2020, the Bio Tic study projects a 4% CAGR between 2013 and 2030.

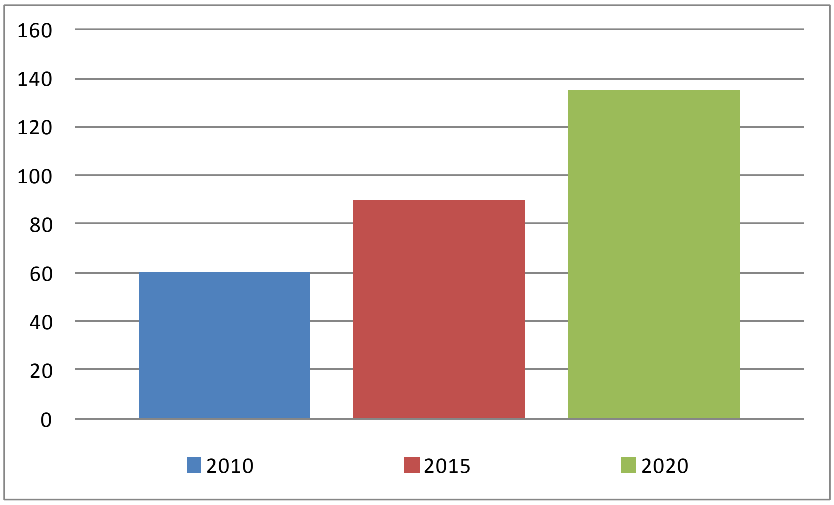
Besides the differences in geographical coverage and also the sectors-specific market studies mentioned in the next sections set different boundaries and include different application sectors or product groups. Moreover, future developments are influenced by various factors, which are hard to predict (e.g. technological uncertainty regarding the ability to use non-food feedstock, prices for fossil and renewable feedstocks, policies, etc.). Usually, the future assumptions of the studies as well as the method for estimations are not made explicit. Related to this, it has to be remarked that former market forecasts had to be revised considerably in the past. These projections already expected an increase of the share of biochemicals in the total chemicals market to 15 to 20% in 2010 (BMBF 2007, Frost & Sullivan 2003, McKinsey 2003), while the actual share is currently estimated below 10% (Bio-Tic 2015b; Frost & Sullivan 2013).

In the following sections, a summary of key markets for IB is presented, covering the current estimated market size and applications as well as future projections including selected key market drivers and needs for IB advances. The assessment is based on existing market studies and qualitative information from literature and the expert interviews conducted in this CSA.

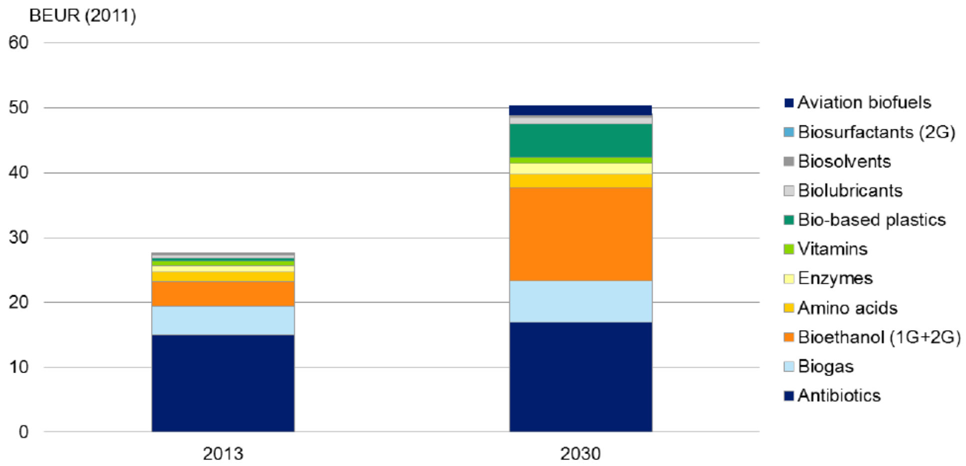
Figure 2: Global and European market projections for IB (in billion €[3])

World market (Frost & Sullivan 2011)

[3] In this Deliverable all information in US$ are converted to € by using OECD information and exchanges rates in 2014, as most of the referred studies have been conducted before 2015, when the US$ has been revalued significantly.



European Market (Bio-Tic 2015b)



Source: Frost & Sullivan (2011); Bio-Tic (2015a)

4.1 Bioenergy: Bioethanol and Biogas

Bioethanol, and prospectively biobutanol, are biofuels based on biotechnological processes to convert biomass. Next to first generation bioethanol, which is derived from sugar or starch produced by food crops (e.g. wheat, corn, sugar beet, sugar cane, etc), cellulosic ethanol is a second generation biofuel that may be produced from agricultural residues (e.g. straw, corn stover), other lignocellulosic raw materials (e.g. wood chips) or energy crops (miscanthus, switchgrass, etc) (EPure 2015). The main application is public transport and potentially aviation.

Biogas is a relatively large application market that uses IB methods to convert biomass into energy. However, IB advances play only a limited role for the market development, as other factors clearly dominate the future market development (e.g. regulations, resource prices, development of alternative technologies like wind and solar, etc.). Hence, it is considered only shortly in this section.

Bioethanol market: The EU total bioethanol consumption for transport fuel is estimated at 4.1 million tonnes, and stagnating in volume growth since 2010 (Philips et al. 2016). Based on OECD/FAO (2016) information the price for bioethanol ranges at around 500 € /1000 l (~ 630 € /t) €/t (EPure 2015). This would indicate a market size of 2,6 billion €. Today, the global production of second generation (2G) ethanol is still very low, but increasing, as several new 2G facilities became operational in the last 3 years (Bio-Tic 2015b; UNCTAD 2015). However, only one full commercial plant is operative in the EU (Beta Renewables in Italy), which represents a bit less than 1% of the overall ethanol production capacity in Europe (Philips et al. 2016).

Because of missing cost competiveness compared to fossil fuels, the bioethanol market is driven by the obligation for a 10% share of renewable energy in transport set for 2020 by the Renewable Energy Directive (Bio-Tic 2015b; Philips et al. 2016). In 2015, the European Commission (EC) officially introduced a seven percent cap on food based biofuels thus limiting future production of these first generation biofuels and an indicative, non-binding 0.5% sub-target for second-generation of biofuels (double counted towards the 10% renewable target in transport).

Most market outlooks for the EU-28 are based on the assumption of a continuity of the obligation for a 10% share of renewable energy in transport until 2020 and after that period in combination with the 30% CO_2 reduction target (compared to 2005 levels) that was set for sectors not included in the Emission Trading System (ETS), such as road transport. On this basis Bio-Tic (2015b) expects a considerable increase of bioethanol from 4 billion € to around 14.4 billion € (13.1 million tonnes). This growth is driven by 2nd generation bioethanol, which is expected to fully substitute 1G bioethanol.[4] However, the Bio-Tic study also points out the high uncertainty of future market evolution. In the low scenario (5% 2G of transport fuels) 2G would have a market of around 7.2 billion €, in the high scenario (15% G2 of transport fuels) the market would rise to around 22 billion €. A quite similar projection is provided by Hirschnitz-Garbers/Gosens (2015)

4 Key assumptions are that the EU will reach its target of 10% renewable energy in transport in 2020 and in 2G biofuels would have replaced 1 G biofuels and combine the share of 10% of road transportation, with Ethanol having a proportion of 30%.

who consider a market potential between 13,6-20,9 billion €[5] for 2nd generation biofuels, although they differ in some assumptions[6].

The OECD/FAO (2016) is more pessimistic about development of consumption of bioethanol. Based on different information about prices, consumption and EU market share, the market is expected to grow from 3.7 billion € (average 2013-2015) to 4,3 billion € in 2025 (compared to around 12,5 billion € in Bio-Tic). Moreover, the OECD/FAO expects a market share of lignocellulosic ethanol of only 0.7% in 2025, a conversion for Europe would mean 0.03 billion €.

Biogas: Biogas contributes 7% to the Gross renewable energy consumption at the global and EU-28 level (EEA Report 2016). Turnover is estimated to around 6.08 billion € in the EU in 2014 (EurObservER 2015). According to Scarlat et al. (2015), based on the aggregated data of the Member States progress reports and predictions, biogas production will grow by around 9% CAGR between 2015 and 2020. Regarding the longer term, the 2030 Framework for Climate and Energy sets a binding target at EU level to increase the share of renewables to at least 27% of EU energy consumption by 2030.

The BIO-Tic(2015) study assessment of the biogas market leads to more conservative numbers. The study projects a growth from about 4 billion € (2013) to around 6 billion € in 2030 (around 2.5% CAGR).

While the regulation of the Renewables Energy Directive and the Framework for Climate and Energy drive the market for bioethanol and bionergy, different factors impact indirectly the continuity of these ambitions and its fulfilment:

- political uncertainty for investments and the currently weak energy prices are a key barrier for further construction investment in research and development of 2G plants (OECD/FAO 2016) and also for further biogas plants
- the public acceptance for biofuels and bioenergy is limited, mainly because of food versus fuel utilization of biomass. This influences policy decisions, regulations and consumer behaviour (e.g. in those countries where customers can choose between E5 vs E10[7]);

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5 ‘Low’ demand scenario: crop-based biofuels supply a maximum of 7% of all transport energy. ‘High’ demand scenario: all biofuel demand will be fulfilled with advanced biofuels

6 They assume a 20% contribution of renewables in transport fuels, but only the half to be generated of waste streams or lignocellulosic.

7 "E" numbers describe the percentage of ethanol fuel in the mixture by volume, for example, E5 is 5% anhydrous ethanol and 95% gasoline.

- bioethanol (first and second generation) tend not to achieve levels of cost competitiveness that are comparable with other alternative energy pathways until 2030 (IEA-ESTAP / IRENA 2013). Still, cutting down costs for second generation bioethanol will be of key importance to compete with 1st generation biofuel and to potentially receive more political support (as less costs would be connected with higher targets);
- currently, fermentation of sugar is the most developed route to produce ethanol from lignocellulosic biomass. Here, the pre-treatment of the lignocellulose still presents a key barrier;
- generally, the highest impact of emerging technologies would arise from increasing possibilities to use non-food biomass efficiently (e.g. waste, lignocellulose, algae) for fuels and energy (Scarlat et al. 2016).

4.2 Bio-based bulk Chemicals

The chemical industry and market have a key role for IB and the bio-economy. The chemical industry is traditionally innovative, with rather high R&D intensity and acts as an innovator for downstream industries. It provides intermediate goods for food and beverage production, textiles and leather, pulp and paper, automotive, construction and provides a significant proportion of innovation performance of these sectors. In recent years, companies have set strategic priorities and set up strategic partnerships in some segments of IB and/or in the use of biomass as raw materials to ensure their international competitiveness in the long term. Biotechnology is now an integral part of the chemical industry and is increasingly used in integration with chemical processes. In particular, bio-based chemical bulk and platform chemicals have attracted increasing attention in the last years. Bio-based platform chemicals, which can be obtained from biomass with few process steps, contain molecules with different functional groups that can be converted into various other useful molecules. While a few bio-based platform chemicals already have reached the market, there have been major developments in the recent years (Bio-Tic 2015b). The development stage of those bio-based products differs and ranges from proof-of-concept in the laboratory to full commercial production (Bio-Tic 2015; E4Tech et al. 2015; Biddy et al. 2016).

The products are intermediate chemicals for a very broad range of potential applications in the B-to-B market. Some companies focus on certain applications (e.g. Braskem for Bio-Polyethylen targets the markets food packaging, cosmetics, personal care, automotive parts, and toys), which may potentially benefit from a green image (Brostow / Datashvili 2016).

Some bio-based chemicals are drop-ins, with identical or similar technical properties as their fossil counterparts. Drop-ins do not face high market uncertainties, can be partly built on existing infrastructure and existing technological knowledge for the conventional product and do not lead to switching costs for users. However, competition to the fossil based products with similar performance is mostly reduced to relative resource prices. Current examples on the market are Polyethylene or 1,4 – Butanediol.

Others (non-drop ins) differ in their functional and properties. While they generate value by offering new functionalities, diffusion is hampered by switching costs for users (e.g. new infrastructure, new knowledge), the need to build up new markets, and requirements to improve the process (cost reduction) and the product (material properties improvement) (de Alemida Oroski et al. 2014; section 2). A current example on the market is Polylactic acid (PLA).

The EU demand for bio-based platform chemicals produced by fermentation is estimated at less than 700 million € in 2013, representing approximately 35% of global production and an CAGR of roughly 10% from 2008 to 2013 (Bio-Tic 2015b). Similar results can be derived from the analysis of the EC sugar platform analysis that reveals data for top-25 sugar based products. Bio-based platform chemicals from this list sum up to 2-2,3 billion US$ (~ 1,5 - 1,7 billion €) for the global market, assuming around a third for Europe would mean around 500-600 million €.

The future market evolution is highly uncertain (see market drivers below). Due to that reason, the Bio-Tic study (2015) bases it’s projection mainly on expected GDP-development (in combination with stakeholder estimations). Accordingly, the market value of IB-based platform chemicals in 2030 is expected to reach 3.2 billion € in the reference scenario and 3.5 and 1.9 billion € in the high and low scenarios, respectively. Research & Markets (2016) already now is much more optimistic and states that the bio-based platform chemicals market would reach a volume of 14.9 million tonnes and revenue of 18.8 billion US-$ (~ 14 billion €) by 2021. This would imply a volume growth of 8.1% p.a. compared to 2015 (9.4 million tonnes).

Key market drivers will be the relative price of resources (biomass vs oil) and its volatility as well as overall production costs:

- Because of the fall of crude oil prices bio-based chemicals struggle to compete with lower-priced petrochemical-based counterparts. However, bio-based chemicals are affected to a different extent by these changes in resource prices. In particular drop-in replacements for predominantly crude oil derived chemicals and polymers such as isobutene and adipic acid are significantly (negatively) impacted by the lower production costs of their fossil competitor (E4 Tech et al. 2016). Drop-ins for chemicals and polymers that are typically derived from natural gas are less affected by price reductions of fossil-based counterparts and non-drop-ins may partly offset lower price competiveness by special functionalities and properties. Here, according to expert interviews, still the real needs have to be identified, e.g. which are the functionalities that bio-based building blocks for polymers should have.

- For most bio-based platform chemicals that already entered the market (or are close to commercialization) processing costs are still relatively high compared to fossil counterparts, e.g. because of low yields, inefficient downstream processing, high energy demand etc. (E4 Tech et al. 2016). Hence, further improvements regarding these process deficits are needed.
- Massive new investments to build new production facilities are needed (Bio-Tic 2016). While there have been many announcements for building up new facilities for the production of bio-based chemicals roughly around the years 2009-2013, the decline of the oil price lead to the abandonment of a significant number of facility plans (e.g. for Bio-Polyethylen) and a significant lower number of new announcements. This slower growth in new capacities, and perhaps even the build-up of fossil-based plants may lead to longer lock-in effects in fossil-based pathways

4.3 IB for fine and speciality chemicals

Fine and speciality chemicals are the main application segments for biotechnology in chemicals. The main reason is that the specific characteristics of biocatalysis offer comparative advantages compared to traditional methods in this segment, such as high specificity, selectivity (in particular enantioselectivity) and activity under moderate reaction conditions. Biotechnological applications for specialty and fine chemicals include vitamins, flavors and fragrances, industrial cleaners, coatings, water and sewage treatments, agrochemicals, fibers, dyes and pigments, adhesives, sealants, pharmaceutical intermediates, enzymes (see extra section), etc. (Frost & Sullivan 2011; Festel 2012). In the present study, we also include consumer chemicals (soaps, cleaning agents, detergents, cosmetics, personal care, paints, varnishes, inks) which address mainly end consumer markets, but are similar regarding volume and value to other fine and specialty chemicals.

Because of the heterogeneity of products and applications the estimation of the total market is not clear-cut, and can hardly be aligned from bottom-up numbers for product groups. Frost & Sullivan (2013) estimates the consumer, specialty and active pharma ingredients to around 75 billion US-$ (~ 56 billion €) in 2010 and projects a market growth to 370 billion US $ (~ 250 billion €) in 2020.[8] Hence, the study is highly optimistic regarding market growth.

While detailed comparable data for the total market is missing, regarding different product groups / segments the picture is more differentiated. The following information is available for sub-sectors / applications:

Bio-solvents: The market estimations and outlook clearly differ. The Bio-Tic study projects a rather stagnant development of biosolvents market with revenues clearly under 1 billion € in 2030. Other sources estimate the bio-solvents market in the EU to around 350 million € in 2010 and to 400 million € in 2020 (Scarlat et al. 2016). Instead, Technavio (2016) values the European bio solvents market at 1.8 billion US$ (~1,3 billion €) in 2015 and expects the market to grow to 2.74 billion US$ (~1.8 billion €) by 2020, growing at a CAGR of 8.5%.

Bio-surfactants:[9] According to a recent market report published by Transparency Market Research (2011) global biosurfactants market was worth 1.7 billion $ (~ 1.3 billion €) in 2011 and is expected to reach 2.2 billion $ (~ 1.3 billion €) in 2018, growing at a CAGR of 3.5% from 2011 to 2018. In the overall global market, the European region is expected to maintain its lead position in terms of volume and revenue until 2018.

Amino Acids: Since the commercialization of microbial fermentation, the amino acid production industry has grown considerably. The outlook for the next years is positive as well, probably mainly driven by animal feed additive demand (Grand View Research 2015). Deloitte expects market growth from 11 billion US$ (~ 8.3 billion €) in 2013 to around 16 billion US$ (~ 12 billion €) in 2020 (CAGR 5,6%). The Bio TIC appears to be more conservative and projects that the EU market will grow from roughly 1.5 billion € in 2013 to around 2 billion € in 2030.

Vitamins: Vitamins produced by biotechnological methods represent a long established market with some growth opportunities due to rising consumption because of health consciousness among the aging population. Deloitte estimates the world-wide market of vitamins at 0.7 billion US-$ (~ 0,5 billion €) and expects a market growth of 2.6% CAGR until 2020. On a comparable level, the Bio-Tic expects only modest growth

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[8] Please note that also enzymes are probably included in these estimations, however they are presented separately in the next chapter. Because of the limited market size of 5 billion € overall figures are only are minorly affected. Moreover, it has to be noted that the estimates of Frost &Sullivan (2013) far exceeds their estimates for the whole IB market in th 2011 study (Frost & Sullivan 2011)

[9] Most biosurfactants are not yet processed by IB processes, but are expected to be produced in future by IB (Bio-Tic 2015a)

of vitamins and estimates the European market roughly at 0.5 billion € for 2030 (no exact figures available)

Biotech active pharma ingredients (API): The continuous rise of the biopharmaceutical sector including the market entrance of more and more biosimilars provide high potential for greater application of biocatalysis (Frost & Sullivan 2011). In particular, the supply of biotech active pharma ingredients for biopharmaceutical production represents a growth sector for IB. The estimation of the global market for biotech API[10] manufacturing highly differ. While a report by Visiongain (2015) forecasts the overall world biotech API manufacturing services industry will achieve revenues of $5.8 billion US$ (4.4 billion €) in 2019, other sources claim a market size of 9.2 billion US$ (6.9 billion €) in 2007 (Van Arnum 2009). Frost & Sullivan (2011) estimate the market size at around 22 billion US$ in 2010, however, in contrast to other studies antibiotics are included. They estimate the market to grow to around 52 billion US$ (39 billion €) (in 2020 (CAGR 9% between 2010-2020). In a more recent publication (Frost & Sullivan 2013) growth projections are raised enormously to 112 billion US$ (84 billion €) in 2020. There are no data for the European market available; pharmabiz.com (2014) estimates the market share of European demand to around 30% of the global market.

The main market drivers are summarized in the following:

- There is a potential growth of the various application markets, e.g. growing meat demand will require additional feed additives such as enzymes, growth of the biopharmaceutical sector for API, etc..
- The willingness to pay for IB products is mostly limited, partly because of objections about GMO (Genetically Modified Organisms), which are used in some processes or unawareness of product characteristics and advantages in other cases. For some markets consumer preference for natural ingredients (e.g. for cosmetics), environmental advantages, less toxic products or use of sustainable resources may lead to a “premium” in the market
- More generally, the chemical properties and functionalities remain the main distinctive aspect of high added-value bio-based specialties. Moreover, providing a flexible and responsive manufacturing environment able to meet the requirements of the customer, and customized services related to research and development, will be necessary

[10] The market studies differ to some degree in the inclusion of manufacturing segment, at least monoclonal antibody manufacturing, recombinant proteins production, , growth hormone API manufacturing, and vaccine manufacturing are usually included (Frost & Sullivan 2011, Transparency Research 2013).

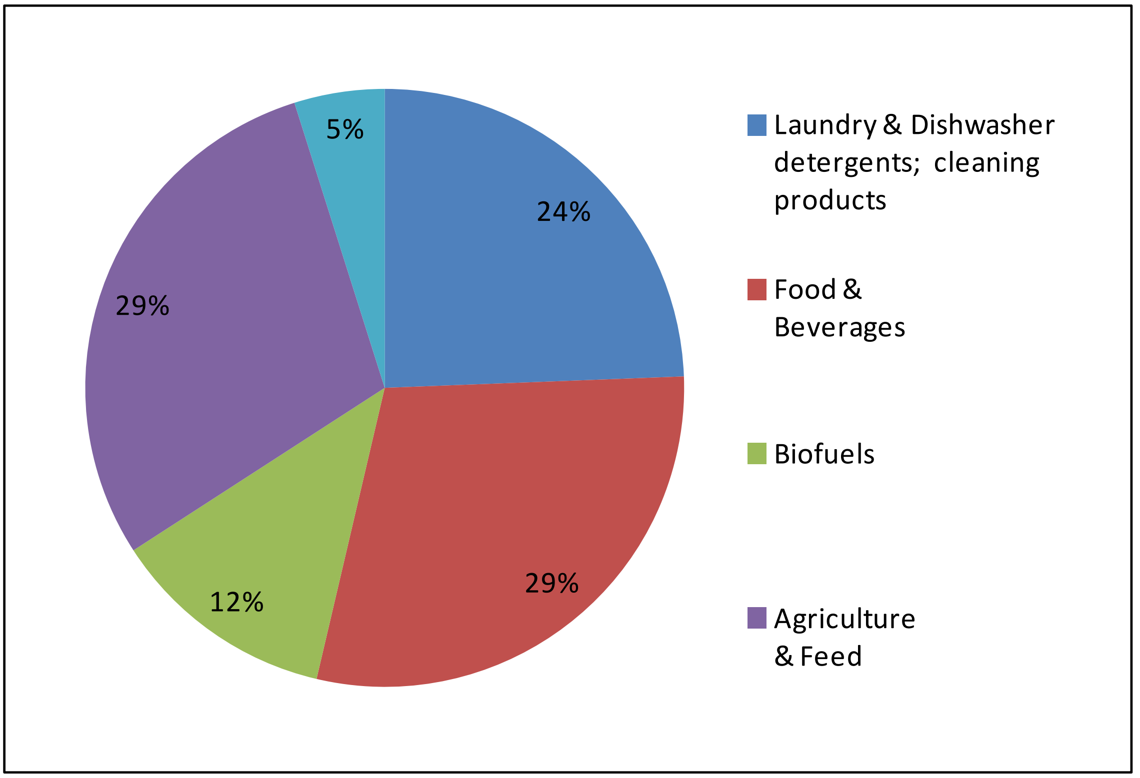
- While the biotech fine and specialty segments are less cost sensitive than the bulk chemicals, the high cost of production also restrain the growth of some value-added applications (e.g. biosimilars)

4.4 Enzymes

Enzymes are a special segment of fine and special chemicals as enabler for production of fine and special chemicals, but also as product for a broad range of applications in different sectors (Aichinger et al. 2016). Enzymes provide several advantages over traditional chemistry, including high selectivity, lower energy use and mild reaction conditions (van de Velde et al. 2013). Advancements in biotechnology (e.g. in genetics, protein engineering) opened up new enzyme application areas, new products and process improvement (Scarlat et al. 2015). While enzymes are established for many applications, it is still a promising area for the future (van de Velde et al. 2013). The spectrum of enzymes application has widened in many different fields, such as pharma, food, brewing, animal feed, biofuel production, detergents, cleaning products, paper, leather, textiles etc.

Worldwide sales of industrial enzymes have risen steadily over the last few years and are estimated by the market leader, the Danish enzyme producer Novozymes, to around 4 billion US-$ in 2014 (about 3 billion €) (Novozymes 2015). Figure 3 provides an overview of the most important segments of the world market for industrial enzymes.

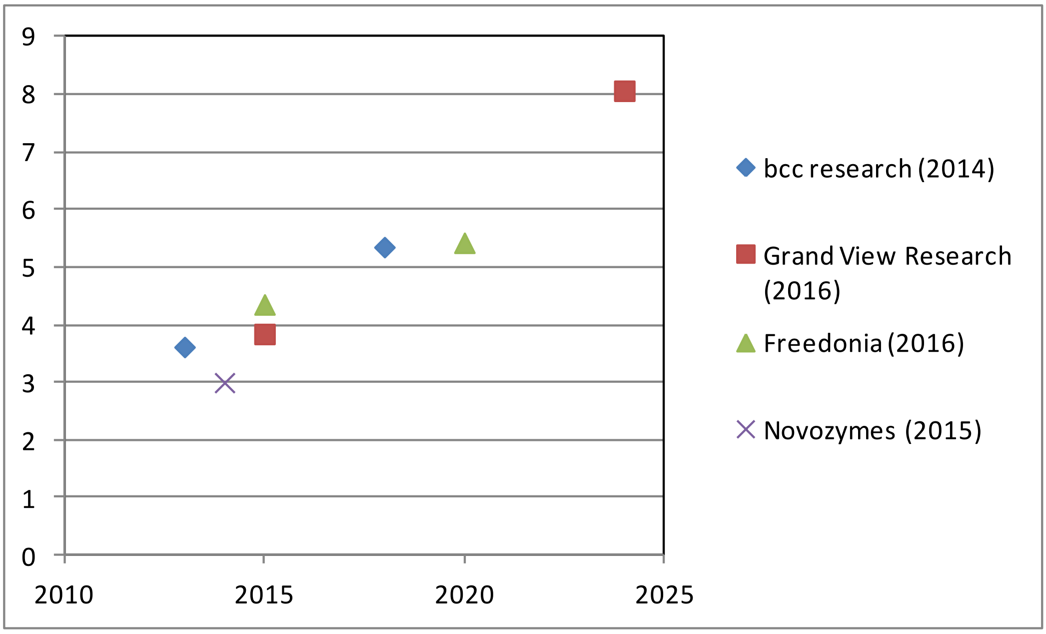
Figure 3: Share of segments for industrial enzymes (world market)



Source: Calculations based on Novozymes (2015)

Various market studies estimate the enzymes market in a similar range and all predict considerable growth for the next years. E.g., bcc research (2014) calculated 4.8 b US$ (approximately 3.6 billion €) for 2013 and projects an increase to approximately 7.1 billion US-$ (about 5.4 billion €) for the year 2018 (bcc research 2014). This would mean a CAGR of 8.2% from 2013 to 2018. The results of other studies are included in Figure 4.

Figure 4: Market estimations for enzymes (world market in billion €)



Source: Own calculations Fraunhofer ISI, data from sources mentioned in the figure

For Europe, the market is estimated to around 1.2 billion € in 2012/2013 (Ambjerg 2012; Bio-Tic 2015b). The Bio-Tic (2015) study expects a market growth to around 1.8 billion €, which would imply a more moderate growth (< 3 p.a.) compared to the global market studies. The positive market outlook for enzymes can be based on different market drivers (Aichigner et al. 2016; Novozymes 2015; Freedonia 2016):

- the increasing demand in emerging countries for consumer products, which use enzymes (e.g. for food, feed, detergents, textiles);
- specialty enzyme markets are expected expanding at a strong pace globally, e.g. enzymes used in research, in diagnostics and for biocatalysts, particularly those used in the production of pharmaceuticals;
- enzymes for lignocellulosic biofuels is a potential key growth market. According to bcc research (2016) the global market for biofuel enzymes in total grows with a CAGR of 10.4% from 2015-2020, leading to a market revenue of about 1.1 billion US-$ (~0.8 billion €) in 2020. More generally, those sectors and applications that succeed in attracting investors, in undertaking new product development activities and in launching novel and unique products in the market are offering new opportunities to the industrial enzyme manufacturers (Jaramillo et al. 2015).
- Industrial markets for enzymes in developed countries are mature, with intensive competition among enzyme manufacturers. Hence, it is not the development of enzymes for new markets but the optimization of industrial production

processes and products which are in focus with regard to resource and energy efficiency as well as the achievement of climate protection goals and cost factors (e.g. lower costs via reduced energy and water usage).

However, also some market barriers have to be taken into account:

- Potential growth barriers differ between the applications, but relate to traditional consumption habits (e.g. consumer scepticism about technology in food & beverage production), conservatism in production (e.g. for pharma), high price sensibility (e.g. agro-food), lack of political commitment (for biofuels).
- For a lot of applications product regulations for enzymes are important. While these do not necessarily hamper the market evolution they may decrease the speed-to-market for producers, particularly if unexpected changes are introduced to the regulatory process.

4.5 Bioplastics

Bioplastics (bio-based polymers) represent an important product segment of IB and the bioeconomy. The term bioplastic refers to the raw material used (biomass instead of fossil fuels), or to production methods (biotechnology instead of chemical synthesis) or to biodegradability. Hence, the main challenges for an appropriate market analysis are differences in the terminology of bioplastics.

An analysis of Aichinger et al. (2015) on the basis of IFBB (2015) on biomass-based plastics shows that in 2013 product groups which are produced via biotech processes have a market share of around 75-85%[11], which may rise by 2018 to 90-95%. Hence, the following analysis for bio-based plastics, for which most data exists, can be regarded as appropriate proxy for IB.

Bio-based plastics[12] are used for a wide range of applications; with packaging capturing almost 70 percent (1.2 million tonnes) of the total bioplastics market (flexible and rigid packaging). But also a range of other markets has emerged in the past (consumer electronics, automotive), as can be proxied by the distribution of production capacities (Figure 5).

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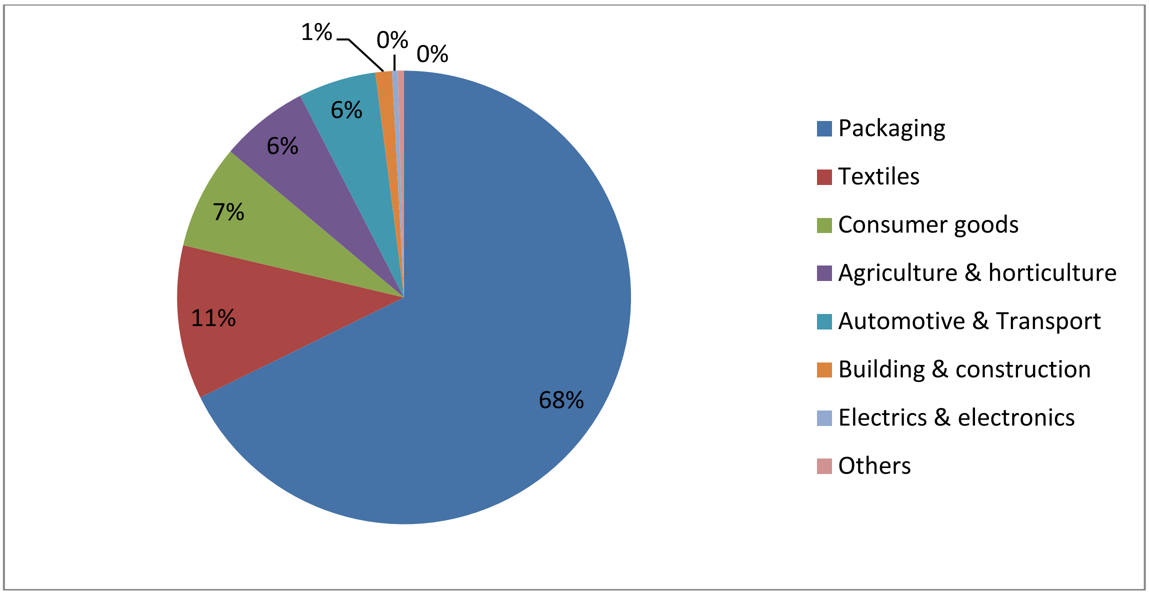
[11] The rest of the share are polymers that directly derived from feedstock (e.g. cellulosic) or chemically synthesized (e.g. Bio PUR).

[12] In the following numbers, also bioplastics are included that only partly use biomass as a feedstock. E.g. BIO-PET 30 means a bio-content of 30%.

Figure 5: Global production of bioplastics by segment (in%)



Source: European Bioplastics (2016)

While today bio-based plastics are still niche products and present less than 1% of the total plastics, a growing market has been established in Europe and the world. According to the Bio-Tic study (2015b) the EU demand for bio-based plastics was estimated at 485 million € in 2013, with a CAGR of 20% between 2008 and 2013. In 2013, Europe was the largest bio-based plastics consumer and the largest producer with around one third of the global bio-based plastics output.

The market is expected to grow significantly in the next years. According to European Bioplastics, global production capacity of bio-based plastics is predicted to sextuple in the medium term, from around 1 million tonnes in 2014 to approximately 6.5 million tonnes in 2019 (European Bioplastics 2016)[13]. The projected market expansion is mainly dependent on the planned extension of Bio-PET[14] 30 for the use of bioplastic bottles by Coca-Cola (see Figure 6). Bio-PET 30 production capacities alone are expected to grow to around 6 million tonnes by 2019 (European Bioplastics 2016). Hence, drop-ins such as Bio-PET 30, Bio-PE[15], Bio-PTT[16] will further dominate and increase their market share to over 85%. But also other types of biopolymers and ap-

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[13] The data of European Bioplastics (2016) for biodegradable plastics is not included in this sum.

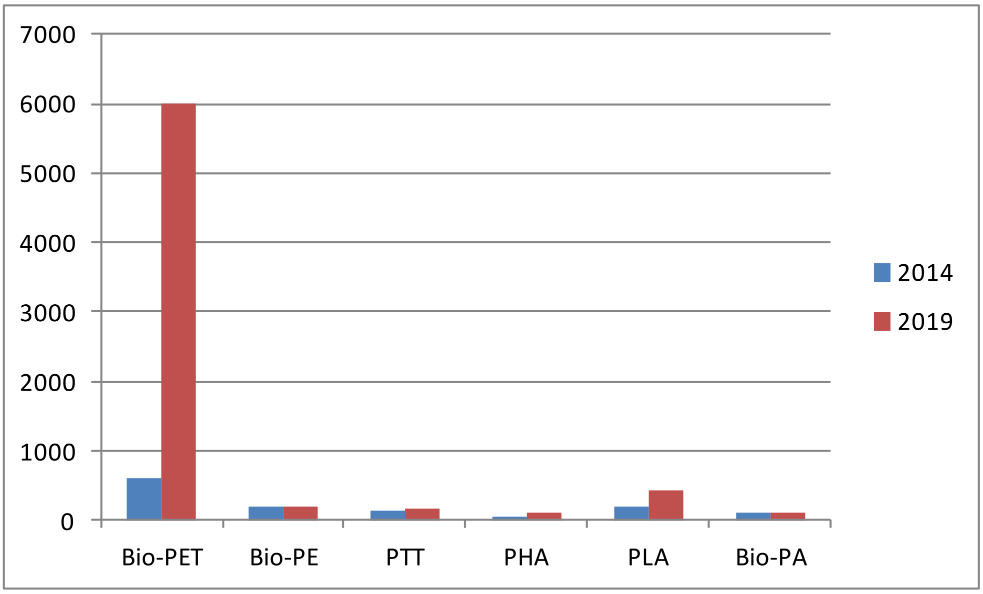
[14] PET = Polyethylene terephthalate

[15] PE = Polyethylene

[16] PTT = Polytrimethylene terephthalate

plications are expected to grow, in particular textiles as well as applications in automotive & transport (Aichinger et al. 2016).

Figure 6: Global production capacities for selected (IB produced) bioplastics



Source: IFBB (2015)

From a technical point of view, the boundaries between the previously clearly separated areas of bioplastics on the one hand and petrochemical plastics on the other hand are becoming increasingly blurred as natural fiber reinforced petrochemical plastics, chemically reinforced biocomposites as well as petrochemical plastics with bio-based proportions (for example Bio-PET30) are gaining importance. Moreover, some new bioplastics are expected to enter the market with Bio-PVC, Bio-PP and PEF (Aichinger et al. 2016 based on IFBB 2015).[17]

For 2030, the Bio-Tic study (Bio-Tic 2015b) projects growth rates of 12% p.a. until 2030 (10% for the low scenario and 15% for the high scenario). The bio-based plastics market value in Europe is expected to reach approximately 5.2 billion € in 2030 in the reference scenario and 4.3 billion Euro and 6.7 billion € in the low and high scenarios, respectively. In these projections, Europe is expected to maintain its position as the main consumer of bio-based plastics.

Such a development is dependent on various market drivers, such as the following:

[17] PEF = Polyethylene furanoate; PP = Propylene; PVC = Polyvinylchlorid

- Cost competitiveness is a key market factor for all applications (Bio-Tic 2015b). In particular, for the dominating drop-ins a continuity of low oil prices would impede cost competitiveness in the future.
- Because of cost disadvantages, regulations are important to market development. Some countries introduced a ban on the distribution of traditional plastic bags (e.g. Italy) or higher taxation of traditional plastic bags. Collection and composting infrastructure will be decisive for realizing the opportunities of those bioplastics that are biodegradable.
- Consumer behaviour towards bio-based polymers and willingness to pay a bio-premium. While various studies show generally a positive attitude of consumers towards bio-based plastics (see section 3), different challenges arise:
    - The environmental advantage of many biopolymers is not unambiguous. E.g. the Federal Environment Agency in Germany (Detzel et al. 2013) states in a meta study that bioplastic lower CO_2 emissions, but farming and processing of the plants used in packaging cause more severe acidification of soil and eutrophication of water bodies than the production of common plastic packaging;
    - bio-plastics' producers still struggle to signal the potential advantages and characteristics (e.g. bio-based content, saved CO_2 emissions, of their product sustainable production/processing of biomass (Hogan et al. 2015);
    - the Bio-Tic (2015b) study points out that bio-premium can be justified in four cases: 1) bio-based origin is a key buying criterion, 2) environmental sustainability is used as a marketing tool to build brand image, 3) bio-based plastics represent a minimal share of the final product value, and 4) there are regulatory requirements for the use of bio-based plastics.
- The decisions of big brands to take up bioplastic solutions currently boost the market. E.g. LEGO, Procter & Gamble, Coca-Cola, Danone, Puma, Samsung, IKEA, Tetra Pak, Heinz, or Toyota have already introduced large scale products in Europe (European Bioplastics 2016).

4.6 Other markets

The IB markets presented in the previous section certainly capture most market volume that can be assigned to IB. However, there are some other applications and business activities related to IB. While those are probably only niches, in the following we aim to point out that it will become more and more difficult to identify markets related to IB, because of its increasing enabling character in modern industrial production processes. In particular, the following "markets" relate to some extent to IB:

Other application sectors:

Besides the applications sectors presented in the previous section, other traditional industries such as the food & feed industry, textiles, leather, pulp & paper use modern IB methods, mostly consisting on processing enzymes. Those markets have been already presented as customers for enzymes (section 4.5). However, the market figures above for enzymes capture only the expenses for the enzymes used as ingredients and do not quantify the value of the biocatalytic processes using enzymes in these sectors. However, it is worth noting that the true innovation potential hardly takes place in those application sectors, and the market introduction of new enzymes or optimization of existing ones may lead to new applications and higher efficiency of production.

Enabling character and convergence with other technologies:

In all application sectors the demarcation of IB knowledge and processes from chemical or other processing methods is getting blurred. IB methods are more and more used integrated with chemical or other processing methods and in convergence with other technologies and sciences (e.g. nanotechnology, information technology). Moreover, convergence includes not only transdisciplinary research and development and the integration of science but also the intersection of previously distinct industrial sectors such as chemical synthesis, IB and bioenergy, information technologies, and enabling tools and platforms from a number of business sectors. The growing convergence of transdisciplinary science, technology, engineering, and mathematics, along with overlapping markets and innovative business models, enables novel solutions to many previously intractable societal challenges (NRC 2015, p.27).

Hence, it is getting more and more difficult to identify and classify IB markets at these interfaces e.g. R&D and services related to next generation sequencing; use of biotechnological know-how and methods for R&D and production of chemically synthesized small molecules; and, advanced biotechnological processing using CO_2 as a feedstock in combination with other technologies along the value chain, amongst others.

Suppliers of IB knowledge and processes

On the upper side of the value chains of the markets presented, biotechnological know-how is a key asset for the supplier companies using IB and IB processes to develop new innovative products or to offer intermediate products and services. Those suppliers frequently are dedicated biotechnology firms. An assessment of Aichinger et al. (2016) based on the German database biotechnologie.de shows that around half of the about 60 dedicated IB companies in Germany only provide R&D or services.

Moreover, some supply equipment firms (e.g. machinery and plant engineering) are partly conducting themselves biotech R&D and are operating pilot and demonstration plants to demonstrate that the product concepts work. In addition, innovative specialized equipment is needed by biotech users. E.g. a recent report by the German association for the electrical industry (ZVEI 2015) shows increasing potential for the automation industry for IB, in particular regarding equipment for biocatalysis as well as digestion and pre-treatment for chemical building blocks from biomass. However, it is not possible to identify all relevant activities which differentiate those markets from conventional supply of equipment, R&D and services.

5 Conclusion

While it is difficult to compare the different market studies due to different geographical coverage, demarcation of markets in terms of products included and probably different methods to estimate and project market size, it can be stated that for most markets a relatively clear picture emerges. Of course, for some early stage sectors (e.g. 2G biofuels) market projections are extremely uncertain and divergent across the various studies, due to differences in key assumptions.

Table 2 summarizes the market findings for the various segments. Accordingly, it was not possible to derive consistent estimations for the world and the European market for each application sector. However, this (partial) overview together with previous ones in the literature (e.g. Festel 2010; Festel 2012; Bio-Tic 2015b) and expert interviews indicate that Europe has reasonable global market shares.[18] Hence, generally Europe has a good starting base for further commercialization in IB.

While one should be cautious to derive too many cross-sectorial interpretations as the sources differ, it is safe to conclude that IB products and processes are expected to grow in all of the current application markets. Of course, there are some markets with higher expected growth rates than others. For example in regard to the global market, enzymes have a very positive outlook for the coming years. Also 2G bioethanol or bio-based platform chemicals have a high potential. However, the last two examples make it clear that markets depend heavily on policy regulation, technological improvement, cost reductions as well as a positive investment climate.

Also, in the expert interviews different markets for IB have been highlighted, some seeing potential also in bulk market for Europe, while others clearly point out Europe's strengths in high value added applications. Generally it can be observed that many companies started out in commodities, but now are moving up the value chain looking for more profitable opportunities (Guzman 2015; expert interviews).

Besides, the complexity of addressing societal challenges (e.g. interdependence with a myriad factors such as regulations, low demand articulation of potential needs, multiple and diverse impacts) and the high heterogeneity of markets, applications and products make it difficult to derive clear-cut messages about growth opportunities and, more specifically, consumer/customer needs and requirements. While the grand challenges of IB become very obvious (e.g. treatment and usage of non-food biomass or waste; efficiency as well as key framework conditions for some markets (policy regulations for some markets, feedstock price and availability)) potential gaps between the demand

[18] That does not necessarily mean that Europe has also production shares in this magnitude. The issue will be further analyzed in forthcoming Deliverables

side and supply/innovation potential can hardly be made explicit on this level of analysis. Rather, this issue will be analyzed in further Deliverables for concrete value chains.

In a significant number of interviews the experts pointed out that the contribution of IB to mitigating climate change is the key for further deployment of IB and to achieve socio-economic goals connected to IB. However, it is clear that further technological advancements in terms of efficiency and functionality are needed but also in measurement of its sustainability contributions and communication of the potential advantages to consumer and policy makers. Another well-known issue is the mostly missing cost-competitiveness compared to fossil-based products. While this is in particular market hampering for bulk markets (bio-based platform chemicals, bioplastics, bioethanol) high costs are also an issue for high value added segments.

Table 2: Summary of IB markets (in bn €, if not otherwise stated)

	world			EU			demands for innovative solutions
	current (2013-2015)	mid-term (~2018-2020)	long term (2025-2030)	current (2013-2015)	long term (2025-2030)	CAGR long term	
Bioenergy: Bioethanol	n.a.	n.a.	n.a.	2,5-4	4,5-15	high differences between studies	efficient use of non-food biomass; biotechnological pre-treatment of biomass
Bioenergy: Biogas	n.a.	n.a.	n.a.	4-6	~6	~2,5%	more cost competitive products
Bioplastics	n.a.	n.a.	n.a.	0,5	5.2	12%	improvement in cost competitiveness improvement of environmental performance
Bio-based platform chemicals	2-2,3 bn$	18 bn$	n.a.	0,7	3,2	~9,5%	improvement in process effiency to reduce costs special functionalities and properties, leading e.g. to environmental advantages
Bio-solvent	n.a.	n.a.	n.a.	0,4	n.a.	n.a.	flexible and responsive manufacturing environment special functionalities and properties more intensive integration of IB and chemical methods
Bio-surfactant	1,7 bn$	2,2 bn$	n.a.	n.a.	n.a.	n.a.	
Amino Acid	11 bn$	16 bn$		1,5	2	~2%	
Vitamins	0,7 bn$	0,8 bn$		0,5	0,5	stagnant	
Enzymes	3-4	~ 5,5	8	~ 1,2	~ 1,8	~ 3%	resource and energy efficiency for a wide range of applications optimizing enzymes for new/ growing markets (e.g. 2nd generation bioethanol) specialty enzymes

Sources: see section 4

References

Ademe (2004) – Bilan environnemental des filières végétales pour la chimie, les matériaux et l'énergie. Etat des connaissances : analyse de cycle de vie (ACV). Available at: www.ademe.fr/partenaires/agrice/publications/documents_francais/ACV_Synthese.pdf

Aichinger, H., Hüsing, B., Wydra. S. (2016): Industrielle Biotechnologie: Verfahren, Anwendungen, Öko-nomische Perspektiven. TAB Arbeitsbericht, Berlin: Büro für Technikfolgen-Abschätzung beim Deutschen Bundestag

Ambjerg H.C., 2012. Bio-based Solutions for the Food and Beverage Industry DSM Food Specialties, DSM Bio-based Business Seminar

Anand, M. (2016): Innovation and Sustainable Development: A Bioeconomic Perspective; Brief for GSDR – 2016 Update; https://sustainabledevelopment.un.org/content/documents/982044_Anand_Innovation%20and%20Sustainable%20Development_A%20Bioeconomic%20Perspective.pdf

Bang, K. J., Follér, A., Buttazzoni, M. (2009). Industrial Biotechnology. More Than Green Fuel in a Dirty Economy? Exploring the Transformative Potential of Industrial Biotechnology on the Way to a Green Economy. WWF Denmark. www.wwf.dk

bcc research (2014): Global Markets for Enzymes in Industrial Applications. www.bccresearch.com/report/enzymes-industrial-applications-marketsbio030g.html

bcc research (2016): Research's Global Markets and Technologies for Biofuel Enzymes (EGY099B). http://www.bccresearch.com/market-research/energy-and-resources/biofuels-enzymes-global-markets-technologies-egy099a.html

Biddy M., Scarlata C., Kinchin C. (2016): Chemicals from Biomass: A Market Assessment of Bioproducts with Near-Term Potential. USA.

BIOPOL (2009): D2. 1.3 b Report of market acceptance of biorefinery concepts amongst consumers.

Bio-Tic (2015a): Overcoming hurdles for innovation in industrial biotechnology in Europe - Non-technological Roadmap

Bio-Tic (2015b): Overcoming hurdles for innovation in industrial biotechnology in Europe - BIO-TIC Market Roadmap

BMBF (Bundesministeriums für Bildung und Forschung) (2007): Weiße Biotechnologie – Chancen für neue Produkte und umweltschonende Prozesse. Bonn/Berlin

Brostow, W., Datashvili, T. (2016): Environmental Impact of Natural Polymers. In Natural Polymers (pp. 315-338). Springer International Publishing. http://link.springer.com/chapter/10.1007/978-3-319-26414-1_10

Carrez (2015): Bio Base NWE analysis report on the bottlenecks SMEs encounter in the bio-economy. Belgium.

Dansereau, L. P., El-Halwagi, M., Chambost, V., Stuart, P. (2014): Methodology for biorefinery portfolio assessment using supply-chain fundamentals of bioproducts. *Biofuels, Bioproducts and Biorefining*, *8*(5), 716-727.

De Almeida Oroski F, Chaves Alves F, Bomtempo JV.(2014) Bioplastics Tipping Point: drop-in or non-drop-in? Journal of Business Chemistry 11(1), 43-49

Deloitte (2014): Opportunities for the fermentation-based chemical industry – An analysis of the market potential and competitiveness of North-West Europe. The Netherlands.

Deloitte (2015): Advanced Biopharmaceutical Manufacturing: An Evolution Underway.

Detzel, A., Kauertz, B., Derreza-Greeven, C. (2013): Study of the Environmental Impacts of Packagings Made of Biodegradable Plastics. Federal Environment Agency in Germany.

E4tech, RE-CORD, WUR (2015): From the Sugar Platform to biofuels and biochemicals‖. Final report for the European Commission

El-Chichakli, B., von Braun, J., Lang, C., Barben, D., Philp, J. (2016): Five cornerstones of a global bioeconomy. Nature, 535(7611), 221-223.

ePURE (2015): European renewable Ethanol – Enabling Innovation and Sustainable Development, State of the Industry 2015. Brussels.

EurObservER, (2015): The State of Renewable Energies in Europe, 15th EurObservER Report, 2015

European Bioplastics (2016): Bioplastics market data; http://www.european-bioplastics.org/market

European Environment Agency (2016): Renewable energy in Europe 2016 - Recent growth and knock-on effects. In: EEA Report No 4/2016. Copenhagen.

Expert Group (Commission Expert Group for Biobased Products - Working Group on Evaluation of the Implementation of the Lead Market (2015): Initiative for Bio-based Products' Priority Recommendations1

Freedonia (2016): World Enzymes - Demand and Sales Forecasts, Market Share, Market Size, Market Leaders, http://www.freedoniagroup.com/World-Enzymes.html

Frost & Sullivan (2003): Advances in Biotechnology for the Manufacture of Chemicals, Parts I and II. London

Frost & Sullivan (2011): White Biotechnology. Report N8E3-39. London

Frost & Sullivan (2013): Emerging Trends in Bio-chemicals. D4C3-TI. London

Genencor (2011): Consumer Attitudes & Adoption of Biobased Products, http://www.biobasedtrade.com/files/Genencor_HSI_SummaryReport.pdf; abgerufen am 23.08.2011

Global Market Insights(2016): Enzymes Market Size By Product; https://www.gminsights.com/industry-analysis/enzymes-mar-ket?utm_source=globenewswire.com&utm_medium=referral&utm_campaign=Paid_Globnewswire

Grand View Research (2015): Amino Acids Market Analysis By Product http://www.grandviewresearch.com/industry-analysis/amino-acids-market

Guzman D. (2015): A Turning Point for Bioplastic Building-Block Investments, http://read.nxtbook.com/wiley/plasticsengineering/march2016/aturningpointforbioplastic.html

Hirschnitz-Garber M., Gosens, J. (2015): Producing bio-ethanol from residues and wastes - A technology with enormous potential in need of further research and development. In: Policy Brief No. 2, November 2015. Sweden.

Hodgson, E., Ruiz-Molina, M. E., Marazza, D., Pogrebnyakova, E., Burns, C., Higson, A., ... & Noël, Y. (2016). Horizon scanning the European bio-based economy: a novel approach to the identification of barriers and key policy interventions from stakeholders in multiple sectors and regions. Biofuels, Bioproducts and Biorefining, 10(5), 508-522.

Hogan O., Jayasuriya R., Uppala S., Holdgate L., Skero N. (2015): The future potential economic impacts of a bio-plastics industry in the UK – a report for the Bio-based and Biodegradable Industries Association (BBIA). Cebr. London.

IDEA (2012): A window of opportunity. Inventory of societal, scientific, technological and innovation trends towards 2025. Draft final report for the Flemish Council for Science and Innovation. December, 2012.

IEA-ETSAP; IRENA (2013): Production of Liquid Biofuels - Technology Brief.

IFBB (2015): Marktzahlen Biokunststoffe; last updates 2015, ifbb.wp.hs-hannover.de/downloads/index.php

Jaramillo P., Gomes H., Monclaro A., Silva C., Filho E. (2015): Fungal biomolecules. Section 2: Production of recombinant peptides, chapter 6: Lignocellulose-degrading enzymes: An overview of the global market. Laboratory of Enzymology, Department of Cellular Biology, University of Brasilia, Brasilia, Brazil.

Jegannathan, K. R., Nielsen, P. H. (2013). Environmental assessment of enzyme use in industrial production–a literature review. Journal of cleaner production, 42, 228-240

Jiménez-Sánchez, G., Philip, J. (2016): Genomics and the Bioeconomy: Opportunities to Meet Global Challenges. In: Genomics and Society. S. 207-233

McKinsey (2003): Industrial Biotechnology. New York.

Meeusen M., Peuckert J., Quitzow R. (2014): Open-BIO Work Package 9: Social Acceptance - Deliverable 9.1: Acceptance factors for bio based information systems. Technische Universität Berlin. Berlin.

Novozymes (2015): Roadshow Presentation FY2014, January 20, 2015, www.novozymes.com/en/investor/events-presentations/

NRC (National Research Council) (2015): Industrialization of Biology: A Roadmap to Accelerate the Advanced Manufacturing of Chemicals. The National Academics Press, Washington D.C.

OECD (2011): Industrial Biotechnology and Climate Change, www.oecd.org/sti/biotech/49024032.pdf

OECD/FAO (2016): OECD-FAO Agricultural Outlook 2016-2025. OECD Publishing. Paris.

Patel, M. K., Crank, M., Dornburg, V., Hermann, B., Roes, L., Hüsing, B., ... & Recchia, E. (2006). The BREW project: Medium and Long-term Opportunities and Risks of the Biotechnological Production of Bulk Chemicals from Renewable Resources–the Potential of White Biotechnology. Utrecht, Netherlands

Pelli, P., & den Herder, M. (2013). Foresight on future demand for forest-based products and services. In Technical Report (Vol. 87). European Forest Institute Joensuu, Finland.

Pharmabiz.com (2014): Biotech, generic sectors to fuel global API market http://www.pharmabiz.com/PrintArticle.aspx?aid=84973&sid=21

Phillips S., Flach B., Lieberz S., Rondon M., Williams B., Wilson C. (2016): EU Biofuels Annual 2016. http://www.fas.usda.gov/data/eu-28-eu-biofuels-annual-0

Research & Markets (2016): World Bio-based Platform Chemicals Market - Opportunities and Forecasts, 2014 – 2021; http://www.researchandmarkets.com/research/q2l3qw/world_bio-based

Scarlat, N., Dallemand, J. F., Monforti-Ferrario, F., Banja, M., Motola, V. (2015): Renewable energy policy framework and bioenergy contribution in the European Union–An overview from National Renewable Energy Action Plans and Progress Reports. Renewable and Sustainable Energy Reviews, 51, 969-985.

Scarlat, N., Dallemand, J. F., Monforti-Ferrario, F., Nita, V. (2016): The role of biomass and bioenergy in a future bioeconomy: policies and facts. Environmental Development, 15, 3-34.

Schiller, J. et al. (2016): Weiße Biotechnologie - Stand und Perspektiven der industriellen Biotechnologie: Umwelt- und Nachhaltigkeitspotenziale. Berlin, Germany.

SuSchem (2015): Strategic Innovation and Research Agenda http://www.suschem.org/cust/documentrequest.aspx?DocID=928

Technavio (2016): Global Green and Bio Solvents Market, 2016–2020 Industrial Biotechnology 12(4): 216-218

Transparency Market Research (2011): Biosurfactants Market – Global Scenario, Raw Material and Consumption Trends, Industry Analysis, Size, Share and Forecasts, 2011 – 2018″, www.transparencymarketresearch.com/biosurfactants-market.html

UNCTAD (2015): Second Generation biofuel Markets: State of Play, Trade and Developing Country Perspectives. In: UNCTAD/DITC/2015/8. Switzerland.

Van Arnum, P. (2009): Promising Outlook for Biotech APIs. In: PTSM Pharmaceutical Technology Sourcing and Management Vol. 5, Issue 1. http://www.pharmtech.com/promising-outlook-biotech-apis

Van de Velde E., Debergh P., Verbeek A. (2013): Production and trade in KETs-based products: The EU position in global value chains and specialization patterns within the EU. Final report. Brussels.

Visiongain (2015): https://www.visiongain.com/Press_Release/834/%E2%80%9CBiotech-API-manufacturing-services-market-to-reach-5-78bn-in-2019-according-to-new-visiongain-data%E2%80%9D

Weiss, M., Haufe, J., Carus, M., Brandão, M., Bringezu, S., Hermann, B., & Patel, M. K. (2012). A review of the environmental impacts of biobased materials. Journal of Industrial Ecology, 16(s1), S169-S181.

Wydra, S.; Hüsing, B.; Kukk, P. (2011): Analyse des Handlungsbedarfs für das Bundesministerium für Wirtschaft und Technologie (BMWi) aus der Leitmarktinitiative (LMI) der EU-Kommission für biobasierte Produkte außerhalb des Energiesektors. Karlsruhe

ZVEI (2015): Integrierte Roadmap III - Nachhaltige Rohstoffversorgung Industrielle Biotechnologie