# Overcoming hurdles for innovation in industrial biotechnology

## Market Roadmap

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# Contents

# 1 Introduction

Despite being able to tackle some of today’s global societal challenges including climate change, dwindling fossil fuel resources and the need for the development of a more sustainable and resource-efficient industry, several hurdles continue to hamper the full exploitation of Industrial Biotechnology's (IB) potential today.

The BIO-TIC project was a solutions-centred approach that comprehensively examined the innovation hurdles in IB across Europe and formulated action plans and recommendations to overcome them.

Three roadmaps have been developed, based on literature study, more than 85 interviews with experts and on the information collected through several regional and business case workshops.

The three roadmaps are:

- The *market roadmap* relates to current markets for a selection of five IB business cases for Europe, and market projections extending to 2030. It aims to obtain a comprehensive overview of the market potential for industrial biotechnology, the current and potential future value chain composition and stakeholders, including segmented market opportunity assessment and projections. The market roadmap provides an important focus for the other two roadmaps; identifying requirements for technology development and for overcoming non-technological barriers to realize the market opportunities.
- The *technology roadmap* revolves around the setting of R&D priorities and identifying needs for pilot and demonstration plant activities. This is centred on obtaining a clear overview and insight into the R&D related hurdles for realising Europe’s IB market potential. The analysis focuses on the identification of R&D bottlenecks and required breakthroughs across a broad range of technological domains and seeks to identify key areas of research to focus on, and to selectively highlight those areas that can be best aligned with current and foreseen end user market requirements, both in the shorter and longer term. The technology roadmap also seeks to identify the relative strength of research areas in different European countries and gathers evidence where it exists of duplication of resources.
- The *non-technological roadmap* is aimed at identifying regulatory and non-technological hurdles that may inhibit IB innovation towards identified market opportunities in the market roadmap. This takes the form of identifying and proposing solutions for key market entry barriers, going beyond recommendations already formulated by other initiatives and projects on bio-based products, and preparing a study for policy makers.

These three detailed roadmaps have been used in the production of a roadmap for IB in Europe entitled 'The bioeconomy enabled: A roadmap to a thriving industrial biotechnology sector in Europe'. The document which follows is the market roadmap. All roadmaps can be downloaded from http://www.industrialbiotech-europe.eu/.

## 2 Scope of the roadmap

The scope of the BIO-TIC-project is the industrial biotechnology (IB) value chain. In particular, BIO-TIC takes a focused approach in analysing the main hurdles, enablers and required actions towards realising IB's potential for Europe. It has been decided to focus the analyses on a limited number of five complementary "business cases for Europe", each of which represent different products and application areas, such that they enable the project partners to discover the widest possible hurdles and enablers that are relevant for the European IB market.

The business cases were selected based on a product group-specific rating carried out by an expert panel comprised of BIO-TIC partners and validated by the Project Coordination Committee and the Advisory Committee of the project. More information on the selection process can be found in Annex I Choice of business cases.

The 5 business cases represent product groups that can make a major contribution to an accelerated take-up of industrial biotechnology into the market place. The selected business cases are:

- Chemical building blocks[1]
- Bio-based plastics[2]
- Advanced biofuels (ethanol and jet fuels)
- 2G bio-surfactants
- $CO_2$ as a feedstock: Using IB as tool for reducing $CO_2$ generated from processes using fossil or bio-based raw materials (Carbon Capture and Utilization).

The BIO-TIC roadmaps were developed in several steps as shown in Figure 1. More information can be found on www.industrial-biotechnology.eu.

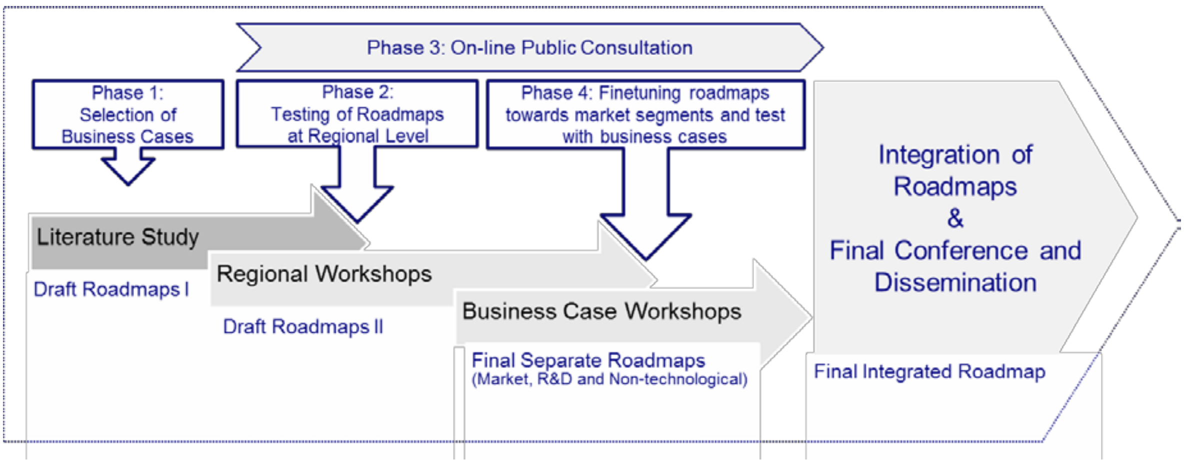



**Figure 1. Roadmapping process**

[1] A decision was made to have a closer look at 5 platform chemicals and these were later defined a s Succinic acid; Isoprene; 3-hydroxypropionic acid (3-HPA); 1,3-propanediol (1,3-PDO); and Furfural.
[2] For biobased plastics the decision was made to focus on PHA (polyhydroxyalkanoate) and PLA (polylacticacid).

# 3 Objectives and methodology

## 3.1 Objectives

There is a lack of a comprehensive picture on the market potential of bio-based products as the various estimates presented are not commensurable. The main differences stem from varying product definitions and geographical scoping, but also from the actual focus of the available market studies: some reports illustrate production capacity and others actual production volume, production value or demand value. In addition, many earlier market estimates have become outdated due to the recent developments such as financial crises and the shale gas boom.

The primary objective of this study is to present an up-to-date market projection for the main product segments of the industrial biotechnology (IB) sector, focusing on the value of consumption in the EU. Building on recent market reports that have been published in the various sub-sectors of bio-based products, the estimates are now extended up to 2030. Moreover, this report includes an overview of the current business environment in the EU, presents a market vision for the five selected product segments mentioned above, and identifies actions that are needed to reach this market vision. More information on the actions is included in the technology and non-technological roadmaps of BIO-TIC.

## 3.2 Methodology

### *Market projections*

The basis for the market projections are the recent market reports in the area of industrial biotechnology and bio-based production. Remaining gaps until 2030 were filled by expert estimates and mathematical modelling.

Discussions with sector experts suggested that straightforward estimations were a feasible approach in the cases of:

- bio-based plastics, where conservative ends of earlier growth estimates were applied when modelling the market development towards 2030;
- bioethanol, where the future market was estimated based on the projected total fuel consumption in road transport and an assumed 2G share/mandate; and
- bio jet fuels, where the market development is estimated to depend on the energy demand in aviation and an assumed bio-blend percentage.

For other product segments, market projections are based on estimating a regression model for market value using historical data and short-term forecasts, and on utilising that regression model to predict long-term market development up to 2030. The approach relies on the assumption that the regression specification adequately characterises the nature of future market development. In other words, potential changes in the market dynamics (such as technical or regulatory disruptions) are not accounted for.

Market projections are reported for four of the selected five business cases of the BIO-TIC project – biofuels, biochemical building blocks, bio-based plastics and 2G bio-surfactants – as well as for the overall industrial biotechnology sector. Carbon dioxide as a feedstock is excluded from the analysis of market volume as to date there is no industrial production in Europe, but prerequisites for future market development are discussed in Chapter 9.

More information on market modelling is included in Annex II.

## 3.3 Definitions

Market value is here defined as the value of consumption, i.e. production – exports + imports, in the EU. The following product groups are included in the analysis:

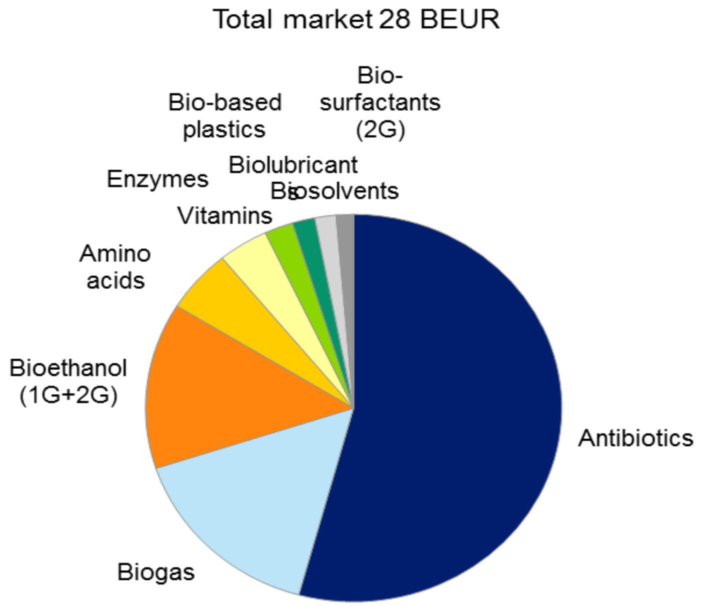
- **Amino acids**, including glutamic acid; lysine; methionine; phenylalanine; and other amino acids. The market estimate is a product group total, i.e. it was not possible to extract the share of IB processes.
- **Antibiotics**, including the following groups: chloramphenicol; erythromycin; penicillins (ampicillin and other); streptomycins (dihydrostreptomycin and other); tetracyclines; and other antibiotics (aminoglycoside antibiotics and other). The market estimate is a product group total, i.e. it was not possible to extract the share of IB processes.
- **Bio-based lubricants**, including biodegradable lubricants manufactured using only bio-based materials. Biodegradable synthetic lubricants or mineral-based lubricants containing bio-based additives are not included.
- **2G bio-surfactants**, i.e. surfactants produced by fermentation. The bio-based carbon content is equal or higher than 95%.
- **Biochemical building blocks,** referring to bio-based commodity chemicals produced by fermentation. These can be used as platforms for various secondary chemicals and intermediates. To clarify product segmentation and market projections, biofuels and biofuel additives are excluded from the scope. Biochemical building blocks are excluded from the overall IB projection to prevent double counting. The largest markets for these biochemicals are in the bio-based plastics, lubricants and solvents.
- **Advanced biofuels,** including bioethanol, aviation biofuels and biogas. For aviation biofuels, it was not possible to extract the share of IB processes.
- **Bio-based plastics,** referring to totally or partly bio-based polymers that may or may not be biodegradable.
- **Enzymes**, including enzymes and prepared enzymes (excluding rennet and concentrates).
- **Green solvents**, i.e. solvents which do not emit volatile organic compounds. These are usually derived from biological sources and renewable feedstocks. The analysis includes terpenes; pinenes; limonene; butanediol; tetrahydrofuran; and others, but excludes ethanol.
- **Vitamins**, including vitamins A, D, E, B complex, C and others (K, carotenoids and others). The estimate is a product group total, i.e. it was not possible to extract the share of IB processes.

# 4 Market for industrial biotechnology

## 4.1 State of the art

Based on available market data, the current (2013) EU market for the IB sector as a whole can be estimated at 28 billion EUR (Figure 2) By far the largest product segment is antibiotics, followed by biogas and bioethanol.

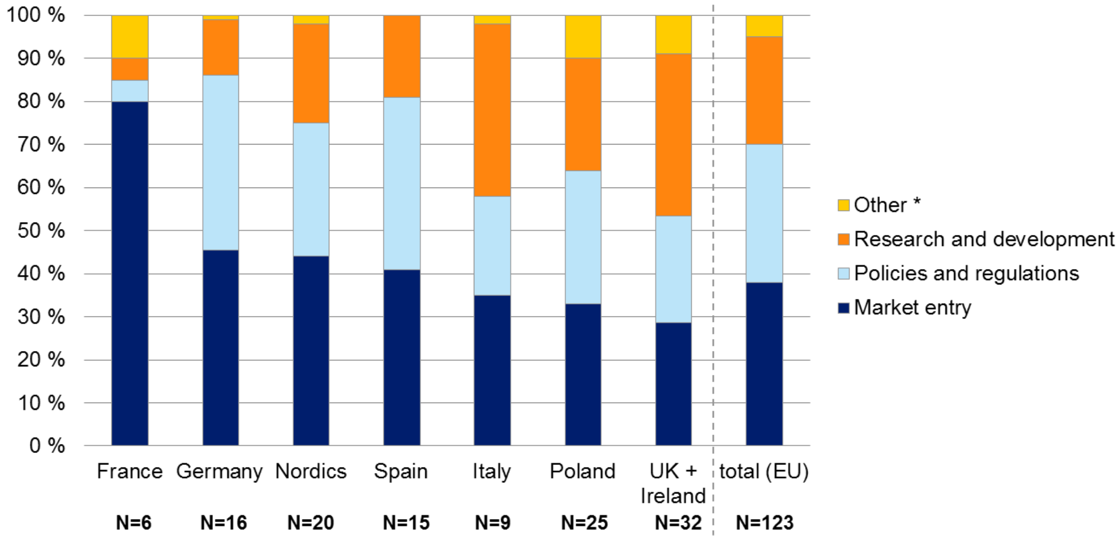
**Figure 2. Value of IB market demand in the EU (2013)**




Source: For data sources, please see **Table 2** of Annex II

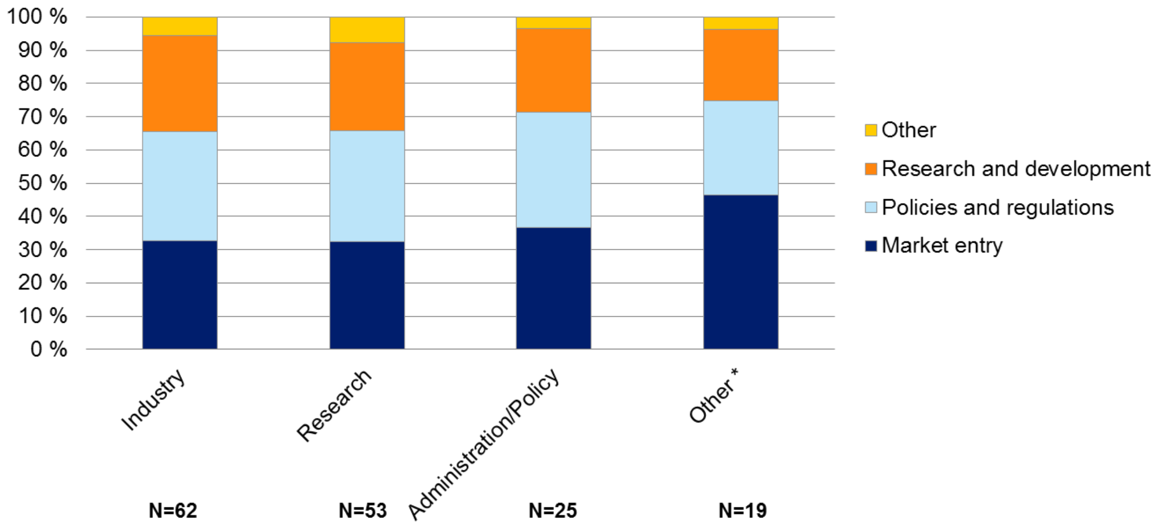
In regional workshops organised by the BIO-TIC project consortium, stakeholders were asked to consider IB-related hurdles. Market entry received 38%, policies and regulations 32% and research and development 25% of the given votes on the EU level. Market entry and the issue of economic viability in particular were most questioned in France, Germany, the Nordic countries, and Spain. Policy barriers were emphasised in Germany and Spain, and R&D challenges in Italy and UK & Ireland (*Figure 3*). Stakeholders in industry, research and administration/policy all shared a very similar view of the hurdles (*Figure 4*).

**Figure 3. Hurdles preventing IB take-off in the EU - by workshop and in total (number of respondents = 123)**




** Funding for research, demonstration and investments, collaboration, education, feedstock supply*
*Note: This question was not asked in the Benelux workshop*

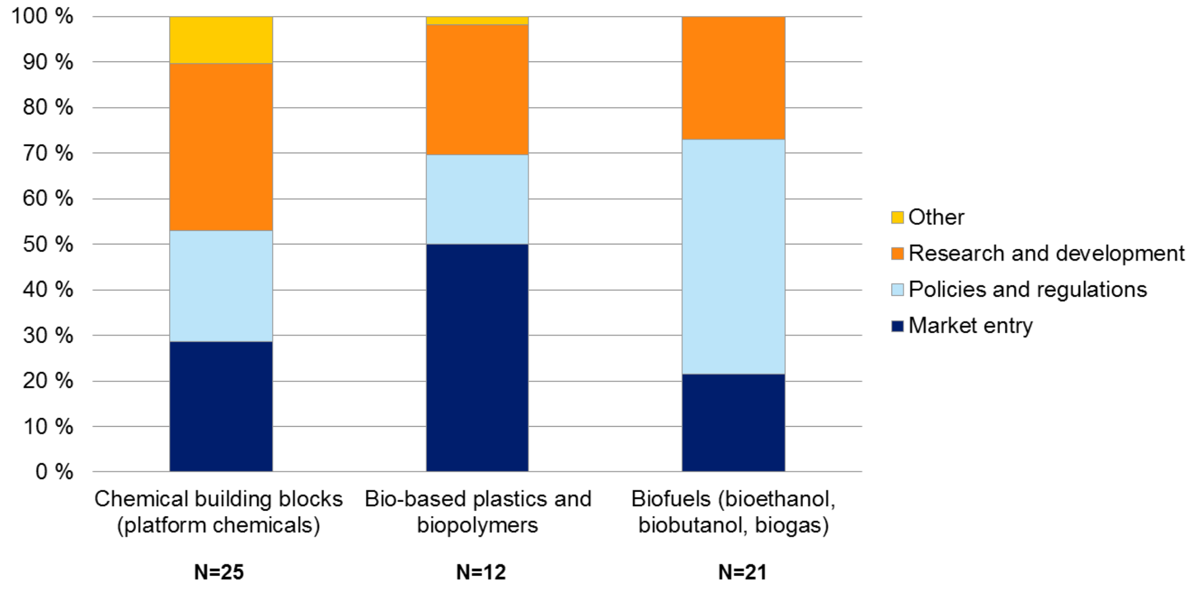
**Figure 4. Hurdles preventing IB take-off in the EU – by stakeholder group (number of respondents = 123)**




* Stakeholder group "Other" mainly includes representatives of regional development agencies, tech transfer offices, networking organisations and consultancies

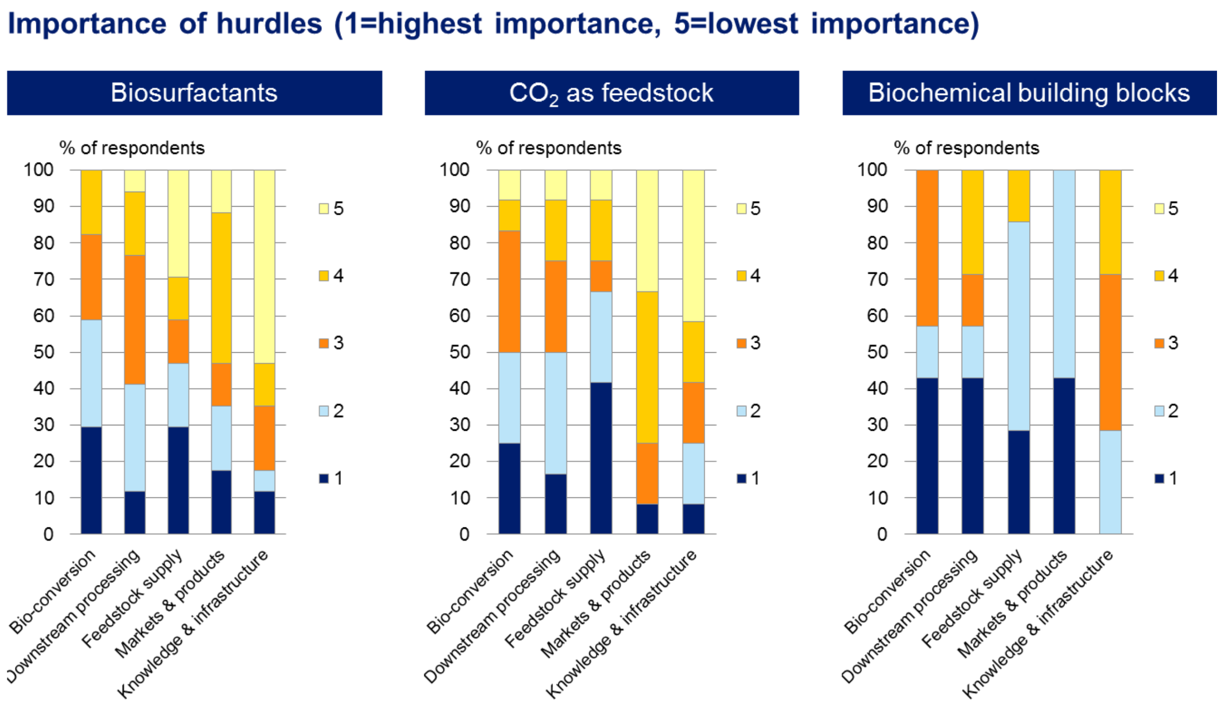
In terms of product segments, biochemical building blocks were dominated by R&D hurdles, whereas for bio-based plastics and biofuels the challenges seemed to be market entry and policy and regulation -oriented, respectively (Figure 5).

**Figure 5. Hurdles preventing IB take-off in the EU – by product segment (number of respondents = 58)**




In business case workshops, bio-surfactant and $CO_2$ stakeholders emphasised production and feedstock-related issues whereas for CBB stakeholders market and feedstock issues were most relevant. Knowledge-related issues were not the main priority for the stakeholders (Figure 6).

**Figure 6. Pre-survey for business case workshop participants (number of respondents = 36)**




Source: Pre-survey for business case workshop participants

The market-related hurdles focus on three issues, namely cost competitiveness, image and functionality. In stakeholder views, however, market, policy and R&D hurdles prove to be intertwined. The cost competitiveness of IB compared to current products/techniques is a market challenge, calling for e.g.

- the creation of fair competition for biomass with other sectors that currently benefit from subsidising schemes,
- measures to bring down biomass transport costs,
- efficient recycling systems enabling new types of feedstock,
- improved process efficiency,
- technologies for economically feasible small volume production,
- development of new and added value products to global markets, and
- support for commercialisation and investments and for the creation of early-stage demand

(i.e. solutions provided by research and policy).

In terms of image, the IB sector calls for an improved public perception, thus reducing the brand risk of IB. This would require new solutions to demonstrate the environmental benefits, to communicate with consumers (GMO and food/fuel debates), and ultimately, to enable a bio-premium. On the other hand, many stakeholders emphasise that there is a tendency to move from bio-based to performance orientation.

In the area of functionality, some areas are still dictated by need for "drop-in" products. This hinders opportunities for new products which may be more economically viable to produce.

## 4.2 Market drivers

On average, stakeholders consider macroeconomics and population growth, environment, product-related opportunities, cost reductions and feedstock cost competitiveness as equally important drivers for the IB market. Feedstock was identified as a particularly strong driver (and a potential hurdle) in the Benelux and Germany, and GDP in Poland (Figure 7). On the level of stakeholder groups, industry, research and the public sector shared a very similar view of the drivers (Figure 8). However, the drivers are clearly different for each product segment – e.g. the biofuels segment can be considered as more regulation and policy-driven than IB in general. For bio-based plastics and biopolymers and biochemical building blocks, brand and feedstock issues are relevant, respectively (Figure 9).

**Figure 7. IB market drivers in the EU - by workshop and in total (number of respondents = 138)**

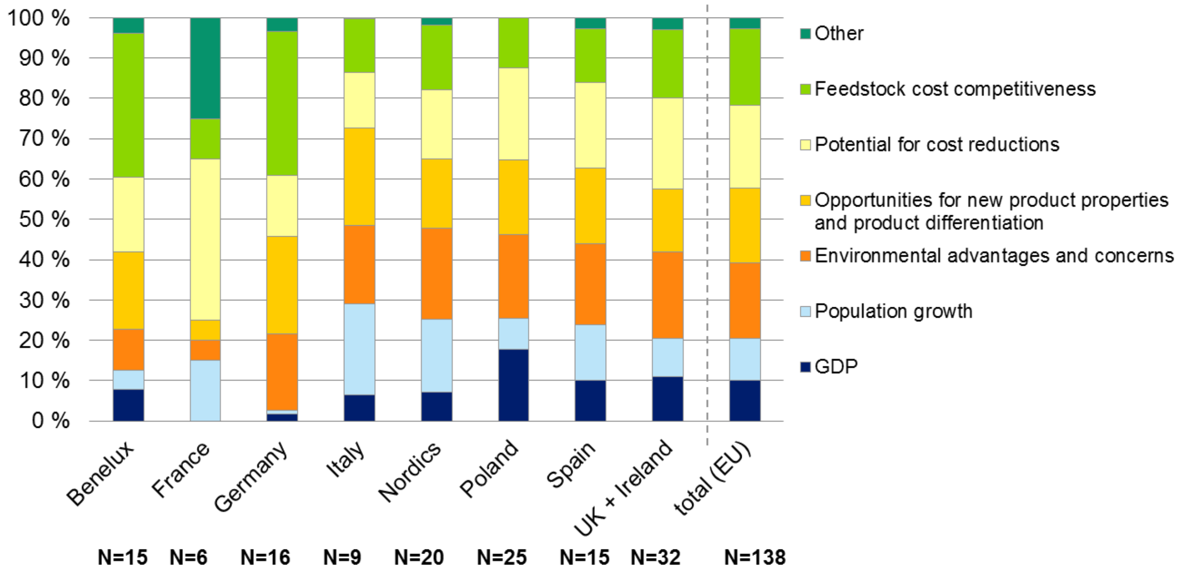
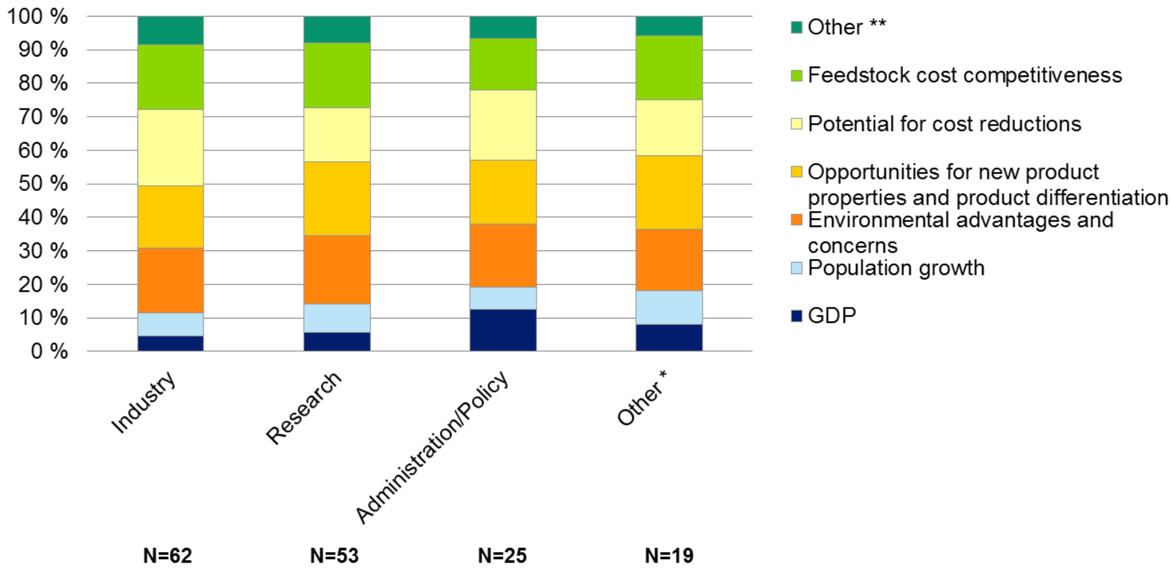


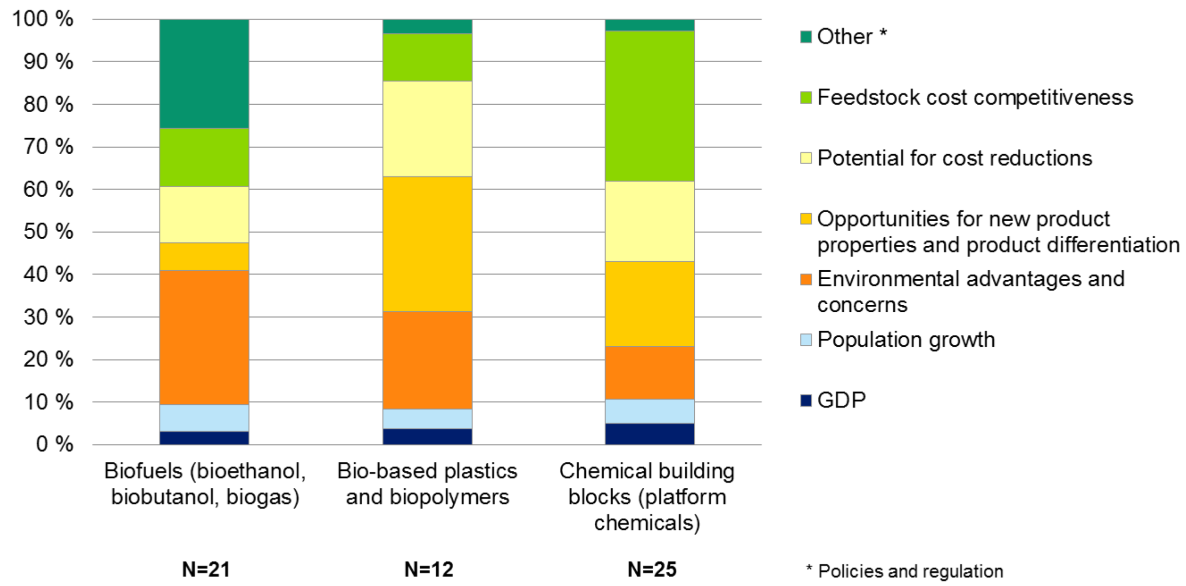

**Figure 8. IB market drivers in the EU – by stakeholder group (number of respondents = 138)**




* Stakeholder group "Other" mainly includes representatives of regional development agencies, tech transfer offices, networking organisations and consultancies

** E.g. policies and regulation

Figure 9. IB market drivers in the EU – by product segment (number of respondents =58)




## 4.3 Market vision for 2030

On average, workshop participants found the future market development very challenging. There is market optimism in France and Italy (both of which had the lowest number of workshop participants) and the Nordic countries whereas all the other countries share a negative view of market development (Figure 10). Of the stakeholder groups, industry representatives were the most sceptical and the mixed group of regional development agencies, technology transfer officers, networking organisations and consultants the most optimistic (Figure 11).

Figure 10. Market optimism vs. pessimism in the EU - by workshop and in total (number of respondents = 138)

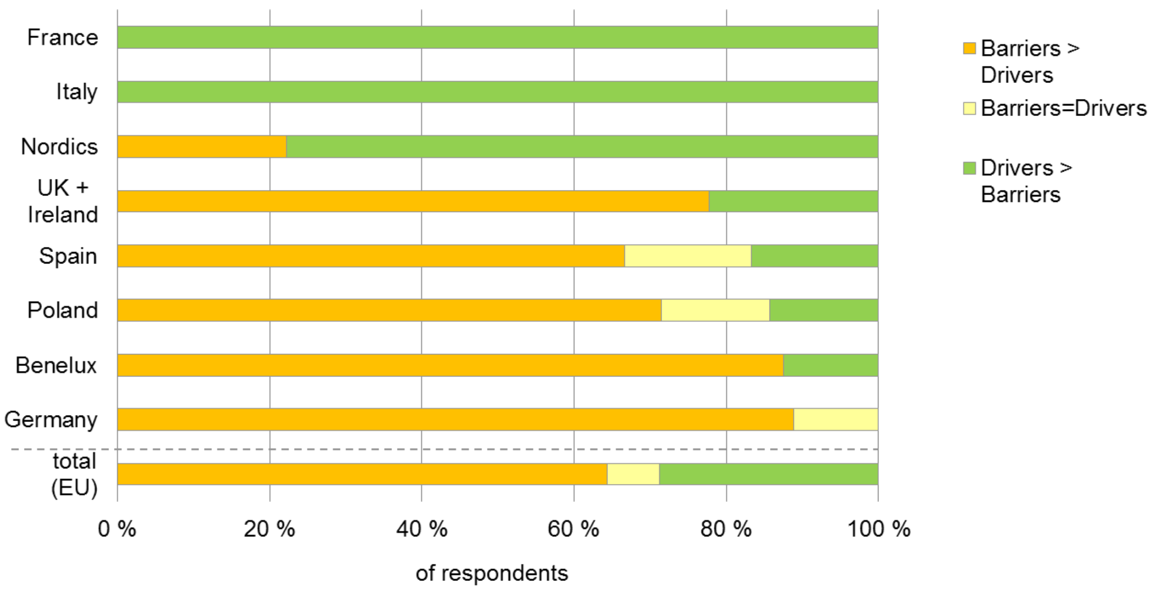
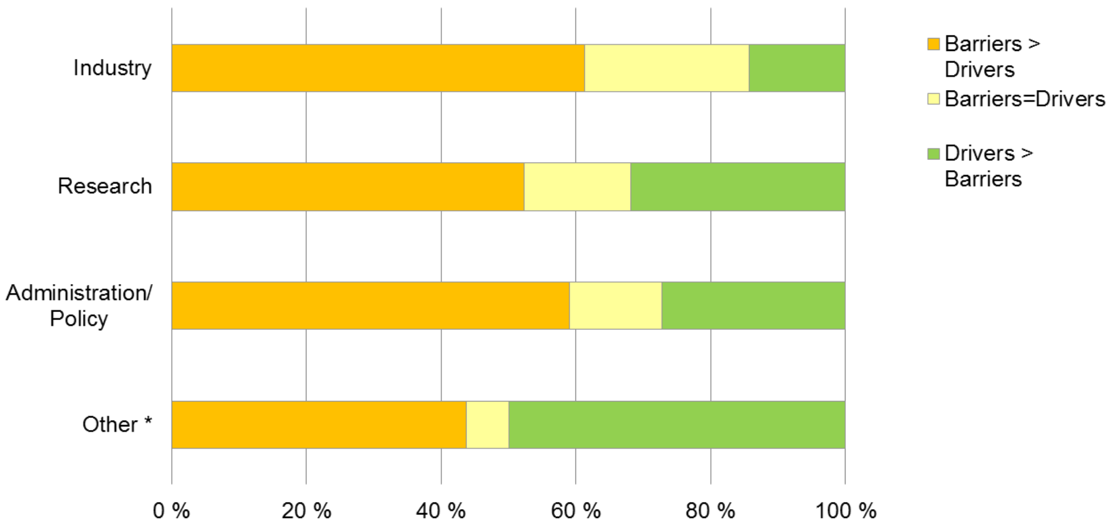


**Figure 11. Market optimism vs. pessimism – by stakeholder group (number of respondents = 138)**




* Stakeholder group "Other" mainly includes representatives of regional development agencies, tech transfer offices, networking organisations and consultancies

The stakeholder views on market drivers and market development were incorporated in the market modelling when considering the market drivers and scenarios and unit price development through to 2030.

According to the updated projections, the IB market is estimated to develop from 28 billion EUR in 2013 to 40 billion EUR in 2020, and up to 50 billion EUR in 2030 **(**Figure 12**)**. This development represents an annual compound average growth rate (CAGR) of 4% between 2013 and 2030.

When looking at the individual product segments, we can distinguish

- two large and rather stagnant product segments, namely antibiotics and biogas,
- two booming product groups, namely bioethanol and bio-based plastics and biopolymers, and
- several smaller and stagnant product segments such as biosolvents and vitamins (Figure 13).

**Figure 12. Estimated IB market demand in the EU up to 2030**

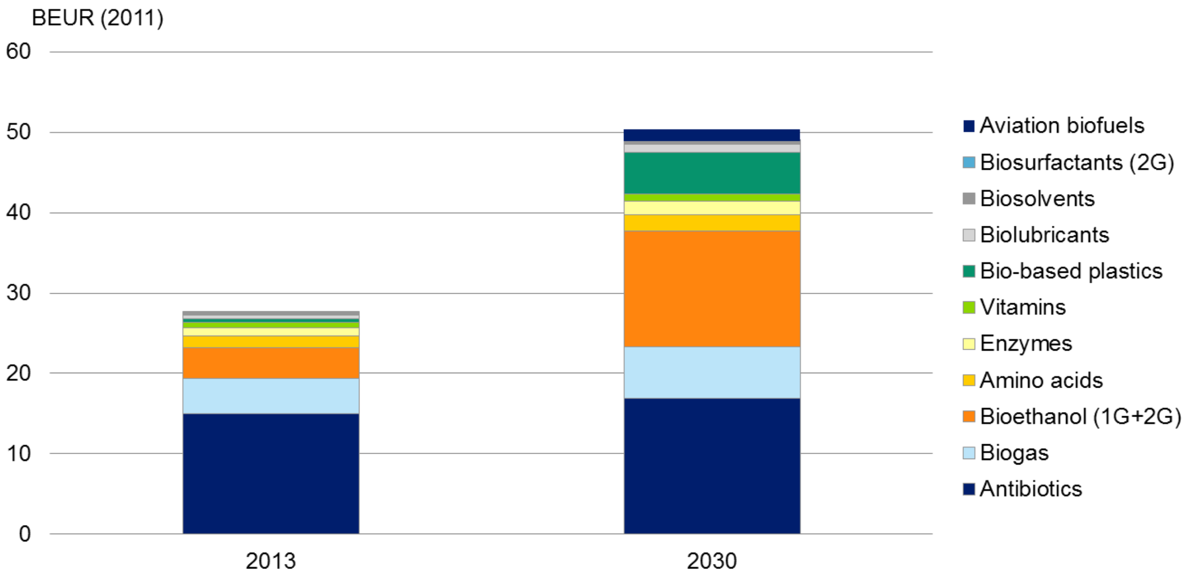
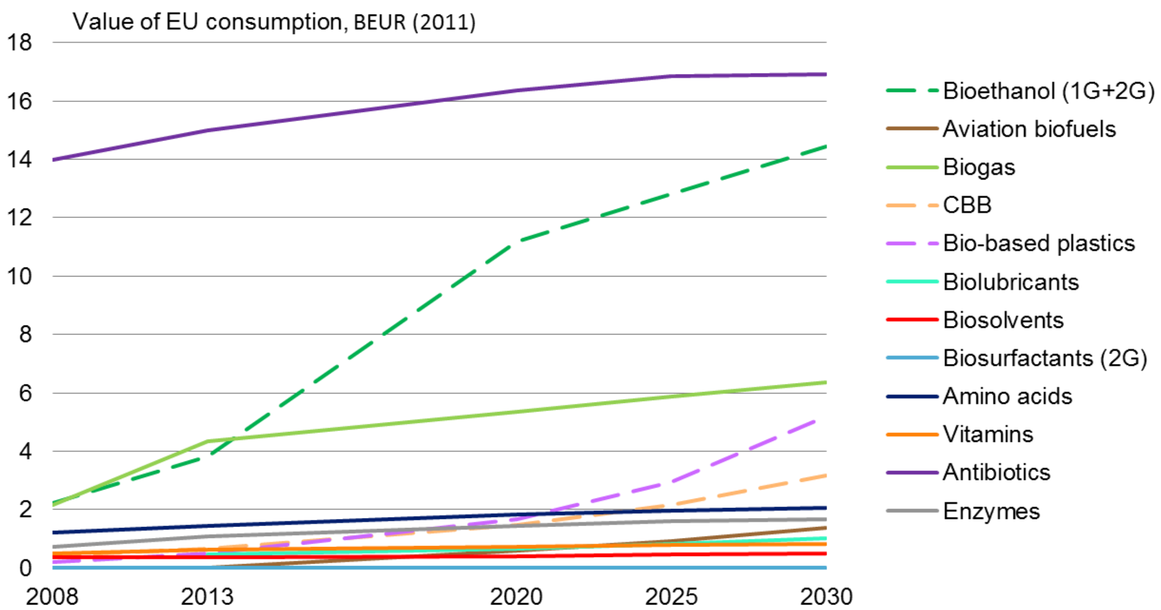



**Figure 13. Estimated market demand in the EU up to 2030 – by product segment**




## 4.4 Milestones

IB hurdles and their potential solutions were discussed in BIO-TIC interviews and regional workshops, resulting in the following list of indicative milestones to be reached by 2020

- New feedstock streams (cellulosic feedstocks, waste, local feedstocks) widely in use. Integration of biomass and waste streams
- Policies (CAP, $CO_2$) support the use of biomass for chemicals. Political stability

- Solutions for biomass transport costs, process efficiency, technologies for economically feasible small volume production, etc.
- GM dialogue with NGOs and private consumers
- Agreement on definitions for “bio-based” and “biodegradable”
- A well-functioning labelling scheme
- A clear picture of environmental benefits of IB
- Identification and realisation of European opportunities in new and added value products
- End products that fit into the “circular economy” concept i.e. can be recycled, re-used etc. in a competitive way
- More IB start-ups and small companies in Europe
- Prioritisation of bio-based products in public procurement

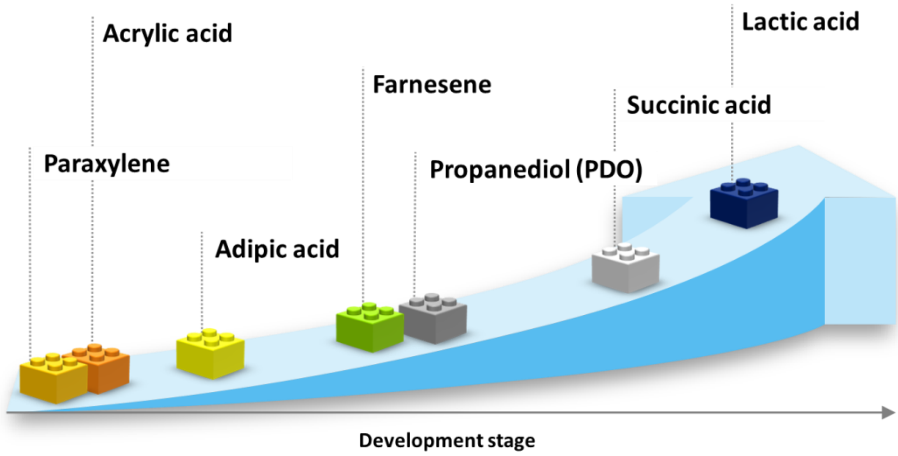
# 5 Biochemical building blocks (CBBs)

*Note: While this roadmap focuses on chemical building blocks produced by fermentation, the relevant reference market is actually the entire bio-based building block market as the demand drivers are identical and there is no distinction between fermentation-based and other bio-based chemicals on the market. However, the market projections presented in Chapter 5.2 below only covers fermentation-based building blocks.*

## 5.1 State of the art

There is an established market for bio-based chemical building blocks (CBBs), but there have been major developments in the recent years. The development stage of bio-based CBBs ranges from proof-of-concept in the laboratory to full commercial production (for examples, see Figure 14), but as of 2013, only a few bio-based building blocks have reached economically favourable production compared to their oil-based counterparts. The EU demand for CBBs that can currently be produced by fermentation is estimated at less than 700 MEUR in 2013, representing approximately 35% of global production and an average growth rate (CAGR) of roughly 10 %/a from 2008 to 2013. Hence, the EU is one of the major consuming regions of fermentation-based CBBs. The EU is investing heavily in the research and development of fermentation-based CBBs, but because of the limited availability of low cost sugars, high operating costs (namely energy and labour), and the global nature of chemical markets, the majority of new facilities are built outside Europe, mainly in Asia and Brazil.

**Figure 14. Development stage of selected bio-based chemical building blocks**




Bio-based chemical building blocks can be divided into drop-in and novel bio-based chemicals. Drop-in chemicals are bio-based versions of existing petrochemicals with established markets. They are chemically equivalent to the incumbent hydrocarbon-based products, and therefore enable reduced risks and faster access to markets. Their market entry is mainly restricted by the reasons of cost competiveness. Novel bio-based chemicals bear higher risks, but may offer unique product properties unattainable with fossil-based alternatives (e.g. biodegradability). Despite potentially superior product properties, the introduction of novel bio-based building blocks is challenged by the change resistance of the other industrial players of the value chain.

The biochemical value chain starts with a feedstock supplier and a building block producer, continues with an intermediate producer, a processor, a brand owner and a retailer, and finally ends with consumers. Strong co-operation within the value chain is required for any new chemical building block to enter the markets, which has called for unconventional partnership networks. The building block producers and developers are not only co-operating with large agricultural giants but also with consumer brands.

Depending on the chemical, the value chain may have either a technology push or both a technology push and market pull. Opportunities for a bio-based premium are significantly lower in chemical building blocks than e.g. in bio-based plastics as the producer is further away from the final consumer. An example of a case where market pull does exist is in the replacement of hazardous chemicals. The key decision-makers in the value chain are either chemical companies or brand owners (Figure 15).

**Figure 15. The value chain for biochemical building blocks**


In the past few years, there has been a great deal of discussion on the impact of shale gas on bio-based chemical building blocks. The transition from naphtha to ethane crackers opens opportunities for alternative sources of C4 and higher chemicals as well as aromatics. A number of large chemical companies, technology developers and research institutes are working systematically to exploit this opportunity. On the other hand, many stakeholders interviewed in the context of this project see shale gas impacting largely the U.S., but leaving European chemical markets relatively unchanged.

## 5.2 Market vision for 2030

By 2030, the EU will have succeeded in attracting investments in fermentation-based chemicals despite limited access to low-cost feedstocks and challenges in the competitiveness of production costs. In other words, the EU has succeeded in speeding up market entry of new IB-based CBBs by capitalising on its strengths in R&D, demonstration facilities and market for final products.

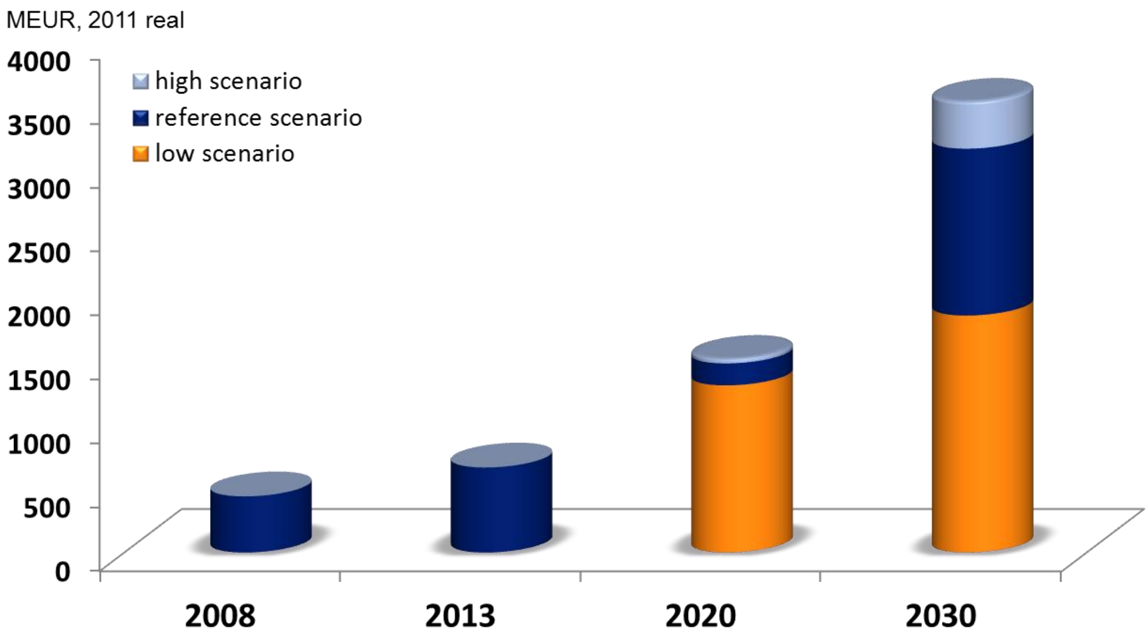
In 2030, the cost and security of supply will still be the dominant sourcing criteria in commodity chemicals, making fermentation-based production more feasible in the value-added fine and specialty chemical markets than in commodity building blocks. Nevertheless, there will be several building block products available at a cost competitive price and at equal quality. Cost competitiveness will be achieved either 1) by reducing production costs by decreasing the number of steps in the production chain (e.g. succinic acid) or 2) as a result of increased chemical market price due to tight fossil-based supply (e.g. aromatics as a result of ethane cracking). In the case of novel bio-based chemicals, by 2030 industrial biotechnology will allow the realisation of commodity products which have not been possible with traditional chemical technologies.

The increasing uncertainty and volatility of crude oil and shale gas markets will result in commodity chemical companies bringing in new feedstock alternatives to allow stable product supply to their customers. In 2030, there is more flexibility in feedstock; both 1$^{st}$ and 2$^{nd}$ generation raw materials will be widely used in industrial biotechnology while algae and waste feedstocks will move to large scale production.

Being business-to-business market with little or no bio-based premium, the IB-based chemical building block market is expected to follow the overall GDP development and the development of bio-based chemical demand in Europe. Despite a decreasing EU trade surplus in commodity chemicals, there will be an increasing demand for bio-based alternatives. Much of the downstream production will remain in Europe thanks to strong operational and technological knowhow, good co-operation in application development and location of leading brands. One of the key end-uses for bio-based building blocks will be in the production of bio-based plastics. Due to a closer co-operation with consumer markets, a bio-premium may be accepted in the bio-based plastics industry.

The market value of IB-based CBBs in 2030 is expected to reach 3.2 BEUR in the reference scenario and 3.5 and 1.9 BEUR in the high and low scenarios, respectively (Figure 16). The high and low forecasts to 2030 follow the GDP scenarios for the EU described in more detail in Annex II. These market projections do not include subsidies or regulations in favour of biochemical building blocks.

**Figure 16. Estimated market demand for IB-based CBBs in the EU**




## 5.3 Recommendations for action

According to stakeholders, the principal hurdles are cost competitiveness of European production and products, and raw material availability, quality and price. R&D challenges related to bioconversion and downstream processing were mentioned too, but knowledge transfer was seen less as an issue (Figure 17).

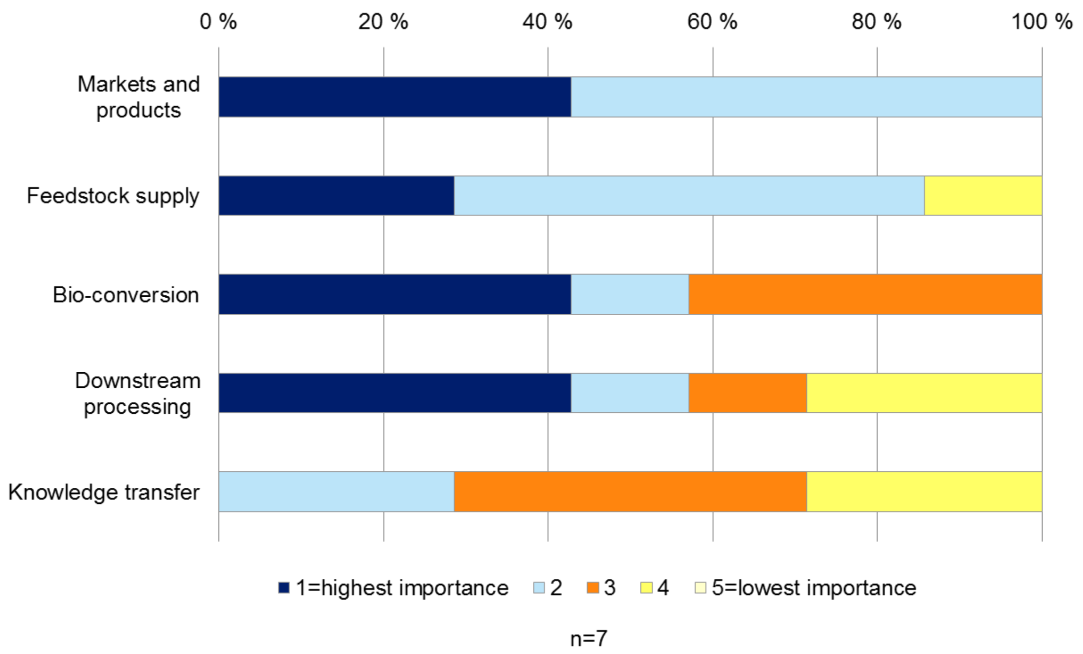
Solutions to be put forward include

- Reform of the agricultural policy and improvement of the use of sugars from sugar beet in the EU by;
    - rethinking of import quotas and tariffs,

- development of production of chemical industry sugars and opening the market for non-food use, including reinstallation of sugar processing capacity, and
- research on cost efficient sugar extraction and processing technology for a variety of feedstocks.

- Integration of IB in to the conventional chemical industry, e.g. use of existing facilities.
- Enhancement of collaboration within the agricultural value chain in order to increase the availability and decrease the cost for agricultural residues, e.g. by development of the harvesting operations.
- Information campaigns to promote bio-based products, to provide facts about GMM and their use in CBB production and to open the discussion with NGOs and public authorities. A critical question for the cost competitiveness of CBB production is also the possibility to use the solids remaining after fermentation for animal feed. However, currently no GM yeast or GM bacteria are approved in the EU for use in food/feed.

**Figure 17. Main hurdles for IB-based CBBs in the EU**



# 6 Bio-based plastics

*Note: In the bio-based plastic market, there is no distinction between IB-based and other bio-based plastics as the demand drivers and market hurdles are the same, and more variation is caused by the drop-in / novel properties of the bio-based plastic. The market projections presented in Chapter 6.2 below cover both partly and wholly bio-based plastics.*

## 6.1 State of the art

Concerns about plastic waste problems, GHG emissions and oil price fluctuation are provoking action both in public and business sectors and households towards more sustainable alternatives to conventional plastics. Even though bio-based plastics are a small section of the overall plastics industry, it is a heterogeneous segment consisting of

- biodegradable and/or compostable bio-based plastics (e.g. PLA and PHAs) that are mainly utilised in single-use disposable applications, and
- non-compostable thermoplastics (e.g. bio-based PE, partially bio-based PET and PTT) and thermosets (e.g. partially bio-based polyurethanes and epoxies) that may offer drop-in opportunities i.e. can be used in the same applications as their fossil-based counterparts.

All of them have unique properties and competitive positions against petroleum-based plastics.

Today, bio-based plastics have an established market with rapid growth both in Europe and globally. In 2013, the EU demand for bio-based plastics was estimated at 485 MEUR, representing a CAGR of 20% between 2008 and 2013. In 2013, Europe was both the largest bio-based plastics consumer and producer, supplying one third of the global bio-based plastics output. However, the future production of bio-based plastics is expected to be located in regions where feedstocks are cheaper and more readily available and production costs lower, e.g. Asia-Pacific. Despite of the shift in production location and weaker policy tools to stimulate demand than e.g. in the U.S., Europe is expected to maintain its position as the main consumer of bio-based plastics. The market drivers include regulatory actions and positive consumer attitudes towards bio-based and biodegradable materials.

The most widespread policy measures affecting bio-based plastics are plastic bag bans. On the EU level, a draft directive calls for the member states to reduce their consumption of lightweight plastic bags by 50% by 2017 and by 80% by 2019, compared to 2010 levels. From the market point of view, the main limiting factors of bio-based plastics include performance issues against fossil-based counterparts and pricing.

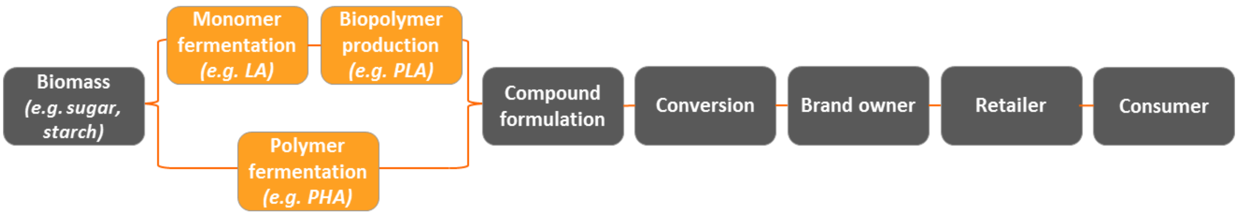
In the BIO-TIC business case workshop (2014), the stakeholders considered the following issues as the main hurdles to the development of the bio-based plastics sector

- Lack of clear definitions for “sustainability”, “green economy” and “bio” and the large number of ecolabels confusing consumers
- Challenges with cost competitiveness
- Lack of a framework to promote bio-based products

The bio-based plastics value chain starts with a feedstock supplier and continues either directly with polymer production (e.g. PHA) or through an intermediate step where a monomer, i.e. a chemical building block (e.g. PLA), is formed. Polymer production is followed by compound formulation, where plastic properties are modified, and by conversion into a product. Direct use of PLA without compounding is also an option. The final steps of the bio-based plastics value chain include a brand owner, a retailer, and consumers (and eventually, waste management) (Figure 18).

In order for a biopolymer to be taken into production it has to be compatible with processing equipment throughout the downstream value chain. It also needs to provide companies an advantage over conventional plastic production, i.e. the polymer should have either (new) superior properties or a cost advantage. In the end, however, the brand owner is the one who takes the greatest risks and is also the main decision-maker in the value chain. The key for the brand owner is to understand the value proposition of the bio-based product. Similarly to bio-based chemical building blocks, bio-based plastics can be divided into drop-in plastics with identical chemical formula to fossil-based counterparts and novel bio-based plastics with unique product properties unattainable with conventional alternatives.

**Figure 18. The value chain for bio-based plastics**




## 6.2 Market vision for 2030

In 2030, there continue to be both biodegradable and non-biodegradable bio-based plastics on the market. Biodegradable plastics will be widely used in disposable products whereas non-biodegradable bio-based plastics will be aimed at durable applications and recycling. Measures have been taken to realise the significant growth potential in the development of completely or partially bio-based analogues of conventional plastics and new geographical markets have been opened for compostable single-use plastics.

The situation has improved in the EU when it comes to recycling and disposal infrastructures for both biodegradable and durable bio-based plastics.

The demand for bio-based plastics will be driven by a competitive product price, superior functionality or a bio-based premium. Price competitiveness will be challenged by low cost shale gas derivatives affecting e.g. polyethylene markets. On the other hand, however, the tightened supply of higher olefins and aromatics may improve the competitiveness of some bio-based plastics. Polymer functionality in given end-use application will continue to be of high importance in 2030. Functional properties can be improved by e.g. developing new improved additives and plasticisers for polymer compounding or by introducing novel bio-based plastics. New properties will thus enable new end-use applications for biopolymers. A clear 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 (Figure 19).

**Figure 19. Cases with a premium for bio-based plastics**

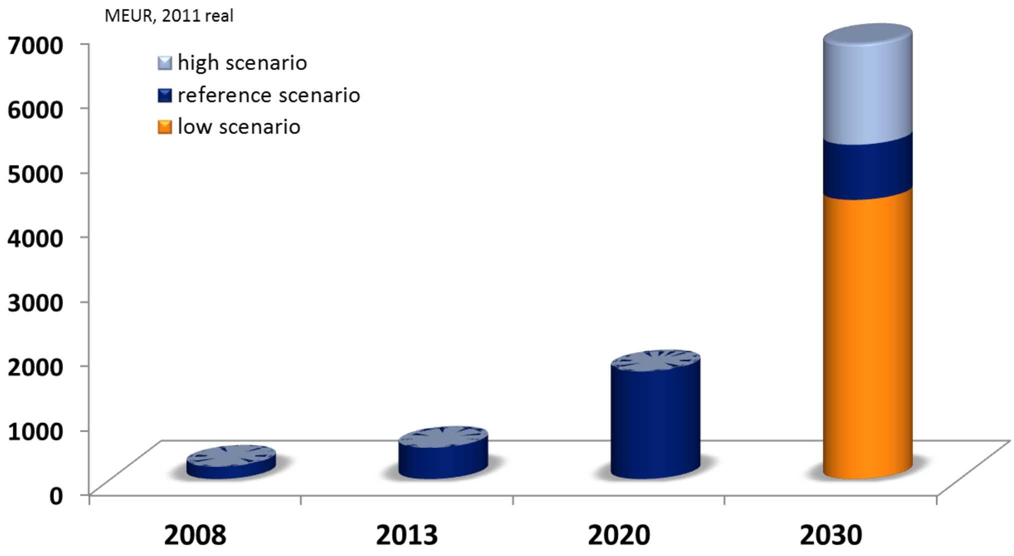
| Bio-premium in bioplastics | Example case | Payer in the value chain |
|---|---|---|
| **Bio-based origin a key buying criteria** | *Organic food packaging* | *Consumer* |
| **Environmental sustainability as a marketing tool** | *Branded consumer products, e.g. PlantBottle™* | *Brand owner* |
| **Bioplastics represent a minimal share of final product value** | *Bio-based materials in automotives or electronics* | - |
| **Regulations force the use of bioplastic** | *Plastic bag ban* | *Brand owner / consumer* |

Similarly to bio-based chemical building blocks, both $1^{st}$ and $2^{nd}$ generation raw materials will be widely used in bio-based plastic production in 2030. Changes in Common Agricultural Policy have removed restrictions to EU sugar production in 2017 and contributed to increasing production volumes and aligning prices with global market levels, making the supply more secure. Consumers are widely aware of the environmental benefits of bio-based plastics and familiar with EU-wide labels indicating bio-based content, biodegradability and recyclability of bio-based plastics.

Published market reports on bio-based plastics have very different views on the expected future demand, with annual growth rates ranging from 15% to 35% between 2010 and 2020. Based on stakeholder interviews and market surveys carried out in workshops, these growth rates seem very optimistic. Therefore, the market projections of this report are more conservative, applying growth rates of 10%, 12% and 15% for the low, reference, and high scenarios, respectively.

The bio-based plastics market value is expected to reach approximately 5.2 BEUR in 2030 in the reference scenario and 4.3 BEUR and 6.7 BEUR in the low and high scenarios, respectively (Figure 20). The main growth is expected in the specialty polymers and packaging applications. Market adoption in all applications is, however, completely dependent on biopolymer cost competitiveness compared to conventional polymers and on consumer willingness to pay a bio-premium.

**Figure 20. Estimated market demand for bio-based plastics in the EU**




Note: In partially bio-based plastics, the renewable carbon content ranges between 20% and 100%.

## 6.3 Recommendations for action

In order to facilitate market adoption, measures should be introduced to address technical bottlenecks and to improve the competitiveness of bio-based plastics. Several interventions could be envisaged, ranging from targets, quotas, mandates or bans to tax measures and to market promotion by public procurement and increasing information (certification and labelling). From the market point of view, the following measures would be highly beneficial

- Uniting of resources and development of a common agenda for sector development, encompassing both durable bio-based and biodegradable plastics. This kind work could be lead by e.g. European Bioplastics.
- Building of an overall framework to promote bio-based chemicals and materials. Alternatively, the use of subsidies and tax incentives to support the development of bio-based plastics should be fully explored at feedstock, production and product use levels by EU member states or regions.
  - Selective bans on non-biodegradable plastics where biodegradable plastics have demonstrable environmental benefits (as in shopping bags, agricultural mulching films, coffee cups, fast food packaging).
  - Introduction of a bio-based product public procurement scheme such as the US BioPreferred[1] to create markets whilst simultaneously educating the public on the benefits of bio-based products. Opinions on what is expected from bio-based products often differ between EU member states, so the criteria for determining compliance with the scheme, whether it is based on bio-based content, GHG savings, etc. need to be

[1] http://www.biopreferred.gov/BioPreferred/

agreed upon. Mandatory reporting could be a way to push the use of bio-based products in public procurement.

- Improving the properties of bio-based plastics will allow new end-use applications to be exploited. Many of the solutions may already be available at the academic level, and in order to leverage this know-how more focus should be put on applications testing and improving information exchange between industry and academia. The creation of an online network or a technical event on bio-based plastics could help promote information exchange between industry and academia in the sector.
- Continuation of R&D to improve cost competitiveness of bio-based plastics from both 1G and 2G feedstocks.
- Organising information campaigns to increase awareness of bio-based plastics by demonstrating their safety, environmental benefits and added value
    - Clarification of the requirements of ecolabels related to bio-based plastics in business to business (B2B) and business to consumer (B2C) contexts.

# 7 Advanced biofuels

## 7.1 State of the art

### 7.1.1 2G ethanol

The global production of second generation (2G) ethanol is still very low, but rapidly increasing. In 2014 alone, four new 2G facilities became operational with a combined nameplate capacity approaching 300 kt/a. The feedstocks include bagasse, straw, corn stover, hemicelluloses from sulphite pulp mills, *Arundo donax*, and waste (e.g. from food industry).

In 2013, the EU total (1G+2G) ethanol demand for transport fuel was estimated at 4.5 Mt and 3.8 BEUR, representing a volume growth of approx. 10 %/a between 2008 and 2013 (USDA). The European ethanol demand is mainly satisfied by local 1G production since the leading 2G ethanol producers, namely USA and Brazil, are currently struggling to produce enough 2G ethanol to meet their own biofuel quotas.

The European ethanol demand is driven by the obligation for a 10% share of renewable energy in transport by 2020. The main driver for 2G biofuels is the so called "double counting" rule included in the Renewable Energy Directive (2009/28/EC). According to the directive, the 10% obligation could be satisfied by only 5% actual biofuel volume, taken it is produced from 2G feedstocks. This has increased the use of drop-in 2G feedstocks, such as used cooking oil and animal fats, but has had a more limited impact on investments in new 2G technologies. Moreover, there is a draft directive that would limit the share of 1G biofuels that can be counted towards the 10% target in 2020. As far as the Council is concerned, it would limit the share of 1G transport biofuels at the level of 7% to drive biofuel production away from feedstocks competing with food and feed value chains. On the other hand, the Commission has suggested a 5% and the Parliament a 6% cap for 1G transport biofuels. The revision is expected to be adopted in April 2015 at the earliest.

In 2014, the EU agreed on a climate and energy policy framework for 2030, setting a target of reducing total $CO_2$ emissions by 40% compared to 1990 levels. A separate 30% reduction target (compared to 2005 levels) was set for sectors not included in the Emission Trading System (ETS), such as road transport. On the contrary, the separate obligations for renewable energy in transport as well for fuel decarbonisation are to be removed.

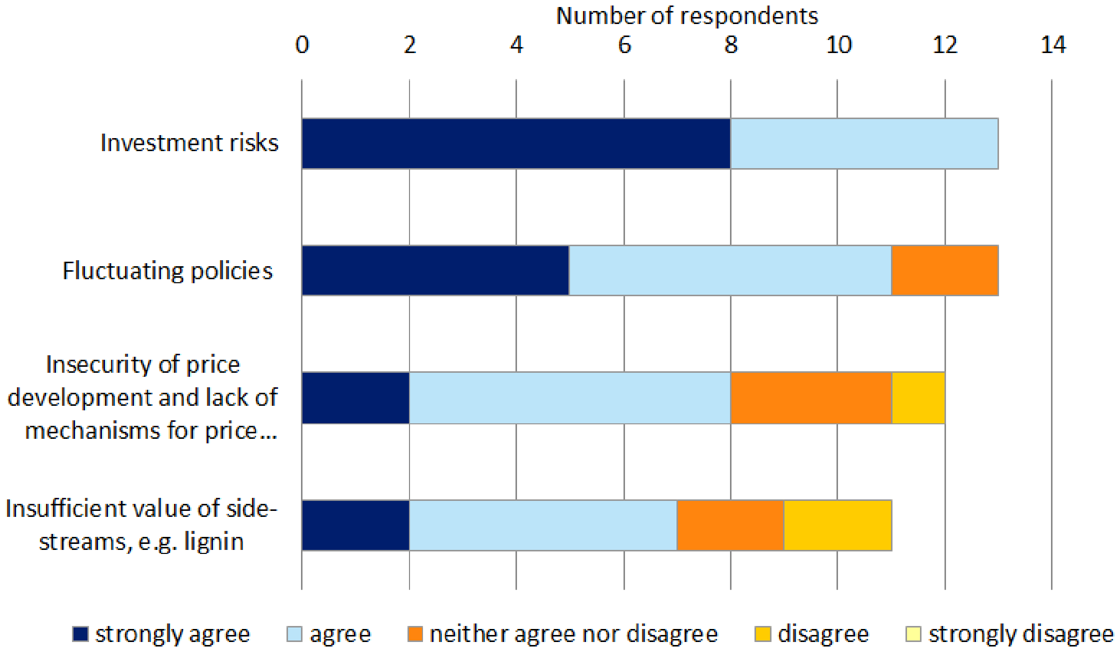
To add to the complexity, an EC legislative proposal on waste (2014) suggests considering waste-based liquid biofuel production as energy recovery instead of material recovery, making it less preferable from the waste hierarchy point of view.

In addition to the EU level regulation; there may be national and regional targets and incentives, including the option for a Member State to include the transport sector to the ETS, driving the demand for 2G ethanol.

In this changing policy environment, it can only be concluded that the magnitude of 2020 and 2030 emission reduction targets indicates that they cannot be achieved without the use of multiple strategies to cut greenhouse gas emissions, 2G ethanol being one of them. According to stakeholders, the intertwined investment, policy and price risks are also the main hurdles hindering market development (Figure 21). The profitability of 2G ethanol production is largely determined by capital and financing costs and by the value of the by-products, i.e. lignin. A commercial scale 2G ethanol facility requires significant investments, with a CAPEX in the range of 100-300 million euros.

Lignin is currently utilised for green energy generation but technologies for higher value end uses are being developed.

**Figure 21. Key factors hindering market growth in 2G ethanol**

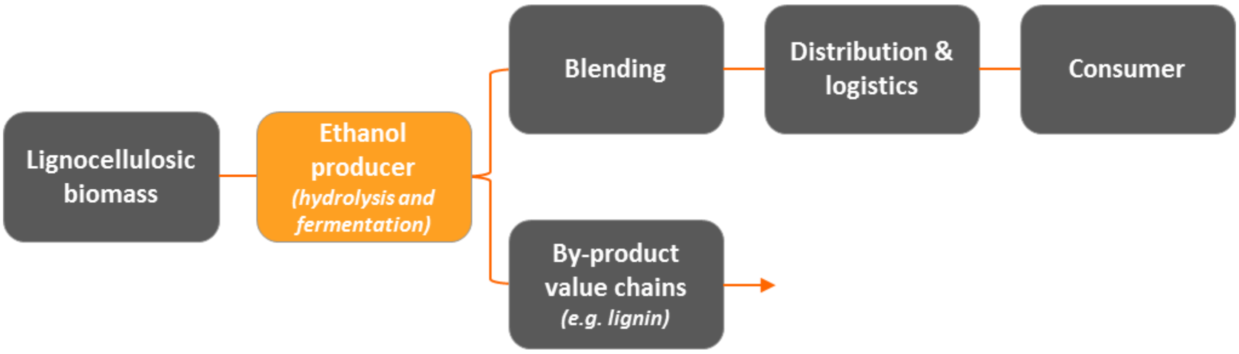



Source: Survey among the participants of biofuels BIO-TIC stakeholder workshop held on 23 October, 2014 in London, UK

The 2G ethanol value chain consists of a feedstock supplier and ethanol producer, after which it is divided into two separate streams; one for the ethanol, consisting of a blender and a distributor, and one for possible by-products. After fermentation and purification, the ethanol is traded, blended and distributed to markets. The technology to produce 2G ethanol has recently achieved commercial status but, despite economic incentives, not yet economically viable.

The ethanol market is highly determined by political decisions and regulations, and since the blending company is the one with the “bio-obligation”, it is also the main decision maker (deciding on whether to use 1G or 2G ethanol). There is little integration between value chain players (Figure 22).

Figure 22. The value chain for 2G ethanol




### 7.1.2 Aviation biofuels

During the past few years, aviation and biofuel producing industries have been heavily involved in development, testing and standardisation activities related to bio jet fuels. The aviation sector has also set ambitious targets for the future. Amongst them, the International Air Transport Association is committed to a 50% reduction of $CO_2$ emissions by 2050 compared with 2005 levels, and the European Advanced Biofuels "Flightpath" aims at 2 Mt/year of advanced biofuels by 2020 (see below).

**Flightpath 2050**

In 2011, the European Commission and aviation and biofuel producing industries published a Flightpath document on the introduction of advanced aviation biofuels in Europe. The roadmap is a non-binding technical document aiming at setting targets and enhancing co-operation to promote production, distribution, storage and use of sustainably produced and technically certified biofuels. In the roadmap, e.g. the following actions are scheduled to achieve 2 million tons of sustainable biofuels used in the EU civil aviation sector by the year 2020:

1. Facilitate the development of standards for drop-in biofuels and their certification for use in commercial aircrafts;

2. Work together with the full supply chain to further develop worldwide accepted sustainability certification frameworks;

3. Agree on biofuel take-off arrangements over a defined period of time and at a reasonable cost;

4. Promote appropriate public and private actions to ensure the market uptake of paraffinic biofuels by the aviation sector;

5. Establish financing structures to facilitate the realization of 2G biofuel projects;

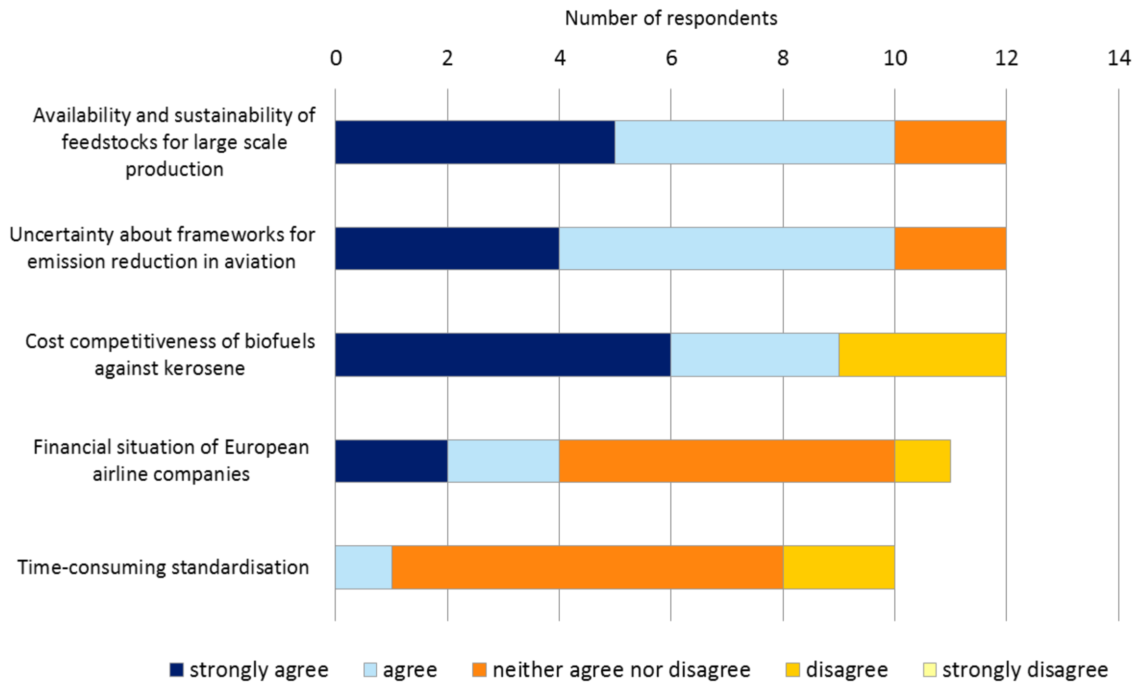
6. Accelerate targeted research and innovation for advanced biofuel technologies, and especially algae;

7. Take concrete actions to inform the European citizen of the benefits of replacing kerosene by certified sustainable biofuels.

Source: ec.europa.eu/transport/modes/air/doc/flightpath2050.pdf

The drivers for the emerging bio jet fuel market include the growth in demand for air travel, the rising fuel cost and cost fluctuation of kerosene, the EU renewable energy directive, the inclusion of aviation in the EU emission trading scheme and corporate social responsibility policies. On the other hand, the main challenges are related to the cost of biofuels (current bio-based jet fuels are 2-3 times more expensive than conventional jet fuel), to the availability and sustainability of feedstock, and to the biofuel quality requirements (Figure 23).

**Figure 23. Key factors hindering market growth in aviation biofuels**



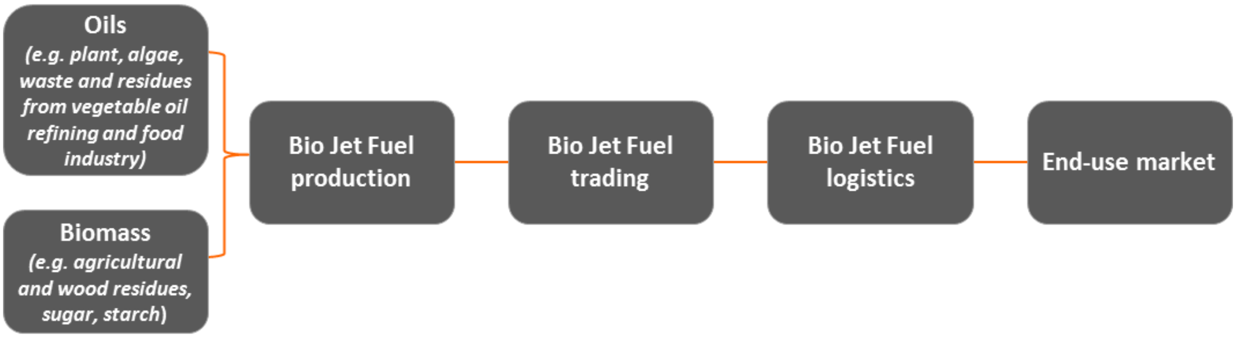

Source: Survey among the participants of biofuels BIO-TIC stakeholder workshop held on 23 October, 2014 in London, UK

Aviation biofuels can be produced from either oils (e.g. plant oil) or biomass (e.g. starch and agricultural residues). The raw material is then processed into bio jet fuel[2], which is traded and transported to end-use markets. In the value chain it is the end-use markets, i.e. the airlines that are the key decision makers (**Figure 24**).

The degree of integration along the value chain depends both on the company and the maturity of a specific technology (early stage development is often focused on one step, jet fuel production), however, in general the biofuel producer works very closely with feedstock providers. Close cooperation/integration throughout the value chain is seen necessary for economically viable production.

[2] There are several routes under development (hydroprocessed esters and fatty acids (HEFA), Fischer-Tropsch (FT), direct sugars to hydrocarbons (DSHC) routes, alcohol-to-jet (ATJ), and upgraded pyrolysis oil), but of these, only DSHC and ATJ can be considered as IB processes. In 2013, there was no commercial IB-based jet fuel production in the EU.

Figure 24. The value chain for aviation biofuels




## 7.2 Market vision for 2030

### 7.2.1 2G ethanol

Ambitious greenhouse gas emission reduction targets for 2030 will continue to drive the development for low-carbon means of road transport, particularly if separate quotas for renewable energy and advanced biofuels in transport are implemented for 2030. Emission limits have been imposed to new cars, but due to the long turnover time of car fleet, drop-in biofuels are also needed. This contributes to an increasing consumption of 1G/2G biofuels, even though they will unlikely be cost competitive with fossil fuels in the EU by 2030.

In 2030, the EU has a flourishing 1G and 2G bioethanol industry resulting in considerable GHG emission reductions in transport. Thanks to advancements in cultivation and increased use of bioenergy in ethanol production, the GHG emission savings from 2G bioethanol make it a competitive means to reduce GHG emissions in road transport.

The demand for 2G ethanol is expected to increase through to 2030. The market projection is based on the following assumptions

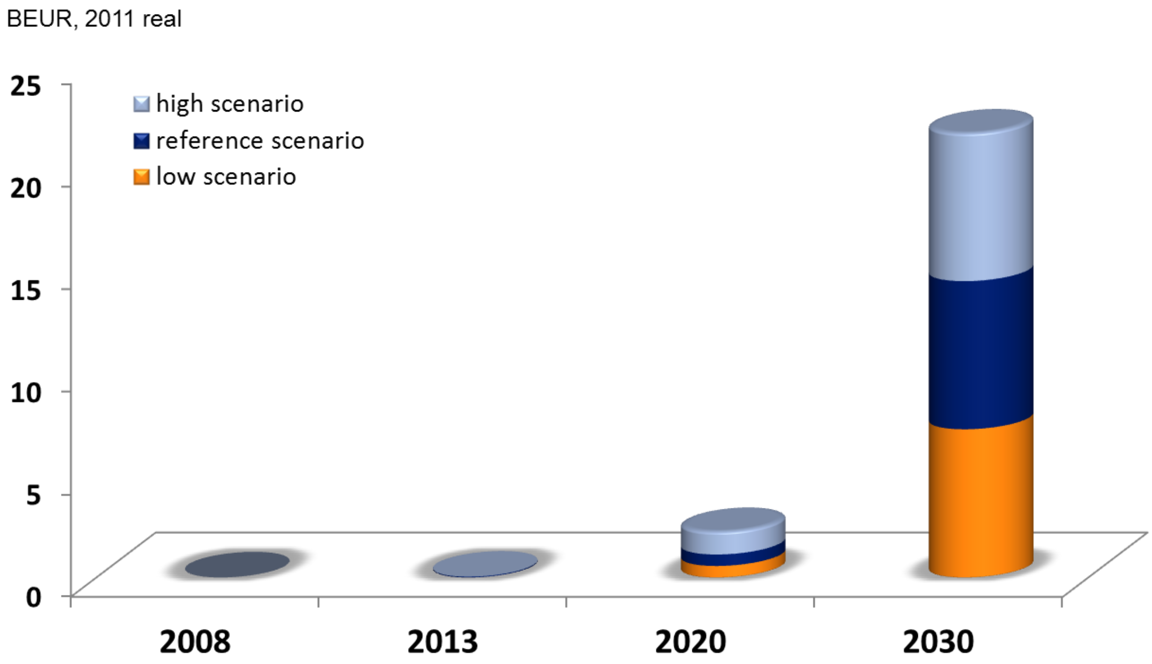
- The total fuel consumption in road transport is expected to decrease 9% from 2013 to 2030[3].
- The ratio between diesel and gasoline demand is projected to increase substantially towards more diesel and less gasoline, although stringent emission standards favour the use of gasoline to diesel engines.
- The EU will reach its target of 10% renewable energy in transport in 2020[4].
- By 2030 the increasing use of electric cars will not have substituted ethanol demand on the market (even though the effect on bioethanol consumption will be larger than on diesel fuels).
- The reference, high and low market scenarios assume a 2G biofuel share of 1%, 2% and 0.5% of all road transport fuels by 2020, respectively. The share of ethanol of all 2G biofuels is assumed to remain constant 30%.
- For 2030, it has been assumed that in the reference scenario 10% of road transportation fuels are 2G biofuels. In the high and low scenarios, the shares are 15% and 5%, respectively.

[3] European Commission (2013), *"EU energy, transport and GHG emissions – Trends to 2050"*

[4] However, a study published in April 2014 by the European Commission's Joint Research Centre indicates that, based on current standard marketed biofuel blends, the share of biofuels in the EU is likely to reach 8.7% by 2020, staying below the 10% target for renewable energy in the transport sector.

The reference scenario would equal to 1.4 million ton 2G ethanol demand in 2020 and 13.1 Mt in 2030. This market would be valued at approximately 1.1 BEUR in 2020 and 14.4 BEUR in 2030 (Figure 25).

**Figure 25. Estimated market demand for 2G ethanol in the EU**




### 7.2.2 Aviation biofuels

In 2030, diverse sustainable feedstocks will be available on a large scale and there will be a performing aviation biofuels supply chain in Europe and globally. The EU governments will have supported the scaling-up of biojet production capacity. Thanks to major efforts on reducing the price for feedstocks, development of more efficient production processes and economies of scale, the aviation biofuel cost disadvantage will have decreased. However, the cost for $CO_2$ in EU ETS is not likely to fully cover the price gap to fossil kerosene. Therefore, only an international agreement on $CO_2$ emission reductions in aviation will make it possible to progress towards the goals set in Flightpath 2050. Without such an international agreement (and with severe international hub competition in place), it will be difficult for the market to grow except on a voluntary basis, relying on air passengers' willingness to pay for additional biofuel costs in their ticket prices. Much will depend on the member states' strategies on transport decarbonisation and allocation of incentive regimes between aviation and road transport, too.

The energy demand in aviation is expected to grow from current 52 Mtoe to 59 Mtoe in 2030[5], but the potential of biofuels and that of IB in particular is very unclear. Assuming 1%, 2% and 10% biofuel blend in low, reference and high scenarios in 2030, the 2030 bio jet fuel market would total 0.7, 1.4 and 6.8 BEUR, respectively (Figure 26), but no specific estimates can be given for IB processes because of their early stage of development and unclear competitive advantage compared to other

[5] EU energy, transport and GHG emissions trends to 2050. Reference scenario 2013.

bio jet fuel processes. In an example case given in Figure 27, the assumed 1%, 2% and 10% biofuel blends would result in 0.04-4% increases in airline ticket prices, depending on the price gap (10-100%) between bio jet fuel and kerosene.

**Figure 26. Estimated market demand for bio jet fuels in the EU**

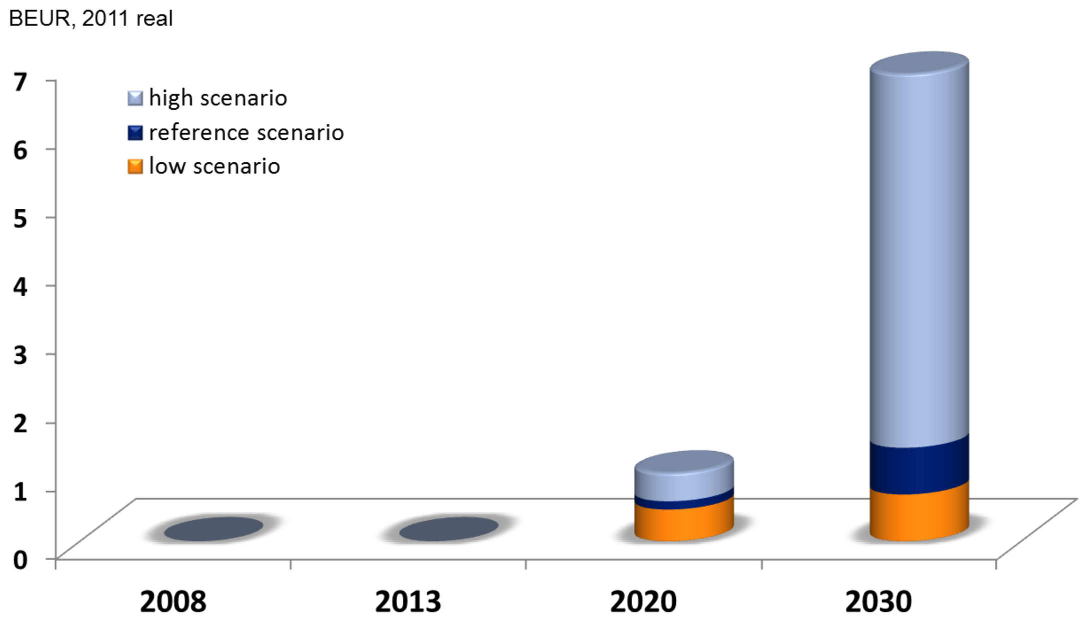
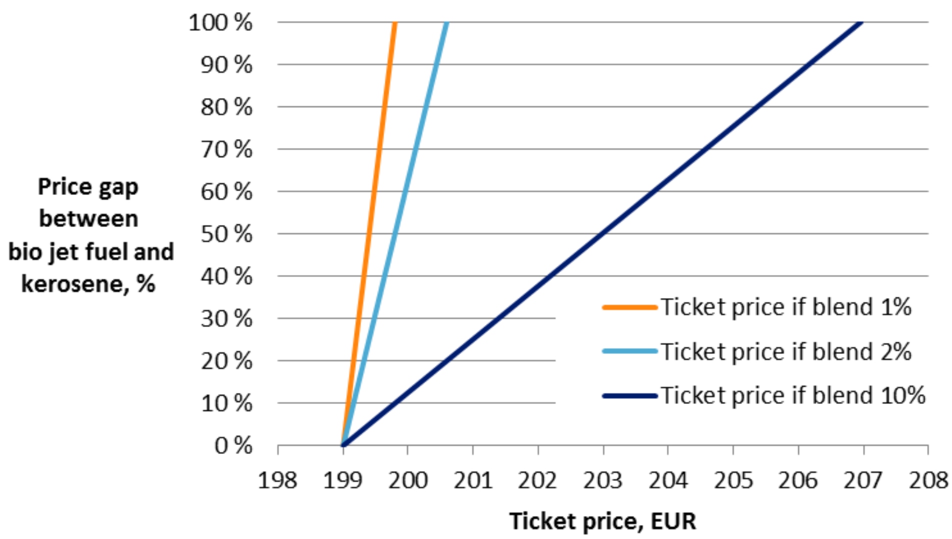



**Figure 27. Impact of 1, 2 and 10% bio jet fuel blend on an airline ticket price of 199 EUR, assuming that fuel cost equals 40% of ticket price**



## 7.3 Recommendations for action

In BIO-TIC interviews and workshops, several technology and non-technology hurdles were identified by stakeholders, and potential solutions were proposed.

There are multiple ways to reduce $CO_2$ emission in road transport (multiple liquid biofuels, biogas, electric cars, fuel-efficiency standards, increase in rail transport etc.) but the alternatives are much more limited in the aviation sector. Aviation biofuels have the potential for major reductions in GHG emission in a relatively short time-frame, whereas the road transport sector takes a long time to change.

For 2G ethanol, measures need to be implemented to tackle the ongoing policy uncertainty. In aviation biofuels, there is an existing technology base able to supply significant quantities of bio jet fuel, but without international agreements, there is no large-scale demand. In the current policy framework, aviation biofuels are simply not as attractive to produce as diesel or gasoline components.

Actions that would improve market take-off of 2G ethanol include

- Establishing a supportive policy framework
  The EU should consider extending the targets for biofuels in road transport up to 2030. For example, Italy has already succeeded in creating a favourable business environment by mandating the use of advanced biofuels at national level. Advanced biofuels will have to be blended in increasing shares in petrol and diesel: 0.6 % from 2018, 0.8% in 2020, 1% from 2022.
- Fostering investments
  The newly established Public Private Partnership on Bio-Based Industries focuses on demonstration and first of its kind flagship biorefineries. In addition, funding is crucial also for subsequent plants to facilitate market development.
- Increasing cooperation within the bioethanol biomass supply chains to improve large-scale collection and storage of biomass from agriculture and forestry.
- Improving the competitiveness of IB by developing high value applications for lignin
  Should lignocellulosic sugars be used for the production of ethanol, this will, as a consequence, produce lignin in very large quantities. Lignin research is not new and there has been much research for the past 20 years on lignin from pulp production process. However, it is also acknowledged that lignin from different sources can vary quite significantly in terms of chemical properties (and therefore its appropriateness for different downstream uses). Currently, most lignin is utilised in bioenergy production, however there are many higher value end-uses under research. A pilot or demonstration facility is needed to study industrial applications and to assess the quality differences.

Actions that would improve market take-off of aviation biofuels include

- An international agreement on emission reductions in aviation
- Improving the competitiveness of IB by maximising cost effectiveness and GHG emission savings

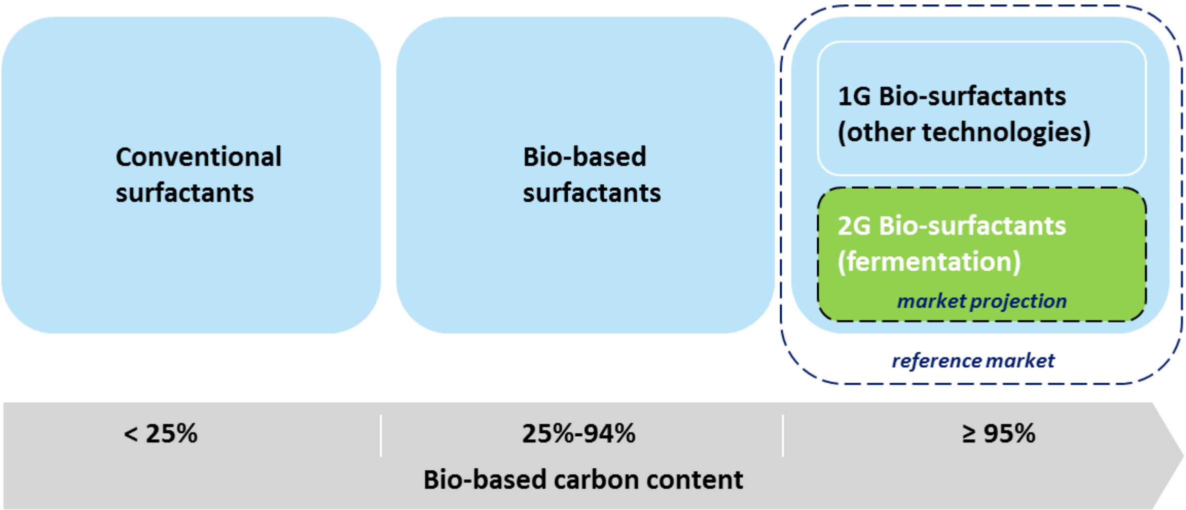
Some commercial technologies, such as HEFA, can be used to produce both bio jet fuel and renewable diesel, but thanks to supporting policy frameworks, the biofuels produced in the EU are currently consumed exclusively in the road transport sector. From the IB sector development point of view, the competitiveness of IB based processes should be a top priority. This can be improved by maximising the GHG emission savings in the entire production chain by technology development and by politically supporting fuel use where the total GHG emission savings are the largest.

- Building demand for bio jet fuels by introducing voluntary schemes
  Airline companies can introduce voluntary schemes to kick-off market demand. To date, these have proven challenging except for the Dutch initiative driven by KLM, SkyNRG, Schiphol Airport, the Port of Rotterdam, and governmental bodies. These kinds of schemes, coupled with effective marketing and consumer dialogue, could stimulate small scale demand for aviation biofuels. Moreover, the “mass-balance” approach could be applied by airline companies, allowing them to source X tonnes of aviation biofuels and then sell a corresponding mileage to their pro-environmental corporate or consumer clients (similarly to e.g. green electricity certificates).

# 8 2G bio-surfactants

*Note: In surfactants, the term 2G refers to bio-surfactants produced by fermentation, regardless of feedstock origin. While this roadmap focuses on 2G bio-surfactants, the relevant reference market is actually the entire bio-surfactant[6] market as the demand drivers are identical and the current market for 2G bio-surfactants is very limited (less than 1% of the total bio-surfactant market). However, the market projections presented in Chapter 8.2 below only cover 2G bio-surfactants.*

**Figure 28. Scope for market projections and reference market**




## 8.1 State of the art

Bio-surfactants have an established market in the EU. There is a wide range of applications, the largest one being detergents followed by personal care products and industrial and institutional cleaners. Globally, bio-surfactants only represent a small share of the total surfactant market. However, some of the leading producers have entered the bio-surfactant market and are investing in product development. Overall, the bio-surfactants market is very concentrated with top five producers accounting for almost 90% of the total market (2011).

The main drivers for bio-surfactants are e.g. increased environmental awareness, a drive for new product properties and fluctuating oil prices. Bio-surfactants often offer low eco-toxicity, biodegradability and are based on renewable resources or waste streams. In addition, they can display biological activity (e.g. antibacterial, antifungal, antiviral, anticancer and immunomodulation activities) and have a lower critical micelle concentration compared to chemical surfactants.

The EU constitutes the largest market for bio-surfactants, representing about half of the global demand. Currently Europe is not only the main consumer of bio-surfactants, but also the leading producer, although production volumes are very small compared to conventional surfactant production.

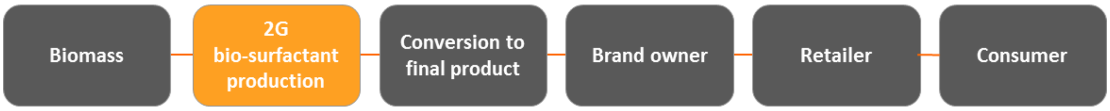
The major hurdle for the development of bio-surfactants is related to the performance of these products. First generation bio-surfactants have been used for a number of years, but still have

[6] Surfactant wholly based on biogenic C / biomass or surfactant produced by fermentation.

problems associated with performance and are mostly used for their biocidal properties. For second generation bio-surfactants, the major development needs are related to performance issues which can only be addressed through genetic engineering. Surfactants are mainly used in product formulations where a change in one component has an effect on the performance of the final product. Therefore, there needs to be clear added value for the brand owner to switch to bio-surfactants as the price is generally higher, one-to-one substitutions with conventional surfactants are unlikely and thus new product formulation development is required. Another market-related hurdle is the uncertainty of secured and steady supply of bio-surfactants due to the limited number of large-scale producers.

2G bio-surfactants are produced from biomass by fermentation. The produced bio-surfactant is then added to a product formula. The value chain continues with a brand owner and a retailer and ends with consumers. The bio-surfactant product development is mainly driven by a technology push. Brand owners are waiting to see what technology developers bring to market before making any major product development decisions (Figure 29).

**Figure 29. The value chain for bio-surfactants**




## 8.2 Market vision for 2030

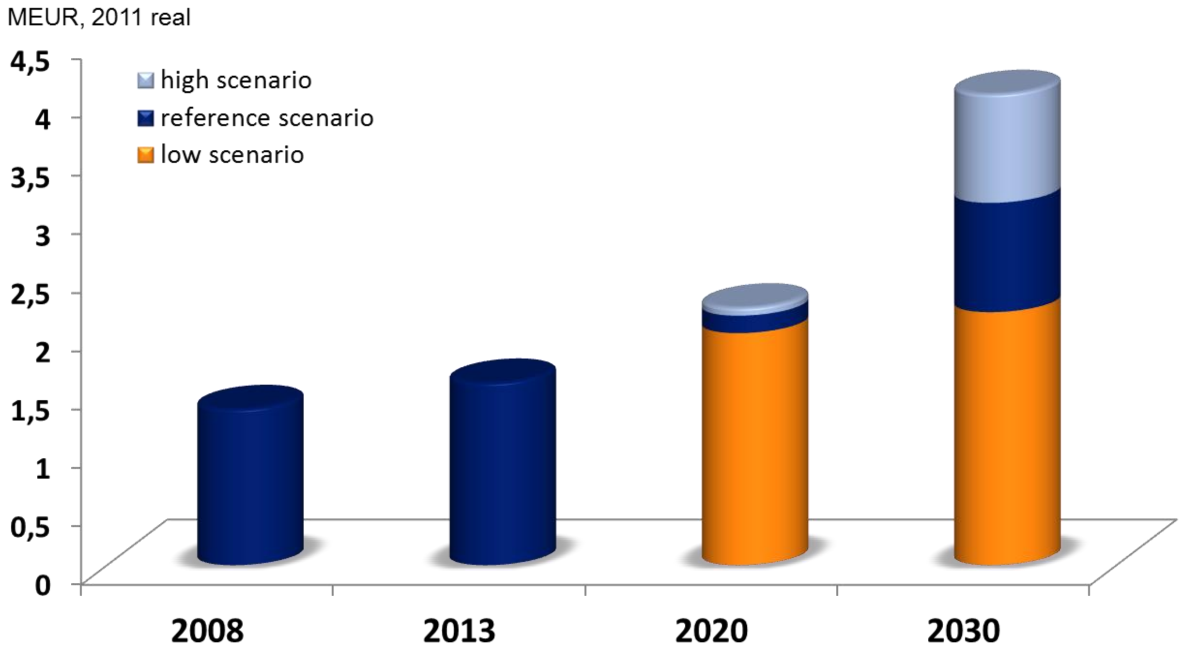
In 2030, bio-surfactants produced via industrial biotechnology will be available for a wide range of applications, however, still as niche products due to their limited cost competitiveness compared to conventional surfactants. On a global scale, Europe will remain as the largest consumer of bio-surfactants.

The main contributing factors for the success of the European bio-surfactant market are increased environmental awareness and opportunities for new product properties at a competitive cost. In 2030, European eco-labels include the use of bio-based or bio-surfactants as one of the criteria in consumer goods. GMM fermented bio-surfactants are widely accepted by consumers in many applications e.g. household detergents.

In 2030, bio-surfactants will be produced from a variety of feedstocks including plant oils, fats and sugar biomass but also algae and waste streams. The cost of renewable raw materials, e.g. vegetable oils, will keep the production costs of bio-surfactants at a higher level than conventional surfactants because of increasing demand in e.g. animal feed, biofuels and bio-lubricants. Another factor hindering market growth is the limited number of bio-surfactant suppliers. In order for brand owners to switch product formula to include bio-surfactants there need to be multiple suppliers of the same surfactant to secure a steady supply at a competitive price.

The demand for bio-surfactants will depend strongly on household spending and industrial activity in detergents and cosmetics where environmental concerns are more evident. The development of the detergent and cosmetic industries can be characterised by general economic development and the 2G bio-surfactants market is estimated to grow from 1.3 MEUR in 2013 to approximately 3.1 MEUR in 2030. In high and low case scenarios, the market value is expected to reach 4.0 and 2.2 MEUR, respectively (Figure 30).

**Figure 30. Estimated market demand for 2G bio-surfactants in the EU**



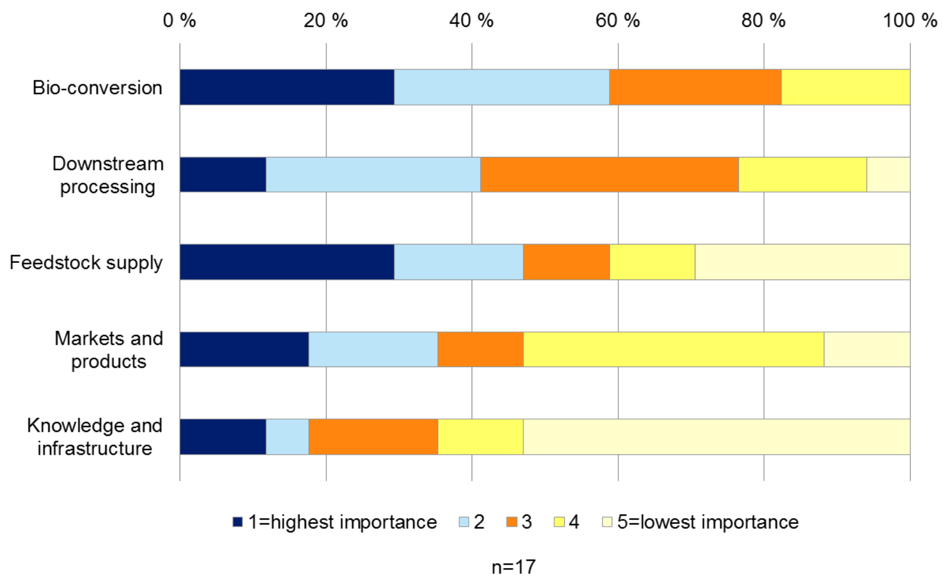

Definition: 2G bio-surfactants include Sophorolipids, Rhamnolipids and MEL. The estimates refer to active ingredients.

## 8.3 Recommendations for action

According to stakeholders, the main hurdles for bio-surfactants are related to bio-conversion, downstream processing and feedstock supply. Markets and products and knowledge and infrastructure were ranked as less important hurdles by the stakeholders (Figure 31).

Within the area of markets and products, the stakeholders emphasised the need for improvements in cost competitiveness and public perception. From the market point of view, the bio-surfactant market is functional but still marginal in size. The demand development is limited by the high price of IB-derived products, which calls for action in R&D (e.g. yields, performance, use of lower cost feedstocks) and in the creation of a supporting policy framework.

**Figure 31. Main hurdles for bio-surfactants**




Source: Online survey for the participants of the bio-surfactant workshop

Recommended market related actions include

- Demonstration of safety, environmental benefits and added value (e.g. superior properties) of bio-surfactants compared to conventional surfactants
    - Marketing efforts by companies can be supported by appropriate labels, customer awareness (general public education) and rules for public procurement
- Better characterisation of individual bio-surfactants and promotion of cooperation with bio-surfactant developers, producers and end users in order to optimise surfactant performance in a product formula and to match bio-surfactant properties and end use needs
- Information dissemination: Information campaigns are needed to promote bio-based products, to provide facts about GMM and their use in bio-surfactant production and to open the discussion with NGOs and public authorities. After all, the performance of bio-surfactants can only be improved through GMM.
- Finalisation of the standard definition of bio-surfactants by CEN TC 276. The definition will include and require that several criteria be met i.e.:
    - Type of feedstock used
    - Properties of the surfactants (e.g. with regard to aquatic environment, etc.)
    - LCA elements with the cradle to grave approach

  Following the publication of CEN TC 276 definitions, there may also be a need for efforts to harmonize definitions on a global level.

# 9 $CO_2$ as feedstock

## 9.1 Background

$CO_2$ is a well-known greenhouse gas (GHG), but less known as a carbon source for industrial biotechnology or for its use as a feedstock for fuels, chemicals and polymers. It is mainly produced by the combustion of organic materials (fossil or biogenic), by fermentation processes and by respiration. It is also emitted to the atmosphere from volcanoes, hot springs and geysers. $CO_2$ conversion technologies to fuels, chemicals and polymers have been gaining momentum in the past few years because carbon dioxide is an abundant source of carbon. Moreover, using $CO_2$ emissions as a raw material could help in boosting a low carbon society.

In the last decade Carbon Capture and Storage (CCS) technology has been brought to the public's attention as a way to handle $CO_2$ emissions. CCS involves capturing $CO_2$ produced by large industrial plants, compressing it for transportation and then injecting it deep into a rock formation at a carefully selected and safe site, where it is permanently stored. CCS is a commercial technology in several regions of the world, and interest in it is growing, although it often faces resistance both among local inhabitants and power companies. In the former case, the resistance stems from fears that the injected $CO_2$ could trigger small earthquakes or other environmental disasters. In the latter case, the resistance arises from the fear of higher production costs for electricity due to carbon capture.

To overcome such resistances, the use of sequestered $CO_2$ as a feedstock for industrial processing is becoming a focal point. If a value could be added to the $CO_2$ at a certain point of the value chain, the rise in electricity cost could be partially recovered. In the concept called Carbon Capture and Utilisation (CCU), $CO_2$ is considered to be a commodity rather than a pollutant[7].

The largest CCU example in terms of tonnage is the direct use of $CO_2$ in the Enhanced Oil Recovery (EOR). In this technology, the $CO_2$ captured from different industrial uses (coal fired power plants, ammonia or cement production, etc.) is pumped in exhausted oil fields where it helps in recovering oil that is still trapped in the field, due to the solvent-like properties of $CO_2$ and the pressure in which is pumped in the field. Other direct uses of $CO_2$ involve the production of carbonated drinks and use as inert gas in packaging, as a fire extinguisher and as a cooling fluid e.g. for fridges. Carbon dioxide is also used since decades as a feedstock for the production of e.g. urea, methanol and in the synthesis of acetylsalicylic acid (aspirin) via catalytic processes.

Figure 32 illustrates the opportunities of $CO_2$ as a raw material for the production of chemicals and plastics. This BIO-TIC roadmap focuses on $CO_2$ as feedstock for industrial biotechnology processes, including

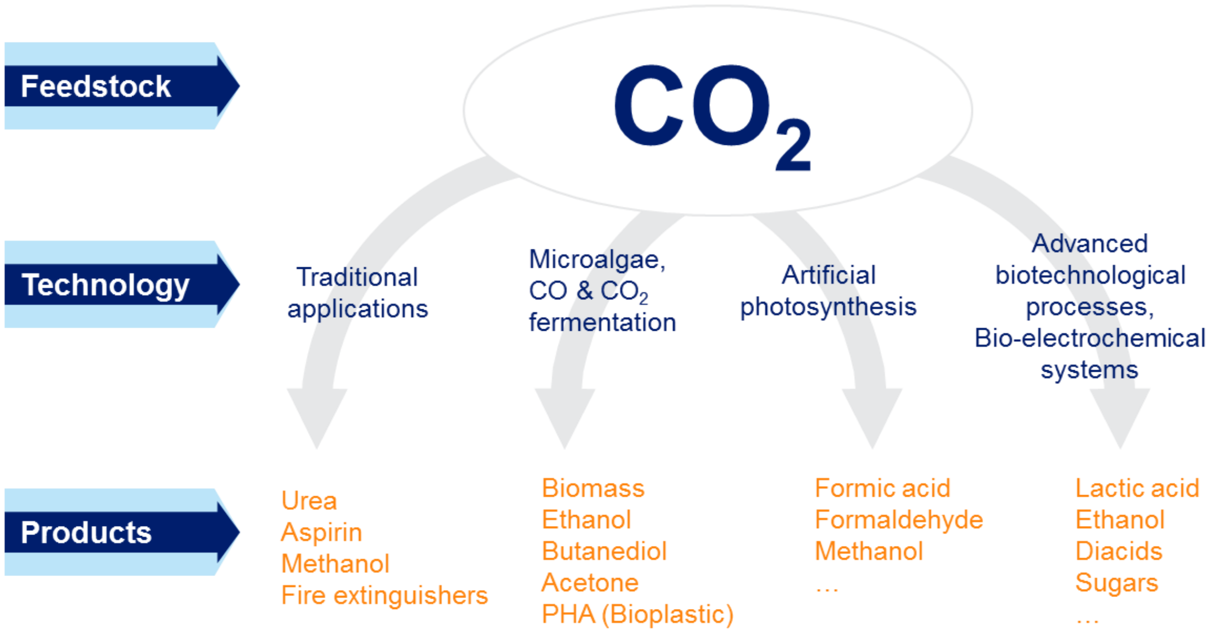
1) **Microalgae technologies**, where microalgae produce biomass from $CO_2$ and sunlight,
2) **$CO_2$ and CO fermentation**, where $CO_2$ is fermented to a desired molecule using hydrogen as an energy carrier,

[7] Worldwide innovations in the development of carbon capture technologies and the utilization of $CO_2$; *Energy Environ. Sci.*, 2012,5, 7281-7305

3) **Artificial photosynthesis**, where $CO_2$ is converted to desired chemicals with a (bio)catalyst using photocatalytic water splitting as an energy source,
4) **Advanced biotechnological processes,** where the abilities of cyanobacteria to use $CO_2$ as a carbon source and sunlight for energy are merged with the metabolic pathways of known micro-organisms,
5) **Bio-electrochemical systems**, where enzymes or micro-organisms use $CO_2$ as a carbon source and electricity as an energy source for their synthesis

(for more information on these technologies and processes, see Annex IV).

Figure 32. Opportunities of $CO_2$ as a raw material for the production of chemicals and plastics

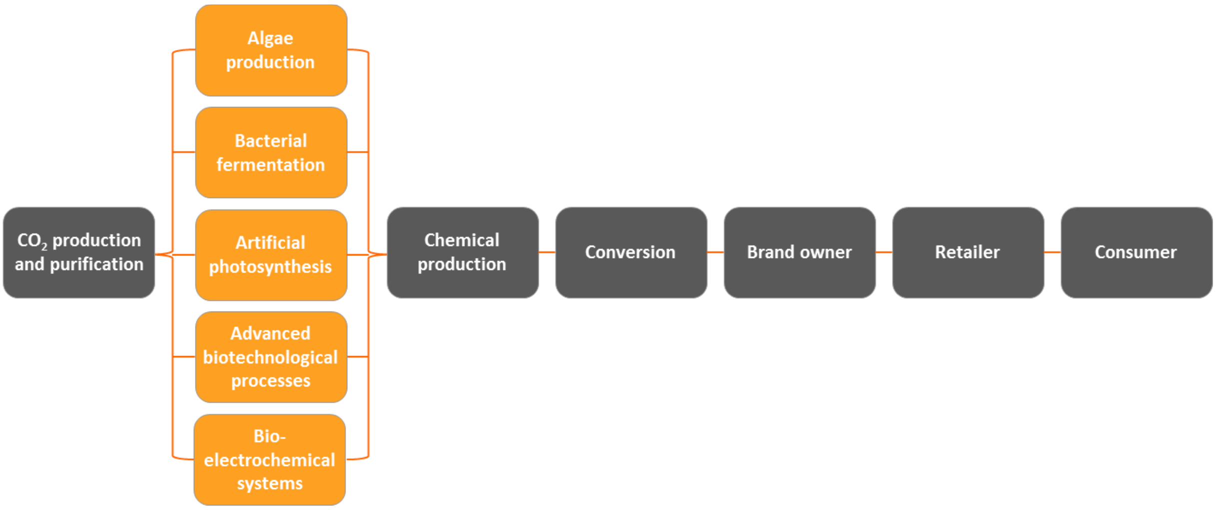



## 9.2 State of the art

Currently, the use of carbon dioxide as a feedstock for industrial biotechnology is at its infancy. There are numerous research initiatives but no commercial scale production. Globally, the U.S. is leading in pilot and demonstration scale activities. However, contrary to other IB processes, in $CO_2$ the EU is not disadvantaged by the availability of feedstock but could benefit from existing infrastructure for carbon dioxide capture and know-how in renewable energy.

The carbon dioxide value chain starts with carbon capture and purification, continues to an industrial biotechnology process that uses $CO_2$ together with an energy source like hydrogen as a feedstock, and to chemical or chemical intermediate production, which is then fed to the conventional chemical value chain consisting of a converter, a brand owner and a retailer (Figure 33).

**Figure 33. The value chain for $CO_2$ as a feedstock**




$CO_2$ can be used as a raw material after it is captured, purified and compressed in a store tank/bottle. There are two main approaches for capturing and purifying $CO_2$ for the use as a feedstock: Post Combustion Capture (PCC) and Direct Air Capture (DAC). PCC is the most widely used technology which mainly involves ammonia-based chemicals that are able to selectively react with $CO_2$ in the flue gases and release the $CO_2$ when regenerated by heating. As per the name, DAC refers to direct capture of $CO_2$ from the atmosphere and the first technologies are currently under investigation[8].

As described above, carbon dioxide can be used as a feedstock for industrial biotechnology processes in five main ways: through algae production, bacterial fermentation, artificial photosynthesis, bio-electrochemical systems, and advanced biotechnological processes. All of these routes are in an early stage of development, although successful bacterial fermentation of $CO_2$/synthesis gas has recently been reported outside Europe by LanzaTech, IneosBio, Coskata and OPXBIO. The downstream steps in the value chain as such do not yet exist but most of the technology developers are aiming at drop-in chemicals that have established value chains.

The key challenge in $CO_2$ utilisation is that carbon dioxide is an inert, stable compound which requires high activation energy for chemical reactions to occur (Figure 34). In the industrial biotechnology processes the required energy for $CO_2$ conversion is obtained either from hydrogen, sunlight or electricity. Moreover, low $CO_2$ concentrations, impurities in the gas stream and the high energy cost associated with the $CO_2$ capture lead to a high preparation cost of the $CO_2$ feedstock.

[8] MacDowell, N., Florin, N., Buchard, A., Hallett, J., Galindo, A., Jackson, G., Adjiman, C.S., Williams, C.K., Shah, N. and Fennell, P., 2010, An overview of CO2 capture technologies, *Energy & Environmental Science*, 3: 1645-1669.
Direct Air Capture of $CO_2$ with chemicals, American Physical Society, 2011

**Figure 34. Key factors hindering market growth according to BIO-TIC workshop participants (n=22)**

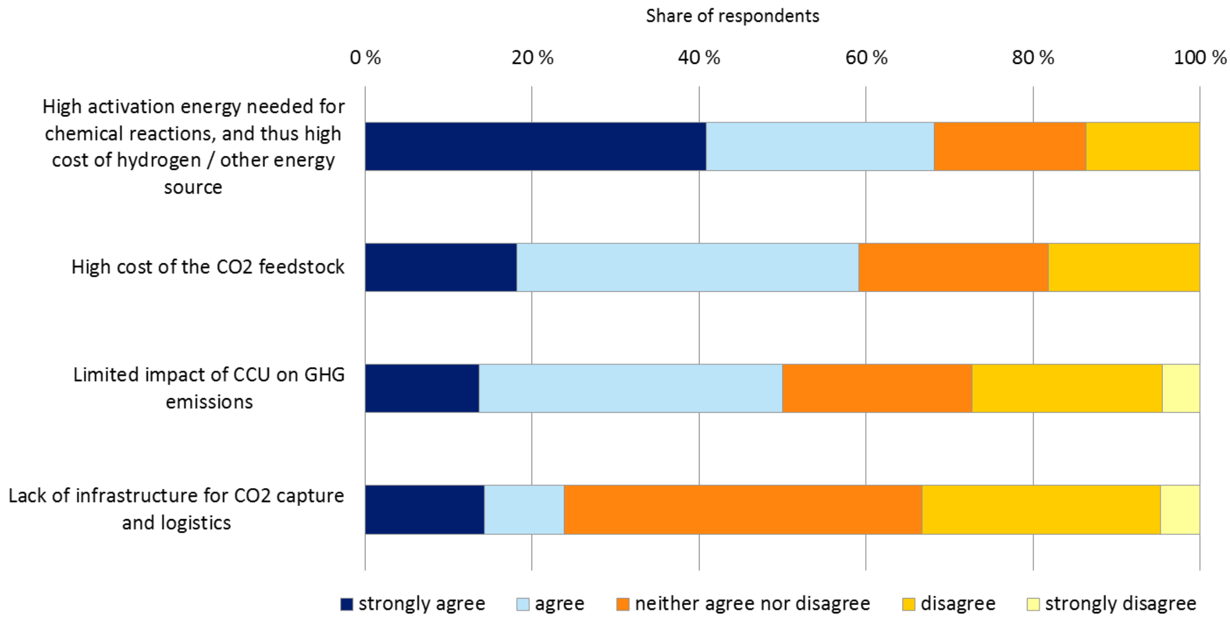



Table 1 summarises the estimated current and future costs for various $CO_2$ capture techniques. The current cost for capture is still far above the price of $CO_2$ in the EU Emission Trading System (EU ETS).

**Table 1. Costs for $CO_2$ capture techniques and a comparison to $CO_2$ price in the EU ETS**

| | Current cost [EUR/t] | Target cost in 2030 [EUR/t] | Comments |
|---|---|---|---|
| **Post Combustion Capture (PCC)** | 100-200 | 15-50 | The price evolution is driven by the technological development and by the thermodynamic limit of the process. The cost of PCC is likely to decrease significantly from today to 2030. |
| **Direct Air Capture (DAC)** | 800-1000 | ~300 | The price is driven by the extreme dilution of $CO_2$ in the atmosphere. The above mentioned consideration for PCC applies also to DAC. |
| **EU ETS** | 3-30 | 20-75 | The price of $CO_2$ in EU ETS has fluctuated greatly since the beginning of the system. The target range for 2030 is based on the same IEA scenarios used for oil price development throughout this market roadmap. |

Sources: Direct Air Capture of $CO_2$ with chemicals, American Physical Society, 2011; IEA World Energy Outlook 2013; Expert interviews

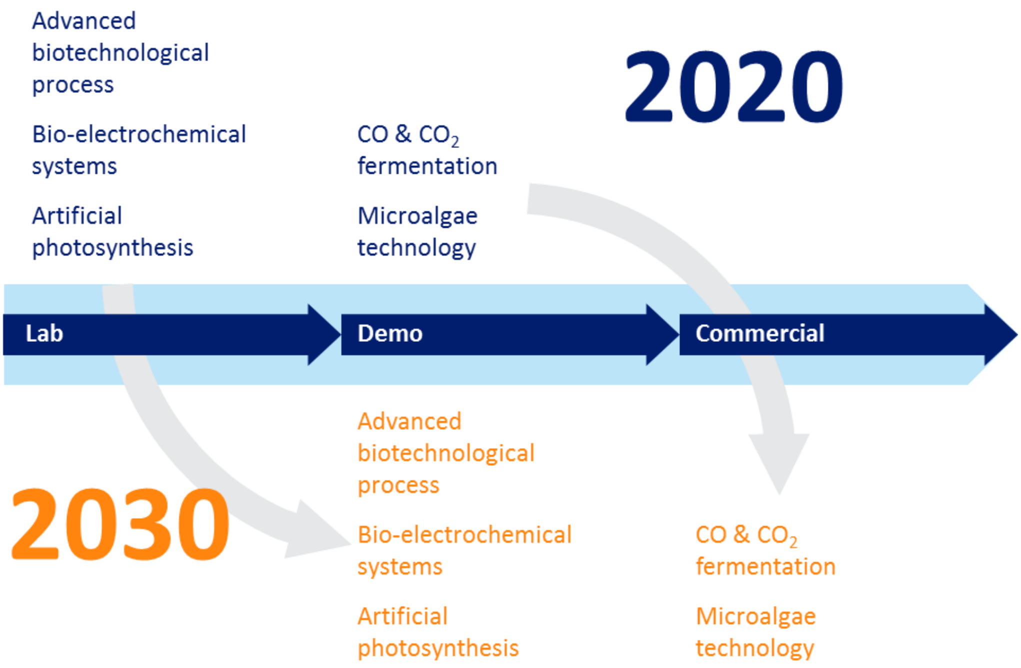
## 9.3 Market vision for 2030

In 2030, carbon dioxide offers opportunities for new cost competitive chemical processes and applications, allowing some complex chemical production chains to be reduced to one or two step microbiological conversions and opening windows for completely new chemical compounds.

Moreover, Europe has succeeded in integrating $CO_2$ bioconversion into existing energy and chemical infrastructures making green energy available for $CO_2$ technologies and allowing the transformation of energy at peak load periods into chemicals and fuels. At the same time, competitive renewable energy prices have attracted leading $CO_2$ technology developers to set up commercial facilities in Europe thus making Europe a forerunner in this industry.

Bacterial fermentation and microalgae technologies are expected to be ready for commercial production by 2030. Realisation of industrial scale facilities will depend strongly on the cost of $CO_2$ capture, on the future political climate, and on the development of energy prices and hydrogen in particular. Advanced biotechnological processes, bio-electrochemical systems and artificial photosynthesis technologies are forecast to develop significantly from today to 2030 reaching demonstration scale production. A key challenge related to all $CO_2$ based IB process development is the success of scale-up, both from laboratory to demonstration and from demo to commercial capacity (Figure 35).

**Figure 35. Expected development of IB processes using $CO_2$ as feedstock**




**Microalgae technologies** continue to be developed for multiple end-uses, although the economic feasibility of algae production for commodity fuels and chemicals in 2030 remains questionable. It is more likely that in 2030, a majority of the microalgae technologies will be focused on high value specialties and polymers. Key challenges related to algae technologies are the efficiency of cultivation systems and product recovery.

**Bacterial CO and $CO_2$ fermentation** development began with simple molecules such as acetic acid and ethanol. Thanks to great advancements in genetic modification of microorganisms, by 2030 bacterial fermentation of carbon dioxide will be able to produce a large variety of chemical compounds. However, $CO_2$ fermentation is strongly intertwined with the availability of clean low-cost hydrogen and is less efficient than syngas fermentation based on CO. Local availability and cost of hydrogen will determine whether bacterial fermentation of $CO_2$ will reach commercial production by

2030 and which products the technology is aimed at. In 2030, bacterial $CO_2$ is likely to be a cost competitive technology in locations where both carbon dioxide and hydrogen are available at low cost and with little impurities.

**Artificial photosynthesis** is unlikely to reach large scale production by 2030 because of the high cost of solar power. Although a prototype of artificial photosynthesis equipment producing formic acid from a catalytic system has already been introduced in 2013 by Panasonic, there is a lot of research required to make this technology industrially viable. In 2030, artificial photosynthesis will continue to be an interesting research topic with operating pilot facilities because it offers opportunities for decentralised chemical production from water, sunlight and $CO_2$. The research focus in 2030 will be in advanced artificial photosynthesis systems such as the artificial leaf or biohybrid systems[9].

**Advanced biotechnological processes** refer to processes where the ability of cyanobacteria to use $CO_2$ as carbon and sunlight as energy source is merged with the metabolic pathways of known micro-organisms. The aim is to use $CO_2$ as a direct substitute to sugars that are used in conventional fermentation. Advanced biotechnological processes are expected to develop strongly through to 2030 enabling the production of similar compounds to $CO_2$ and CO fermentation. However, this technology will still be in research in 2030. One of the key challenges in advanced biotechnological processes is the design of bioreactors[10].

**Bio-electrochemical systems** refer to processes where $CO_2$ is converted to chemicals by enzymes or microorganisms and the required energy comes from electricity transported via suitable "mediator" (usually a molecule that can be brought to a higher energy state via electrochemistry) instead of hydrogen or sunlight. Bio-electrochemical systems are forecast to be in pilot demonstration in 2030. In addition to providing a new pathway to a great number of compounds [11], bio-electrochemical systems offer a possibility to store renewable electricity in chemical form.

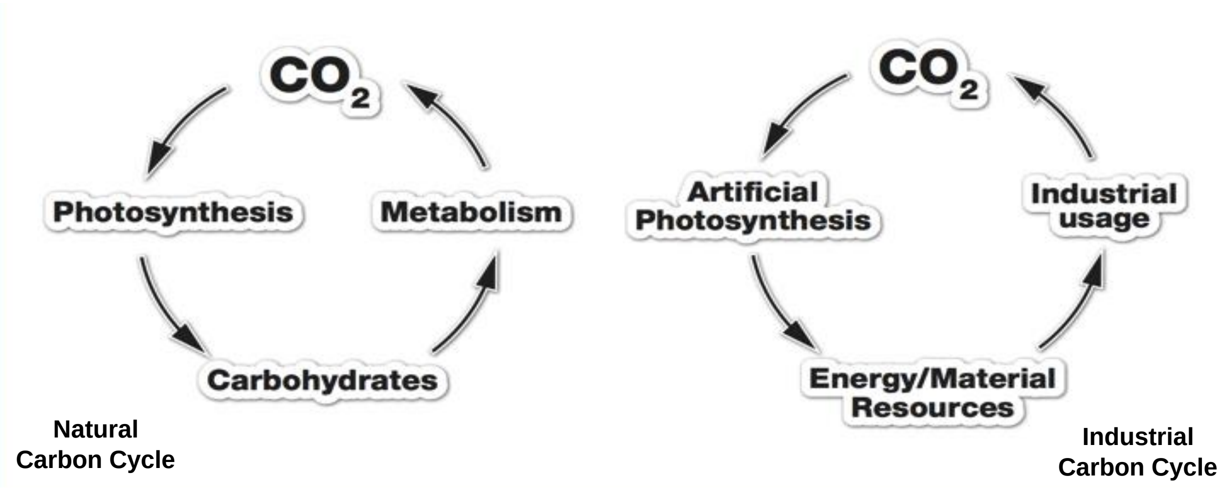
Beyond 2030, the use $CO_2$ as a feedstock could contribute to promoting the concept of "$CO_2$ economy" (Figure 36). In this vision, the industrial CCU cycle (on the right), with the use of recycled $CO_2$ as an abundant carbon source and renewable energy to upgrade it to various chemicals and materials, mimics the natural carbon cycle (on the left).

[9] Bensaid S, Centi G, Garrone E, Perathoner S, Saracco G. Towards artificial leaves for solar hydrogen and fuels from carbon dioxide. ChemSusChem. 2012 Mar 12;5(3):500-21

[10] Angermayr SA, Hellingwerf KJ. On the use of metabolic control analysis in the optimization of cyanobacterial biosolar cell factories. J Phys Chem B. 2013 Sep 26;117(38):11169-75.

[11] Nevin, K. P., T. L. Woodard, A. E. Franks, Z. M. Summers, and D. R. Lovley. 2010. Microbial electrosynthesis: feeding microbes electricity to convert carbon dioxide and water to multicarbon extracellular organic compounds. mBio 1(2):e00103-10.

**Figure 36. Natural carbon cycle and industrial carbon cycle ($CO_2$ economy). (Source: Nova-Institute)**




## 9.4 Recommendations for action

From the market development point of view, a prerequisite for business activity is the availability of

- renewable energy at a competitive price,
- low-cost $CO_2$ at site, and
- low-cost $CO_2$ purification technologies or bioconversion processes that can utilise dilute and impure $CO_2$.

Moreover, improved market communication is needed in order to stimulate market entry and adoption of $CO_2$ based products.

The solutions could include

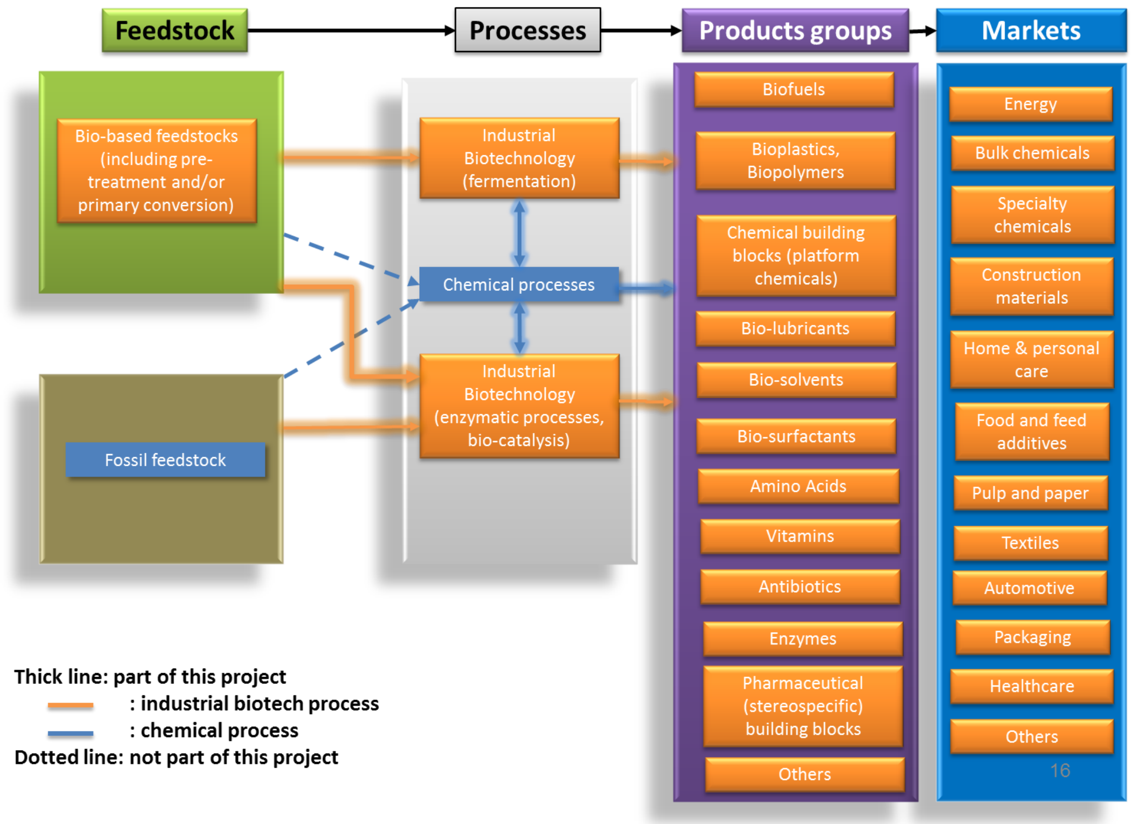
- leveraging existing European know-how in renewable energy,
- joint technology development by $CO_2$ emitters, $CO_2$ converters, renewable energy producers and conventional chemical companies,
- development of international standards for assessing the carbon footprint of $CO_2$ based products, and
- raising awareness of the GHG footprint of $CO_2$ based products compared to petrochemical based products.

## Annex I Choice of business cases

The scope of the BIO-TIC-project is the industrial biotechnology (IB) value chain (Figure 37). While BIO-TIC aims to develop roadmaps with a scope that covers the wider IB market and value chains, it takes a focused approach in analysing the main hurdles, enablers and required actions towards realising IB's potential for Europe. It has been decided to focus the analyses on a limited number of five complementary "business cases for Europe", each of which represent different products and application areas, such that they enable the project partners to discover the widest possible hurdles and enablers that are relevant for the European IB market.

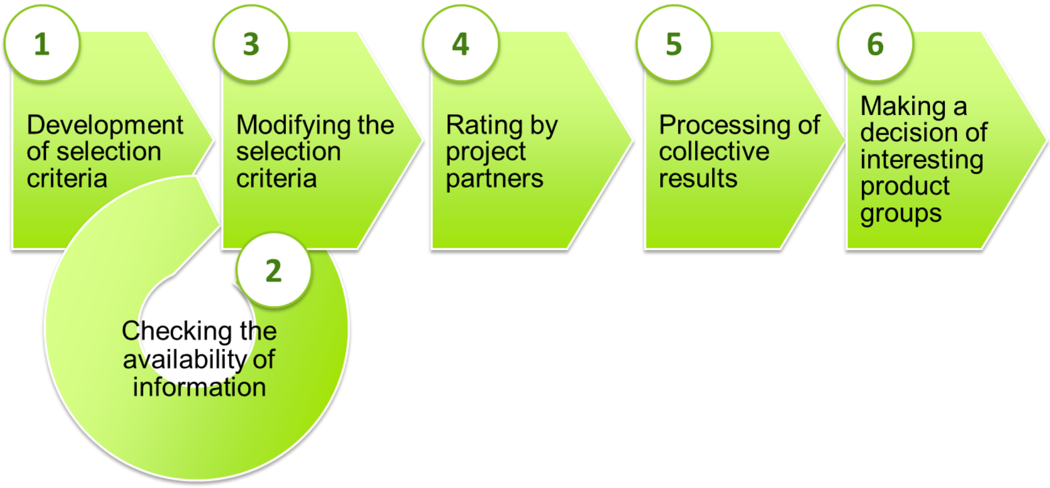
The 5 *business cases* represent product groups that can make a major contribution to an accelerated take-up of industrial biotechnology into the market place. The selection process and criteria are explained below.

**Figure 37. The industrial biotechnology value chain**




The business cases for the roadmaps were selected based on a product group-specific rating carried out by an expert panel comprised of BIO-TIC partners and validated by the Project Coordination Committee and the Advisory Committee of the project. The process included (1) Development of selection criteria, (2) Checking the availability of product group and criteria -specific information with the project partners, (3) Making modifications to the list of criteria on the basis of observed information gaps, (4) Collection of partners' ratings, and (5) Processing of collective results. Finally (6), a decision was made on the most interesting product groups by the Project Coordination Committee and the Advisory Committee of BIO-TIC (Figure 38).

**Figure 38. The selection process**




In accordance with the aim to identify business sectors that can contribute to the take-up of IB, the selection criteria focused on the potential of IB and on the future market value of the product groups. However, other criteria were considered, too. In fact, the selection criteria represented a continuum from identified societal/consumer needs to market solutions that respond to these needs, to enabling technologies that facilitate these market solutions, and to resources that are needed to support these technologies (Figure 39).

**Figure 39. The selection criteria**

| Category | Criterion | Indicator |
|---|---|---|
| Societal / Consumer needs | Environmental impacts | • Savings in GHG emissions |
| | | • Improvement in resource efficiency |
| | Societal impacts | • Value added in the EU |
| | | • Need for incentives |
| | | • Political/ethical disputes |
| | | • Effects on employment |
| Market solutions | Critical mass | • Predicted IB/bio-based market growth in the EU in 2010-2030 |
| Enabling technologies | Potential for breakthrough | • Potential of IB to change the market through innovation in the next 10 years |
| Resources needs | Access to biomass | • Availability of biomass in the EU |
| | EU competitiveness | • EU competitive advantage |

Based on the rating of BIO-TIC project partners, the short list of most promising product groups in order of ranking were:

1. Bio-based polymers and plastics
2. Chemical building blocks (platform chemicals)
3. Biofuels
4. Enzymes
5. Pharmaceutical (stereospecific) building blocks
6. Biosolvents
7. Biosurfactants

In discussion with the Project Coordination Committee and the Advisory Committee, minor modifications and correctives were made:

- Biofuels were further narrowed down to bioethanol (primarily as a test case to illustrate the effect of subsidies and regulations on markets) and bio-based jet fuels (which have great potential future impact).
- Enzymes were determined to be cross cutting, and should be considered as part of all the 5 selected business cases rather than a business case as such.
- Pharmaceuticals were disregarded due to the extensive role of regulation in this industry.
- Biosurfactants were chosen instead of biosolvents because the latter would be partly tackled in the context of chemical building blocks.
- A new category of $CO_2$ for biotechnology (CCU = Carbon Capture and Utilization) was tabled, as it could have a huge impact on the industry, lead to diversification away from biomass as a feedstock, and impact on the society and the environment. The dogma of a need of biomass for non-fossil liquid fuels or chemicals is not any longer true with CCU technologies.

The final list of business cases, as agreed and validated by the Advisory Committee, is comprised of 4 business cases that are from bio-based origin:

1. Advanced biofuels: bioethanol and bio-based jet fuels
2. Biochemical building blocks[12]
3. Bio-based plastics
4. 2G bio-surfactants

In addition, one business case is based on a fossil raw material (with IB processes):

5. $CO_2$ as a feedstock: Using IB as tool for reducing $CO_2$ generated from processes using fossil or bio-based raw materials (Carbon Capture and Utilization).

[12] A decision was made to have a closer look at 5 platform chemicals and these were later defined as Succinic acid; Isoprene; 3-hydroxypropionic acid (3-HPA); 1,3-propanediol (1,3-PDO); and Furfural.

# Annex II Market projections

## Data sources

The basis for BIO-TIC market projections are the recently published market reports listed in **Table 2**. They provide information on the current market situation, market drivers as well as short-term projections for products produced via industrial biotech processes. The literature data was then complemented by results of 13 stakeholder workshops organised across Europe in 2013-14 and 70 expert interviews conducted during the project.

**Table 2. Main data sources for market information**

| Report Title | Source |
|---|---|
| Amino Acids – A Global Strategic Business Report | Global Industry Analysts (2012) |
| Antibiotics Market in Europe to 2016 | Global Research & Data Services (2012) |
| Biolubricants Market: Global Industry Size, Market Share, Trends, Analysis and Forecast, 2012 – 2018 | Transparency Market Research (2012) |
| Biosurfactants Market: Global Scenario, Raw Material and Consumption Trends, Industry Analysis, Size, Share and Forecasts, 2011 - 2018 | Transparency Market Research (2012) |
| Global Industrial Enzymes Market Report | Koncept Analytics (2012) |
| International trade statistics | Eurostat (2013) |
| OECD-FAO Agricultural Outlook 2012-2021 | OECD & FAO (2012) |
| PRODCOM statistics | Eurostat (2013) |
| Renewables Information 2012 | International Energy Agency (2012) |
| Renewable Chemicals - A Global Strategic Business Report | Global Industry Analysts (2011) |
| Solvents - A Global Strategic Business Report | Global Industry Analysts (2010) |
| Vitamins - A Global Strategic Business Report | Global Industry Analysts (2011) |
| World Bioplastics to 2015 | Freedonia (2011) |
| World Bioplastics | Freedonia (2013) |

## Model specifications

Remaining gaps until 2030 were filled by modelling. In majority of the studied business cases, a multi-variable linear regression was employed. The impact of various market drivers (e.g. GDP, population growth, oil price, biomass prices and environmental or technology-related time trends) on the historical market development of bio-based products was studied, and the future market value forecast was based on observed market vs. driver relationships.

In the case of bio-based plastics, bioethanol and bio jet fuels, a different approach was applied. Based on discussions with sector experts, it was decided to model bio-based plastics market utilising conservative ends of earlier growth estimates, 2G bioethanol market based on the projected total fuel consumption in road transport and an assumed 2G share/mandate, and jet biofuel market based on the energy demand in aviation and an assumed bio-blend percentage.

The data on the market drivers and prices are either publicly available or derivable from such data. The main data sources include

- GDP development: OECD Economic Outlook (2013) (**Figure 40**)
- Population growth: Eurostat EUROPOP2010 (2013) (**Figure 41**)
- Oil price development: IEA World Energy Outlook (2013) (**Figure 42**)
- Energy demand in road transport: EU Energy, Transport and GHG Emissions Trends to 2050 (2013) (**Figure 43**)
- Biomass prices: OECD-FAO Agricultural Outlook 2012-2021 (2012)

For each product group, several possible model specifications were tested, utilising original and translog data and various combinations of variables. When testing the model specifications, attention was paid to

- the "right" sign of coefficients (the growth in e.g. GDP should result in positive market development)
- that the coefficients of factors are statistically significant
- that the specifications fulfil statistical mis-specification tests

Finally, the best specification that fulfilled these criteria was selected and results were validated in workshops and expert interviews. Indicators selected for each product group are listed below (**Table 3**).

**Table 3. Selected indicators per product group**

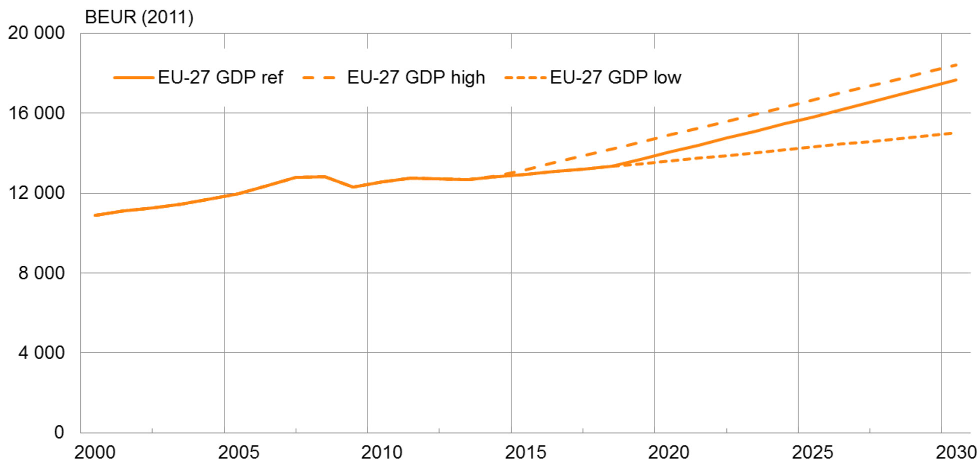
| | GDP | Pop. growth | Feed-stock price* | Oil price | Time trend | Bio-energy demand | Chem. demand | Transport energy demand | Regu-lations | Stake-holder input |
|---|---|---|---|---|---|---|---|---|---|---|
| 2G ethanol | | | | | | | | x | x | x |
| Aviation biofuels | | | | | | | | x | (x) | x |
| Biogas | | | | | | x | | | | |
| CBB | x | (x) | (x) | (x) | (x) | | (x) | | | x |
| Bioplastics | (x) | (x) | (x) | (x) | (x) | | | | | x |
| Biolubricants | x | (x) | (x) | (x) | (x) | | | | | |
| Biosolvents | x | (x) | (x) | (x) | (x) | | | | | |
| Biosurfactants | x | (x) | x | x | (x) | | | | | x |
| Amino acids | (x) | x | (x) | (x) | (x) | | | | | |
| Vitamins | (x) | x | (x) | (x) | (x) | | | | | |
| Antibiotics | (x) | x | (x) | (x) | x | | | | | |
| Enzymes | (x) | x | (x) | (x) | (x) | | | | | |

*x = indicator used for final projection, (x) = indicator tested for modelling, *sugar, starch, vegetable oil*

Altogether three market scenarios for 2030 were created, namely reference, high and low case scenarios, utilising scenarios for e.g. GDP growth, oil price development and transport energy consumption.

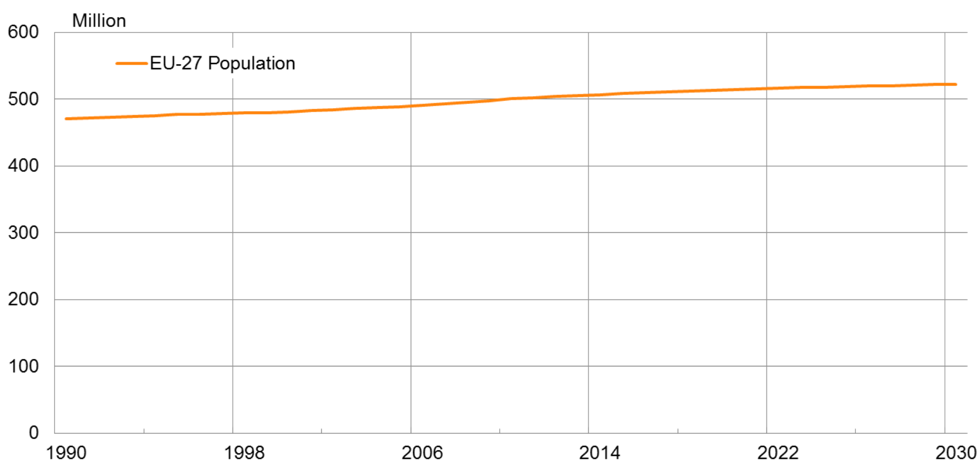
- After comparing the OECD GDP projection with the short term forecasts of DG ECFIN, it was decided to name the OECD projection as a high case scenario and apply a lower growth rate (1.0%) for the low case scenario. In the reference scenario, the OECD growth projection is applied after 2018, but the lower growth rate between 2014 and 2018 (**Figure 40**)
- The scenarios for oil price development were derived from IEA (**Figure 42**) and those for transport energy consumption from the European Commission (**Figure 43**)

**Figure 40. GDP projection for the EU as defined by OECD (high case scenario) and by Pöyry (reference and low case scenarios)**



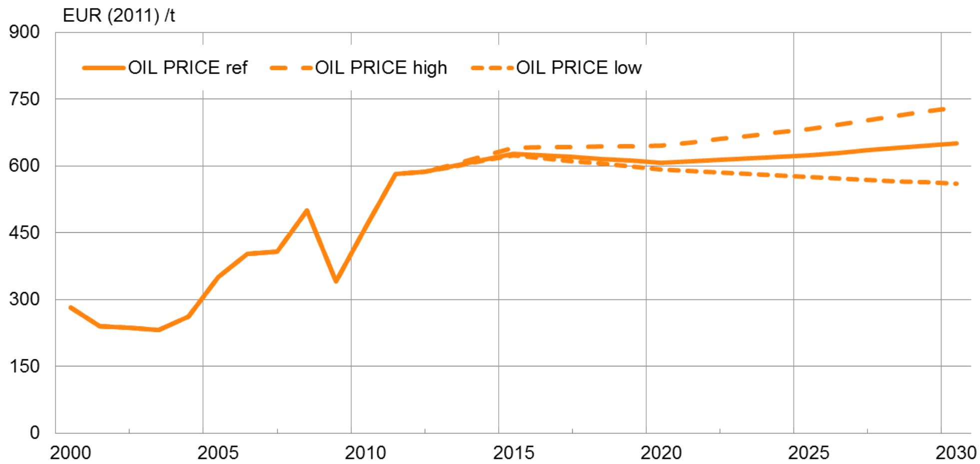

Source: OECD Economic Outlook No 93 - June 2013, Pöyry

**Figure 41. Population projection for the EU as defined by Eurostat**



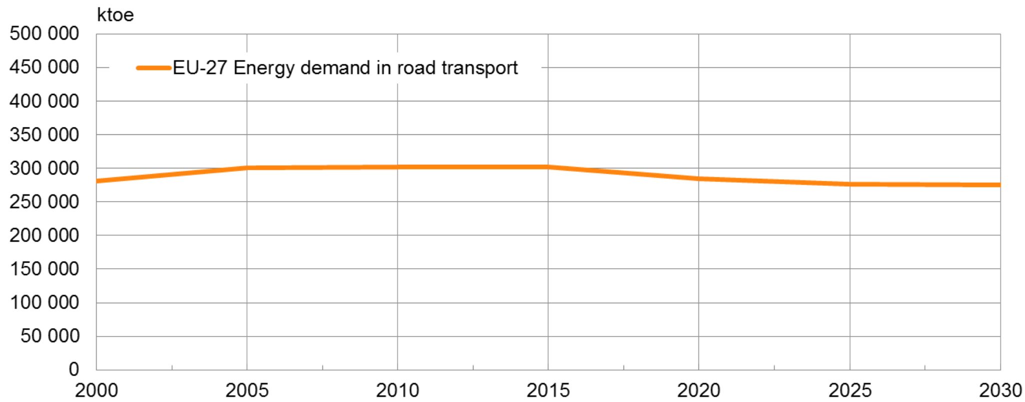

Source: EUROPOP 2010

**Figure 42. Oil price scenarios for the EU as defined by IEA**




Source: IEA World Energy Outlook 2013

**Figure 43. Scenario for road transport energy consumption as defined by the European Commission**



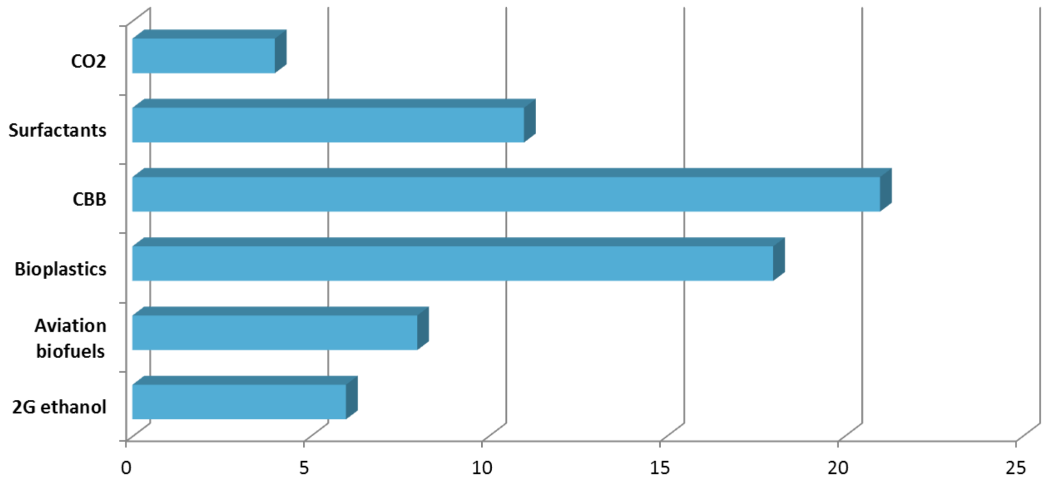

Source: EU Energy, Transport and GHG Emissions Trends to 2050 (2013)

# Annex III Stakeholder inputs

## Expert interviews

Altogether 70 expert interviews were conducted during the course of the project both to gather background information for market projections and to validate the findings. Interviewed experts included among others representatives of industrial associations, managers of the leading European chemical companies, biotechnology entrepreneurs, university professors, and top-rated researchers from independent research organisations. Majority of the interviews were related to either chemical building blocks (21) or bio-based plastics (18) but all selected business cases were well represented (Figure 44).

**Figure 44. Expert interviews by business case**

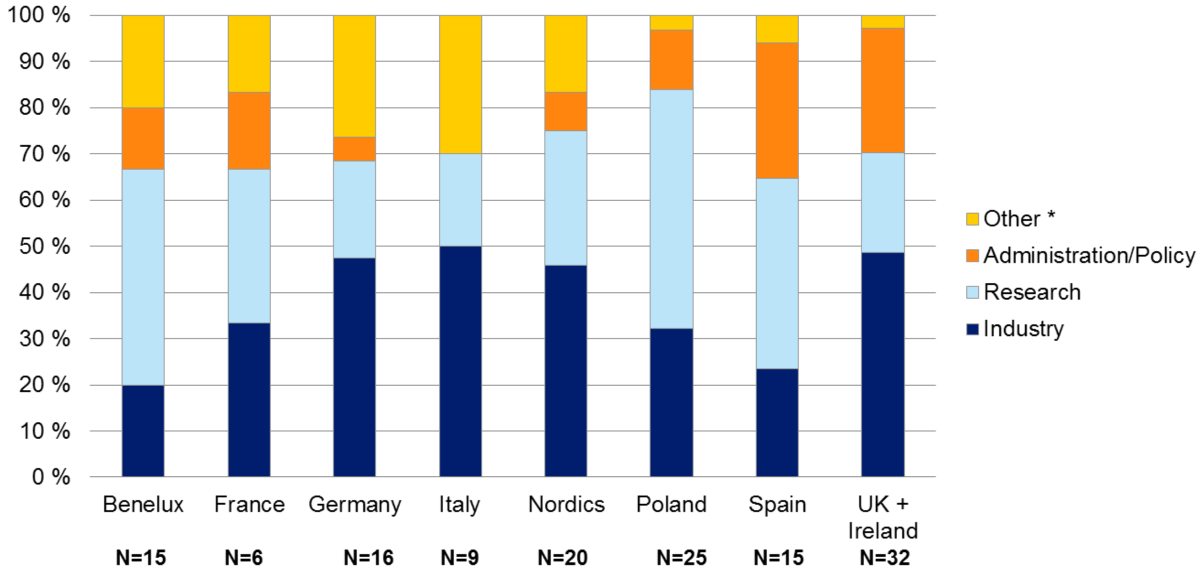



*Note: Some companies have been interviewed on several value chains, and are therefore present in more than one column.*

## Stakeholder workshops

Initial market projections and roadmap findings were validated in eight regional workshops across Europe. The workshops were held in the Netherlands, Poland, Spain, Finland, Italy, UK, Germany, and France between June 2013 and February 2014. These regional workshops brought together over 140 participants with a good balance of industrial, research, and administrative/policy-making representatives (Figure 45).

**Figure 45. Regional workshop participants**

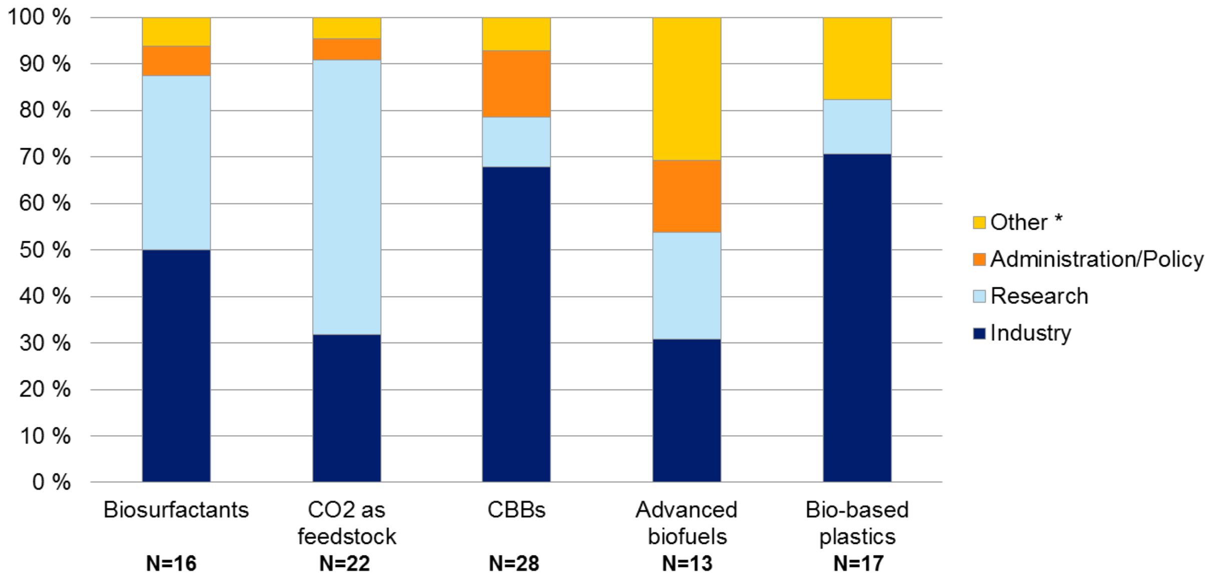



* Stakeholder group "Other" mainly includes representatives of regional development agencies, tech transfer offices, networking organisations and consultancies

Note: The number of participants refers to respondents to the market survey. 1

Moreover, in 2014 five business case workshops were organised and the draft market roadmaps were discussed and amended by another 100 participants (Figure 46).

**Figure 46. Business case workshop participants**




* Stakeholder group "Other" includes representatives of investors, consultancies, tech transfer offices, industrial areas, scientific societies, public research funders and start-ups

Note: The number of participants refers to respondents to the market survey. 2

# Annex IV Introduction to $CO_2$ technologies

**Microalgae technologies**

The microalgae technology is based on providing $CO_2$ and light to microalgae that can utilize these sources to grow. From the produced algal biomass molecules, such as lipids or carbohydrates, may be extracted or the biomass may be processed into biogas. In order to improve process economics genetic modification of the algae may be done to obtain carbohydrates and lipid of higher value.

This technology provides an opportunity to produce biomass without using land to grow it on. It also captures some flue gas emissions and thus contributes to GHG reduction targets. However, the technology also faces challenges, the main one being designing of reactors and ponds to obtain the best yields and minimize the energy required (in terms of illumination and stirring).

An example of a company utilizing microalgae is Pond Biofuels, who uses raw flue gas from cement production to produce a bio-crude similar to biodiesel.

**Bacterial CO and $CO_2$ fermentation**

In bacterial CO and $CO_2$ fermentation acetogenic bacteria, such as different Clostridia species, are used to produce chemicals from $CO_2$ and $H_2$. The production process is carried out in bioreactors to which $CO_2$ (carbon source) and $H_2$ (energy source) gases are fed. In order to improve yields of desired compounds the bacteria may be genetically modified.

In comparison to microalgae technologies the cultivation media of bacterial $CO_2$ fermentation is more expensive due to high hydrogen costs. However, the process does not require light, reducing complexity of the bioreactor.

Examples of companies active in this field are Lanzatech, who can produce e.g. ethanol and butanediol from steel mill flue gases, OakBio who can produce bioplastics through bacterial $CO_2$ fermentation and Newlight technologies who has a patented fermentation process by which polyhydroxyalkanoates (PHA) are produced from methane or a mixture of $CO_2$ and $H_2$. Other companies like Evonik Industries, BASF, IneosBio or Coskata are working on topics of CO and $CO_2$ fermentation to products like ethanol, PHB or even acrylic acid.

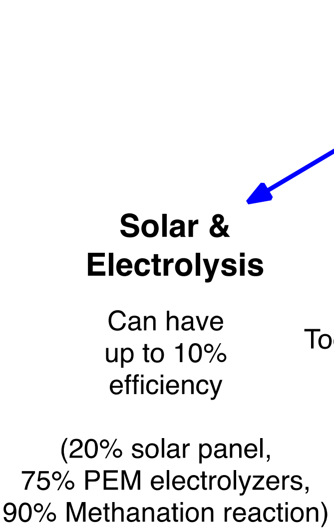
**Artificial photosynthesis**

Artificial photosynthesis (AP) is an emerging technology that aims at mimicking plants' use of sole $CO_2$ and sunlight to produce chemicals. The reactions that are involved in AP can be divided in two steps: 1) water splitting with direct sunlight to obtain $H_2$ or electrons and 2) reaction of $CO_2$ with the produced $H_2$ or electrons to produce a desired chemical. The main challenge with the technology is the cost of obtaining $H_2$ in the first production step.

Although this technology is at its infancy and mainly being developed by academia and research organizations, there are some companies working in this field. Noteworthy is the Panasonic

Corporation that has introduced a working prototype that can use $CO_2$ and hydrogen to produce formic acid via a catalytic reaction that occurs under sunlight[13].

**Figure 47. Comparison of the efficiency of different natural and artificial photosynthetic systems (source: nova-Institute, $CO_2$ as feedstock for chemistry and polymers, Essen, 2013)**




**Advanced biotechnological processes**

In advanced biotechnological processes photosynthetic bacteria (purple bacteria) are genetically modified to produce specific molecules. Using synthetic biology and metabolic engineering bacteria can be modified to require only $CO_2$ and light for their metabolism. An example of a company active in the field of advanced biotechnological processes is Photanol, who is able to produce lactic acid the technology.

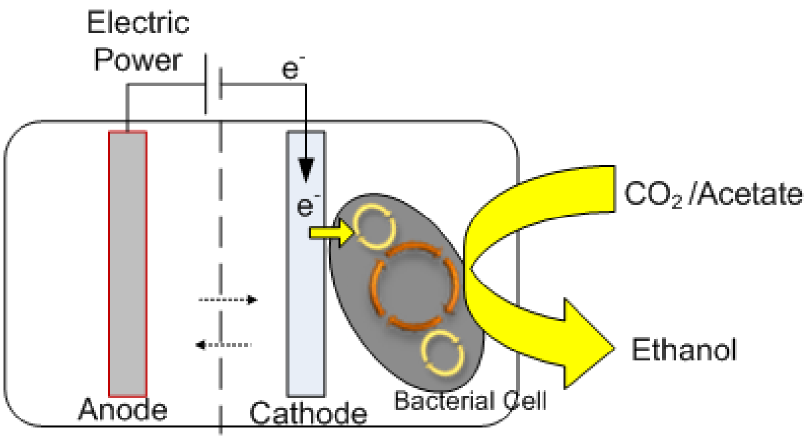
**Bio-electrochemical systems for the conversion of CO2**

In bio-electrochemical systems microorganisms or single purified enzymes in immobilized systems utilize $CO_2$ and electrons (obtained from electrodes) to produce chemicals (Figure 48). This technology is at its infancy and has had limited success so far.

The main advantage of the technology is the microoganisms ability to utilize electricity to reduce $CO_2$ to carbonate and then further into other chemicals. Challenges that still need to be solved include the design of suitable, cheap and robust electrodes and the design of proper reactor systems in order to maximize the contact surface between the electrodes and the media.

[13] Panasonic Develops Highly Efficient Artificial Photosynthesis System Generating Organic Materials from Carbon Dioxide and Water http://panasonic.co.jp/corp/news/official.data/data.dir/2012/07/en120730-5/en120730-5.html

**Figure 48. Graphic representation of a bio-electrical system for the production of ethanol from CO2 and electricity (courtesy of Prof. Ludo Diels, VITO)**



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