Original Article

# Anticipating opportunities in industrial biotechnology: Sizing the market and growth scenarios

Received (in revised form): 21st December 2010

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**ABSTRACT Bio-based chemicals are being touted as the next big thing for the chemical industry and its customers. In particular they can offer significant opportunity for the chemical industry and its customers through cost reduction, delivering unique functionality and/or marketing benefits. This article undertakes to better characterize the make-up of the bio-based chemical industry, in terms of technology platforms employed and sales, as well as to develop scenarios for the growth of the bio-based chemical market. As can be shown, the market for bio-based chemicals is comparatively small, 50–75 Bn EUR or 3–4% of global chemical industry sales. Future growth is strongly determined by a number of high-uncertainty developments including technology breakthroughs and government policy. It can nevertheless be concluded that bio-based chemicals sales will continue to grow and outpace general chemical industry growth. In particular, the dedicated production of chemicals through biocatalysis and fermentation is expected to exhibit strong growth in all scenarios. However, a wholesale transformation of the industry is not expected, with bio-based chemicals constituting another option in the chemical industry toolkit, causing a more or less gradual shift from a petroleum-based industry towards one with additional feedstock options.**
*Journal of Commercial Biotechnology* (2011) **17,** 159–164. doi:10.1057/jcb.2010.40; published online 25 January 2011

**Keywords:** industrial biotechnology; white biotechnology; chemicals; market growth

## INTRODUCTION

Bio-based chemicals, that is, chemicals derived from biological raw materials like wood and straw, but also obtained through fermentation and biocatalysis, are being touted as the next big thing for the chemical industry and its customers. The technology that will make this possible, industrial biotechnology, or 'IB', is regarded by many as a potential game-changer. This possibility

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is not just of interest for the chemical industry itself; all the main chemical-using sectors such as food and drink, pulp and paper, textiles, automotive, aerospace and packaging would be impacted.

One of the more attractive benefits for both companies and consumers are the new and different functionalities of bio-based chemicals. They can offer innovative and better products, and may, in addition, reduce environmental impacts. Indeed, IB advocates boast about the lower net carbon emissions (since growing the feedstock would subtract carbon dioxide from the atmosphere) while on the political-economic side, a bio-economy would rely less on oil imports from parts of the world deemed less stable.

But there are critics too, who state that the expectations are exaggerated. They argue that IB remains of little importance for chemical production overall, especially where IB products are more expensive than alternatives, and that industry should not exploit valuable farmland that can be used to grow food and feed. In addition, they highlight that the petrochemical industry is not a key contributor to climate change; of all crude oil that is produced, only about 5 per cent is used by the petrochemical industry. It does so very efficiently, converting it into useful products first and eventually into energy when it is burned in incinerators, thus providing double use.

To shed further light in these matters, at Arthur D. Little we have analyzed in detail both the current state and future path of IB for the (petro)chemical industry. First, we have characterized what technologies can be used to make bio-based chemicals and how big the market actually is. And second, we have evaluated what future developments may be expected and how companies can capitalize on these.

## THE STATE OF PLAY

To truly understand IB for chemicals, at Arthur D. Little we believe it is important to recognize that bio-based chemicals can be derived through three fundamentally different technology platforms:

- *Dedicated production*: The most developed branch of IB, involving the production of chemicals using (modified) enzymes through biocatalysis and whole cells (possibly genetically modified) through fermentation.
- *Biofuel-derived*: Up-and-coming but depends on the development path of biofuels as it involves the production of chemically useful products *as a by-product* of biofuel (bio-ethanol and bio-diesel) production.
- *In planta*: Mostly uncertain but promising; production of chemicals by crops (possibly genetically modified) or algae, and extracting these after harvesting.

Moreover, as in the traditional petrochemical industry, it is necessary to distinguish between high- and low-volume chemicals. So far, no explicit attempts have been made to differentiate between such different technology platforms.

Figure 1 summarizes the key features of the six resulting segments and provides commercial and technological examples. Importantly, each of these platforms is shaped by different drivers and a failure to recognize the differences is already causing significant confusion in the debate, and may lead companies and governments down the wrong strategic path without careful understanding of key differences here.

Using this view on the market, we estimate the current size of the bio-chemicals market to be EUR 50–75 billion, or 3–4 per cent of total global chemical sales – still small given the enthusiasm, publicity and optimistic growth projections made over the last decade. In Box 1 and Figure 2 we provide further details of our assessment which, it should be noted, *excludes* biofuels – just like traditional petrol and other fuels are not counted as chemical industry sales, similarly bioethanol and biodiesel and the like should not be included in the bio-chemicals market. Note also that a very significant portion of the total

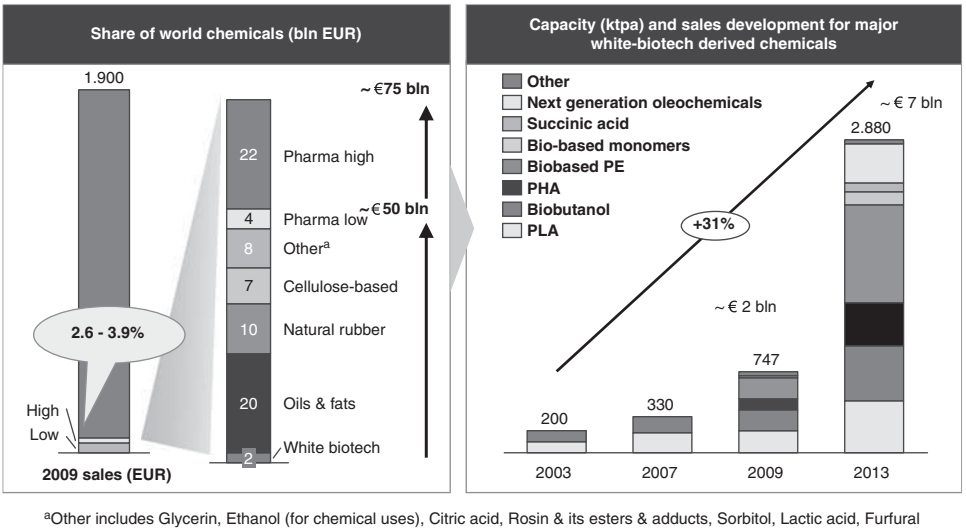
| Technology platform | Dedicated single compound production | Biofuel-derived | *In planta* |
|---|---|---|---|
| **Description** | Chemical production by means of enzymes or fermentation | Production of chemicals as a by-product of biofuel production | Production of chemicals in (genetically modified) crops or algae |
| **Feedstock** | Various, high-value glucose, sucrose | Low-cost sugars, vegetable oils, biomass (e.g. straw, wood) | Arable crops or algae |
| **Low volume** (Specialty and fine chemicals) | 1 Products include drugs, vitamins and amino acids from e.g. **BASF** and **DSM**. Numerous specialty companies and larger companies such as **Avecia** and **Croda** are active in this area | 3 Products include e.g. protein-based plastics or lignin-derived glues, sealants and detergents-various start-ups are active here | 5 Products include PHA (polyhydroxyalkanoate) resins, from **Metabolix / Archer Daniels Midland**, and specialty oils from companies like **Croda** |
| **High volume** (Commodities and platform[a] chemicals) | 2 Products include acrylamide (from acrylonitrile by **Mitsubishi Rayon**),citric acid, succinic acid (**DSM/Roquette**),corn-derived 1,3-propanediol (**DuPont Tate & Lyle**),Polylactic acid (**Natureworks**), and Isoprene (**Genencor**) | 4 Products include ethanol, butanol (**DuPont and BP**),1,3-propanediol (from glycerol, **DuPont Tate & Lyle**). | 6 Already, rubber is grown commercially in high volumes. **Cereplast** is offering starch-based plastics. Examples of future products could include (poly)methylmetacrylate, or acrylamid from cyanophycin |

[a] Platform chemicals, defined as chemicals of which the primary use is to transform them into multiple different chemicals

**Figure 1:** Technology platforms and examples of chemicals.

**Box 1:** Sizing up the bio-chemicals market

Estimates have been derived in large part from what we judge are the most reliable numbers available to date, namely those compiled from the United States International Trade Commission (USITC) questionnaire. We have used the USITC numbers to estimate the sales in Europe, Asia and globally, based on the industry composition in the different regions. Chemical industry sales figures were taken from the European Chemical Industry Council (Cefic) and Chemical & Engineering News (C&EN). A 'low' and a 'high' estimate has been made for pharmaceuticals, to reflect that for certain multi-step synthesis processes the occurrence of one IB step may lead to count the full pharmaceutical sales value as IB (high estimate), or only part (low estimate).




[a]Other includes Glycerin, Ethanol (for chemical uses), Citric acid, Rosin & its esters & adducts, Sorbitol, Lactic acid, Furfural

**Figure 2:** Break-out of bio-based chemical sales and capacity and sales development of the major white-biotech derived chemicals.
*Source*: ICIS, CEH, company websites, Product overview and market project of emerging bio-based plastics, Product overview and market projection of emerging bio-based plastics, PRO-BIP 2009, Universiteit Utrecht, Patel *et al* (2009), Arthur D. Little analysis.

**Box 2:** Modelling the growth of the bio-chemicals market

Our assessment is based on the economic attractiveness of IB-derived bio-chemicals compared with traditional petroleum-based chemicals for each of the categories described in Figure 1. The starting point for our analysis is the market for IB chemicals in 2009. We then analysed wider emerging trends in the economy and identified the drivers impacting the IB market and different chemicals categories of which four are described here in more detail:

- Technology breakthroughs: in order to be able to exploit opportunities, breakthroughs are required in technology to produce chemicals at lower costs than current petrochemical alternatives. In particular, new technologies need to be developed to cost-effectively transform lignocellulose (from for example straw and wood chips) into biofuels, as well as to use algae to produce biodiesel. Also the *in planta* technology requires significant further development. These breakthroughs may need to occur to improve extraction rates or to enable scaling up production to achieve the necessary economic scale. Note that in the case of fermentation and biocatalysis, already commercially viable, more incremental technology developments are likely to happen, simply building on existing fundamental knowledge bases to increase market share.
- Prices for traditional feedstocks such as oil and naphtha in relation to the prices of bio-based feedstocks: it may be assumed that high oil prices will encourage investments in IB.
- Feedstock availability for IB and competition with crops for food and feed (feedstock prices are especially relevant for biofuels, and hence bio-fuel derived chemicals, and – to a lesser extent - for *in planta* production).
- Government mandates and societal preferences for IB-derived products.

estimated sales of EUR 50–75 billion comes from high-value pharmaceuticals, that is, the share of bio-chemicals in the non-pharmaceutical and commodity segments of the industry is even smaller.

## A FUTURE OF GROWTH – BUT HOW FAST?

What can be expected for the future? To get an understanding about 'the size of the prize' and thus enable better decision-making by future producers and users, we have analyzed what different scenarios might apply for the IB market until 2025 (see Box 2). We identify three:

*Future 1 – Green Bloom*: This is the most optimistic potential future for IB. By 2025 many different technologies that we are talking about today have been commercialized, making it possible to grow and exploit agricultural feedstocks for biofuel production that do not compete with food crops. For example, bioethanol can now be produced from switch grass and wood, as well as waste products like straw, while algae are on the rise to make biodiesel at sea, avoiding competition with land-based food production completely. The plentiful production of biofuel has resulted in the development of a thriving bio-chemical industry. The situation may be compared to the petrochemical boom of the early 1900s – large-scale production of cheap fuel for a world demanding transport allows chemical companies to piggyback and valorize part of the fuel into more useful chemicals.

*Future 2 – Stuck*: In this potential future for IB, unfortunately even by 2025 the anticipated technology breakthroughs that would have enabled large-scale biofuel production have remained elusive for a variety of reasons including limited success in producing cheap, unsubsidized biofuels, societal resistance to GMO's and biofeedstocks being seen to compete with other land use. The only segment experiencing growth concerns the direct production of fine and speciality chemicals, a technology that was viable and profitable already before the year 2000.

*Future 3 – Electrified*: In this possible future, electric cars are breaking through on a large scale, driven by government policies and technological advances. As a result, a real or anticipated drop in demand for oil leads to structurally low prices. Low crude oil and thus naphtha prices render the existing petrochemical products highly competitive and prevent the growth of IB processes and products unless there is a clear cost or functional advantage.

At present, we cannot be sure which of these three futures is more or less likely to occur. Too much depends on highly

uncertain, difficult to predict technology breakthroughs in a wide number of areas: biofuel production; genetic modification of plants; battery technology for electric cars; as well as in solar and wind energy to produce electricity for transport cheaply but without emissions. Similarly, changes in societal and political opinions, for example, with respect to the acceptance of genetic modification, or the dependence on foreign oil imports, may change or be influenced by specific events on the world stage yet to happen. It will be clear that the size and composition of the IB sector will vary significantly in each of these futures. Our model shows – in order of magnitude terms – by 2025 a variation in size between EUR 175 and 420 billion, or a chemical production market share of between 7 and 17 per cent (Figure 3).

In summary, we are confident that IB will continue to grow and outpace general chemical industry growth. In particular, the dedicated production of chemicals through biocatalysis and fermentation is expected to exhibit strong growth in all scenarios, which is good news for those chemical firms that are currently pursuing this platform. That said, we do not expect we will witness in this timeframe a wholesale transformation of the industry. A sector that has relied for nearly all of its feedstock on traditional petrochemistry will more or less gradually shift towards one that has other options. IB is another option in the toolkit, and on a case-by-case basis the industry can choose to exploit alternative feedstock.

Within this setting, how do we see the chemical industry benefit? Ultimately, the enthusiasm of the chemical-using industries (for example in food, cosmetics and electronics) to exploit some of the unique features of bio-chemicals will drive much of the nascent bio-chemicals industry. Bio-chemicals can lead to differentiated products and increased profitability in a three ways.

- IB may allow existing products to be produced at a lower cost. Technologies such as biocatalysis and fermentation are sometimes used to make existing chemical

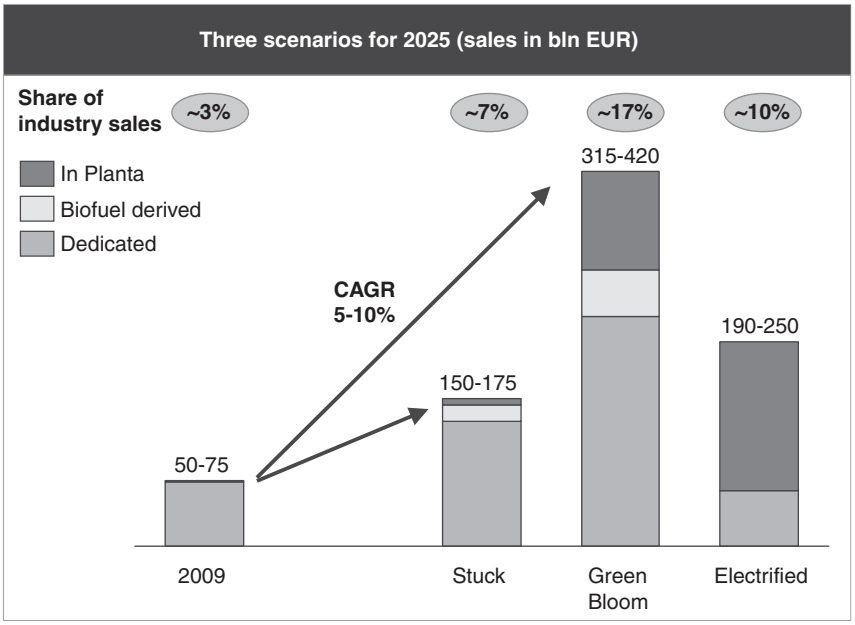



**Figure 3:** Size of bio-chemicals market 2025 versus 2009 in three scenarios.
*Note:* In 'Green Bloom', the corresponding biofuels market is 20–50 times the value of the biofuel-derived chemicals market.

products more simply, and using less energy. For example, the production costs of DSM's cephaloxin or BASF's vitamin B2 have been significantly reduced.

- IB technology will allow companies to achieve unique effects in products that are not achievable through traditional processes. For example, cosmetics and personal care company Croda International plc's subsidiary Sederma has developed a unique range of biochemical 'active ingredients' that are more effective in 'adjusting' dry or oily skin, wrinkle reduction, skin firming, protection from causes of skin damage among other benefits. Another example is 1,3-propanediol, pursued, for example, by DuPont and Tate & Lyle. This material can be obtained from glycerol as well as by direct fermentation, and has great potential to become a building block for a variety of derived products and materials that cannot otherwise be accessed cost-effectively.
- Third, there will be opportunities created by IB through marketing of 'green' or nature-based products. Bio-based products can potentially be marketed as renewable and offering reduced climate impacts. An intriguing example concerns Genencor's teaming-up with Goodyear to produce bio-isoprene, the key ingredient of natural rubber used to manufacture tires. The tyres obtained in this manner would be partially renewable, and/or have a lower climate impact.

## A GROWING BUSINESS – BUT WATCH THE THICKET

To summarize, IB is a big deal, but its scale to date remains small. Dramatic displacement of petrochemicals by bio-chemicals produced through IB is not widely expected unless there is significant technology development and, for high volume chemicals, high oil prices.

That said, just looking at the attractive growth figures that we anticipate, there still is ample opportunity for innovative companies, whether suppliers, producers or users, to find their place in the value chain. But this is not without risk or uncertainty, as our analysis of different development paths shows. The most successful companies will be those that understand some of the fundamental differences between IB-based business models and the traditional petrochemical industry. Chemical companies that would want to benefit from IB developments would need to consider many new aspects compared to their existing business models, but the key to success is that they deliver products that are either more cost-competitive, or that provide new functionality or consumer benefits (which may include 'being green' as such). It is risky in this endeavour to depend on government interventions for the business to succeed, since politics are fickle, government budgets are more likely to tighten than to expand, and more broad-based measures like carbon pricing would only have a minor impact on the final cost of most chemicals.