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Advanced Technologies for Industry – Product Watch

Bio-based flavours and fragrances

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Section 1

1. Background and objectives of the report

Background

The Product Watch Reports have been developed in the framework of the 'Advanced Technologies for Industry' project and serve to identify and analyse 15 promising advanced technology (AT)-based products and their value chains, with an assessment of the strengths and weaknesses of the EU positioning.

Promising AT-based products can be defined as "*enabling products for the development of goods and services enhancing their overall commercial and social value; embedded by constituent parts that are based on AR/VR, Big Data & Analytics, Blockchain, Cloud, Artificial Intelligence, the Internet of Things (IoT), Mobility, Robotics, Security & Connectivity, Nanotechnology, Micro-nanoelectronics, Industrial Biotechnology, Advanced Materials and/or Photonics; and, but not limited to, produced by Advanced Manufacturing Technologies*".

1.1 Background of this report

Flavours and fragrances (F&F) are chemical substances that trigger the olfactory system, i.e. the senses of tasting and/or smelling. They are used (industrially) to influence the taste/smell of (typically consumer) products such as food, personal care or cosmetics. Natural aromas usually blend hundreds to thousands of different components. Although they normally account for small fractions of finished products, F&F may significantly influence consumers' purchasing decisions[1].

Conventional processes to produce F&F comprise extraction from natural sources like plants or chemical synthesis. Nevertheless, biotechnology including denoting processes such as biosynthesis or biotransformation constitute an innovative production option.

Compared to conventional substances, biotechnologically produced products provide an array of benefits that industry has not entirely managed to harness yet. Moreover, by the Regulation (EC) No 1334/2008 of the European Parliament and of the Council, European policy created a potentially favourable legal basis for bio-tech flavour manufacturers. This regulation allows the marketing of these products as natural flavours, provided they stem from material of vegetable, animal or microbiological origin, and correspond to substances that are naturally present and have been identified in nature. In the US, the regulation is rather similar, but the production methods are less defined. Thereby companies can capture a significant green premium. The natural labelling constitutes a main motivation for firms to enter the bio-tech flavour market[2]. In addition, technological advances such as synthetic biology may enable firms to achieve better performance and lower costs compared to traditional biotechnological methods.

Moreover, with respect to both, flavours and fragrances, more sustainability-related considerations may grow in importance over time as research and development efforts may become increasingly driven by goals such as:

[1] Wydra S., Hüsing B., Jäger A., Lerch C., Pullmann L., Fischer, P. (2016): Progress Project Deliverable D 6.6: Final Conference report.
pwc (2019). The value of fragrance. A socio-economic contribution study for the global fragrance industry. Retrieved April 2020, from: https://ifrafragrance.org/docs/default-source/policy-documents/pwc-value-of-fragrance-report-2019.pdf?sfvrsn=b3d049c8_0.

[2] Waltz E. (2015). Engineers of scent. Nature biotechnology 33 (4), pp. 329–332. DOI: 10.1038/nbt.3191.
Bicas, J. L., Molina, G., Cavalcante B., Francisco F., Pastore, G, M, (2016): CHAPTER 12. Production of Aroma Compounds by White Biotechnology. In Maria Alice Z. Coelho, Bernado D. Ribeiro (Eds.): White biotechnology for sustainable chemistry. Cambridge, UK: Royal Society of Chemistry (RSC green chemistry, no. 45), pp. 310–332.

- To secure constant F&F supply vis-a-vis limited intensification possibilities of natural resource extraction (e.g. due to climatic or crop breeding restrictions)
- Provide natural ingredients (in contrast to chemically synthesised)
- Making production more environmentally sustainable (e.g. by generating less detrimental by-products, using waste as input)

However, as it is the case concerning many bio-based products, bio-tech F&F are not per se more sustainable than conventional options. Instead, whether they provide notable benefits depends on various parameters such as the type of resources, configuration of processes, location as well as the performance of conventional production processes with respect to the substance in question. Moreover, F&F are not produced in high volumes, so even if their production was more sustainable, their eventual contribution to overall sustainability goals could be limited. Nevertheless, from the point of (longer term) economic competitiveness and dynamic capabilities bio-tech F&F represent a promising field. F&F may constitute a lucrative first application for emerging firms to commercialise their technologies, which can be potentially applied in other segments such as pharma and chemicals. Being rather a low-volume high-price segment, it is hence lucrative for SMEs.

Throughout the economy, many (mainly consumer) industries like pharmaceuticals, perfumes and cosmetics or food and beverage rely on F&F for their products. Following market research, the current value of the global F&F market amounts to about €19.6 bn[3][4]. It is expected to grow up to about €28.6 bn by 2026[5] with annual compound annual growth rate (CAGR) estimated between 2.67% and 4.9%. Among the stated drivers for that growth are increasing incomes, growing demand for specific consumer goods and changing lifestyles and attitudes. Europe constitutes one of the largest F&F markets next to China and the US[6].

The market share of biotechnologically produced F&F is estimated to lie below 10% of the overall F&F market volume, with fragrances being an especially small fraction[7]. Market research on bio-tech ingredients seems to support such estimates, yielding roughly 7% market share for 2020. Market growth is estimated to be about 8% until 2025[8]. Taking the biotech flavour market size of the four largest EU Member States plus the Benelux area as conservative proxy for the EU27, the market size[9] is estimated as €112.6 m for 2020, which is expected to grow to about €164.3 m by 2024[10]. In general, market growth is said to be fuelled by increasing demand from the food and beverage industry[11].

1.2 Objectives of this report

While biotech F&F represent a niche, they may yet constitute an interesting example for an entry point to commercialise products based on synthetic biology, which is considered as a promising technology for bio-based products. The value chain represents high value, low volume products with a broad application potential for which biotechnological production may have competitive advantages over current production methods. In addition, many F&F substances feature additional benefits like insect repellent effects that could make them high-value food ingredients, cosmetics or pharmaceuticals for instance.

The report aims to provide an overview of relevant stakeholders with an analytical and empirical base to see how ATI based products can help EU industry to stay ahead of global competition. The

[3] Reports and Data. (2019). Flavors & Fragrances Market ; Grand View Research. (2019). Flavors and Fragrances Market Size, Share & Trends Analysis Report.
[4] All values were converted from USD into EUR, using the European Commission's official monthly conversion rate for March 2020 (USD1.0=EUR0.91208) as provided by European Commission 2020.
[5] Ibid
[6] Markets and Markets. (2018). Flavors & Fragrances Market Global Forecast to 2022.
Mordor Intelligence. (n.d.). Flavor & Fragrance Market - Growth, Trends, and Forecast (2020 - 2025)..
[7] Wydra S., Hüsing B., Jäger A., Lerch C., Pullmann L., Fischer, P. (2016). Progress Project Deliverable D 6.6: Final Conference report.
[8] Grand View Research. (2018). Biotech Ingredients Market Size, Share & Trends Analysis Report.
[9] Most sources provide no detailed explanation of how they define "Europe". Moreover, even official-EU level trade associations like EFFA have members outside the EU such as Switzerland, Turkey and the United Kingdom. As a consequence, no market or business information could be retrieved that would explicitly or exclusively pertain to the EU-27.
[10] Transparency Market research. (2017). Biotech Flavors Market– Global Industry Analysis, Size, Share, Growth, Trends, and Forecast, 2016–2024.
[11] Grand View Research. (2018). Biotech Ingredients Market Size, Share & Trends Analysis Report ; Research and Markets. (2018). Biotech Ingredients Market Size, Share & Trends Analysis Report.

objective is to map the EU biotech F&F industries and their interactions in the value chain, as well as to identify their strengths and weaknesses. Analyses were based on desk-research as well as on the internal expertise of Fraunhofer ISI in the subject as well as an external interview. The report aims to provide relevant stakeholders with a thorough overview on the F&F sector with respect to biotechnology.

Section 2

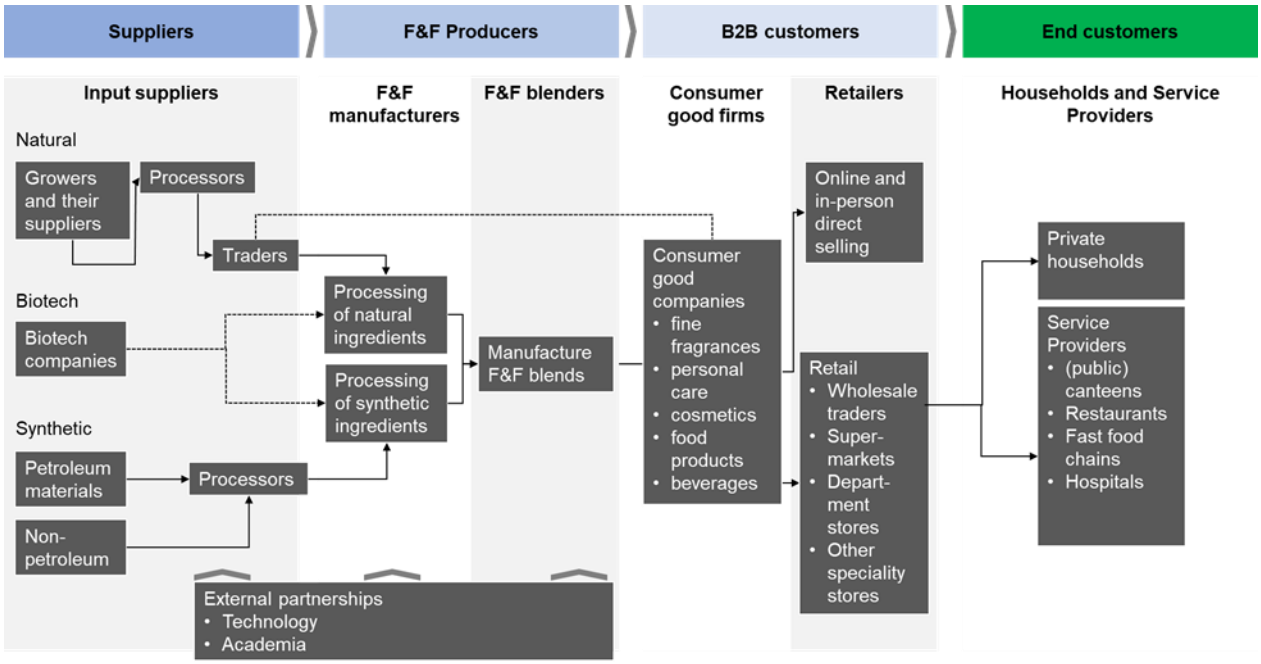
2. Value chain analysis

The following chapter explores the specific value chain of biotechnologically produced F&F including the key actors and the current state of play of the linkages across the value chain.

2.1 Value chain structure

The F&F industry constitutes an established economic sector. Figure 1 depicts the general value chain structure, which may differ in the case of specific flavours or fragrances. Biotechnological F&F production is different from conventional manufacturing in particular in the stage of raw material supply, i.e. upstream.

Figure 1: Flavors and fragrances value chain



Source: Fraunhofer ISI, adapted from PwC 2019; Wydra et al. 2016

The chain starts with suppliers that manufacture inputs, either by employing conventional production processes like chemical synthesis or traditional extraction from plants, or by biotechnological means such as fermentation. In a second step, F&F manufacturers process the obtained inputs into F&F compounds, which are then blended by F&F blenders into finished F&F substances. Following blending, B2B customers such as consumer good firms integrate the finished F&F into their products. The final consumer goods are then distributed to end consumers via various retail channels like online or wholesale. Ultimately, F&F are consumed as part of the corresponding consumer good by end customers such as households and service providers like public canteens or fast food firms.

Over the last decades, the F&F industry has significantly consolidated, with market shares of the 10 largest multinational companies rising from around 60% in the early 2000s to over 74% in the recent past. Whereas large incumbent F&F companies dominated the recent F&F market mergers and acquisition period, consolidation among them has not materialised so far. Consequently, the F&F market is highly competitive and rather concentrated with major firms usually covering several F&F value chain steps, while smaller firms may focus on specific steps or regions. Not achieving consolidation, leading firms pursue diversification strategies instead[12]. Most recently, e.g. large multinational IFF (International Flavors & Fragrances) announced to merge with the Nutrition and Biosciences business of DuPont.

It was during the last decade that synthetic biology firms entered the F&F market, mainly in R&D or partly producing small batches. Some of the younger biotechnology companies initially started out with a focus on high-volume low-margin products such as biofuels but have switched to high(er)-margin low(er)-volume chemicals later on[13]. In a similar vein, large F&F incumbents have started to engage in the production of biotechnological F&F as well.

Since 2014 non-F&F companies have started to show interest in entering the F&F market. For instance, in 2014 US food processing company ADM acquired Swiss flavour business Wild[14]. Similarly, German chemicals company BASF, a large multinational supplier of synthetic aroma ingredients, recently entered the market for biotechnologically produced F&Fs vanillin, nootkatone and valencene by acquiring Dutch biotech F&F company Isobionics and partnering with US firm Conagen in 2019.

2.2 Key actors in the value chain

Reviewing the key actors is essential to understand the value chain of biotechnological F&F. Focussing mainly on the EU27, the main stakeholders relevant for the various segments of the F&F value chain are mapped out in non-exhaustive tables below, with exception of retailers and end customers. Thereby the focus is on small, specialised providers of technology on the one hand and large integrated companies on the other hand. To distinguish between EU and non-EU companies, those with their headquarters located in the EU are indicated in blue.

Input suppliers play a key role, since they provide the necessary technological know-how behind biotechnologically produced F&F and they set technological trends. Nevertheless, many biotech input suppliers are rather small and thus more flexible in their strategy. A detailed list of innovative F&F input suppliers from the field of biotechnology is presented in Table 1.

Table 1: Biotechnology companies active in F&F

Company	Exemplary product	Country	Website
Allylix[15]	Valencene	United States of America	
Amyris	Artemisinin, fragrance percursors, patchouli, stevia	United States of America	https://amyris.com
Byosintia	Stevia	Denmark	https://www.biosyntia.com
Evolva	Nootkatone, resveratol,	Switzerland	https://www.evolva.com

[12] Mewton P. Leffingwell J. (2017). Diversifying F&F growth. In perfumer&flavorist 42 (5), pp. 26–35.
Tully & Holland. (2014). Flavors & Fragrances Industry Update.
[13] Chatsko M. (2017). How to Make Money From Engineered Biology. Retrieved February 2020, from: https://www.fool.com/investing/2017/06/02/how-to-make-money-from-engineered-biology.aspx.
[14] Mewton P. Leffingwell J. (2017). Diversifying F&F growth. In perfumer&flavorist 42 (5), pp. 26–35.
[15] Acquired by Evolva in 2014

	sandalwood oil, stevia, vanillin		
Genomatica	n.a.	United States of America	https://www.genomatica.com
Ginkgo Bioworks	Rose	United States of America	https://www.ginkgobioworks.com
Isobionics[16]	Nootkatone, patchouli, sandalwood oil, valencene	The Netherlands	http://www.isobionics.com
Oxford Biotrans	Nootkatone, valencene	United Kingdom	https://oxfordbiotrans.com
Phytowelt GreenTechnologies	R-alpha-ionon	Germany	https://www.phytowelt.com
Stem (formerly: Cambridge Glycosciences)	Sweetener	United Kingdom	https://www.stemsugar.com

Source: based on Wydra et al. 2016; expert interview; desk research

Please note that most of these firms are not dedicated to the F&F sector, but develop or manufacture products that can be applied in the F&F business as well. Mostly they focus on certain niches with specific biomolecules and are hardly in direct competition with each other. The limited number of firms, which are active in biotech F&F are also mostly located in Western-Central Europe.

Among F&F producers, large vertically integrated and internationally operating F&F manufacturers are especially important for the F&F value chain. These actors hold prime resources like money, know-how or consumer insights. What is more, thanks to their dominant position in the F&F value chain as well as their pivotal role for adjacent markets like consumer goods, these companies may exert influence on the F&F market.

Table 2: Key incumbent F&F companies

Company	Market share in %	Market share in €m (2017 values)	Country	Website
Givaudan	19.5	4,681	Switzerland	www.givaudan.com
Firmenich	13.9	3,346	Switzerland	https://www.firmenich.com
IFF	12.9	3,099	United States of America	https://www.iff.com/
Symrise	10.2	2,437	Germany	https://www.symrise.com
Mane	5.0	1,191	France	https://www.mane.com
Frutarom[17]	4.8	1,159	Israel	https://www.iff.com/en/taste/frutarom
Takasago	4.5	1,081	Japan	https://www.takasago.com/
Sensient	2.4	564	United States of America	https://www.sensientflavorsandfragrances.com/
Robertet	2.2	520	France	https://www.robertet.com/
T. Hasegawa	1.6	390	Japan	https://www.thasegawa.com/

Source: Leffingwell & Associates n.d.

[16] Acquired by BASF in 2019
[17] Acquired by IFF in 2018

In addition to these firms, other large chemical enterprises are active in the ingredients market such as BASF from Germany or Zhejiang NHU, an important player from China.

Large consumer goods companies are the major customers of F&F. Because of their gatekeeper role as interface between end consumption and the F&F value chain, they may influence the development within the F&F sector. Table 3 depicts the ten largest consumer good companies globally.

Table 3: Ten largest consumer good companies according to net sales

Company	Product category	Net sales in €m (2018 values)	Country	Website
Nestlé	Packaged foods	85,189	Switzerland	https://www.nestle.com
Procter & Gamble	Household Products	60,503	United States of America	https://www.pg.com
PepsiCo	Beverages	58,976	United States of America	https://www.pepsico.com
Unilever	Household Products	54,834	The Netherlands/ United Kingdom	https://www.unilever.com
Anheuser-Busch InBev	Beverages (alcohol)	49,817	Belgium	https://www.ab-inbev.com
JBS	Packaged foods (meat)	44,732	Brazil	https://jbssa.com
Tyson Foods	Packaged foods (meat)	36,531	United States of America	https://www.tysonfoods.com
British American Tobacco	Tobacco	29,785	United Kingdom	https://www.bat.com
Coca-Cola Company	Beverages	29,056	United States of America	https://www.coca-colacompany.com
L'Oréal	Household Products (cosmetics)	28,974	France	https://www.loreal.com

Source: Statista 2019

Governing and supporting bodies

The F&F industry is a well-established sub-field of the specialty chemical industry as well as an application field of rather horizontally specialised biotech firms. Consequently, there are hardly any dedicated associations or governing bodies regarding F&F.

Instead, actors are organised in institutions with a wider scope such as

- Chemical associations, e.g. the European Chemical Industry Council (CEFIC)
- Biotechnological associations, e.g. Europa Bio
- F&F industry organisations, the European Flavour Association (EFFA) and the International Fragrance Association (IFRA)

Moreover, there are networking activities, such as the Bioflavours conference that takes place every 2-3 years. In a similar vein, most biotech F&F research is funded as a part of broader research topics in H2020.

2.3 Linkages along the value chain

As mentioned before, there is a high degree of vertical integration in the F&F value chain with respect to major incumbent manufacturers. Moreover, supply chain control has become a more important issue in the past[18]. For large F&F enterprises it is important to control the production

[18] Mewton P. Leffingwell J. (2017). Diversifying F&F growth. In perfumer&flavorist 42 (5), pp. 26–35.

chain from raw materials to final products, to know the customer trends and the flavours in fashion[19].

Nowadays, most F&F companies cooperate with biotechnology platforms[20]. What is more, all major companies have acquired competences in the field of biotechnology, thanks to in-house development efforts or by cooperating with or acquiring relevant biotechnology firms. Table 4 shows biotechnology oriented activities by the largest multinational manufacturers identified above (Table 2). Besides those companies, depending on the specific market, there are additional important firms that engage in biotechnology. With respect to biotech flavour production, examples include Bell Flavors & Fragrances (USA), Kerry Group (USA) or Naturex (France)[21].

Table 4: Key global F&F companies' biotech activities

Company	Country	Biotechnological activities	Cooperation with synthetic biology companies
Givaudan	Switzerland	In-house development, acquisitions, cooperation	Amyris, Evolva
Firmenich	Switzerland	In-house development, acquisitions, cooperation	Amyris
IFF	United States of America	In-house development, acquisitions, cooperation	Amyris, Evolva, acquisition of Frutarom in 2018
Symrise	Germany	In-house development, acquisitions, cooperation	
Mane	France	In-house development, acquisitions	
Frutarom	Israel	In-house development, acquisitions, cooperation	
Takasago	Japan	In-house development, acquisitions, cooperation	Amyris, Evolva
Sensient	United States of America	Cooperation	
Robertet	France	Cooperation	Ginkgo Bioworks
T. Hasegawa	Japan	Cooperation	

Source: Wydra et al. 2016; Waltz 2015

Table 4 shows that cooperation runs often transcontinental between the USA and Europe. Nonetheless, European companies collaborate with each other as well, even if their networks are rather regionally concentrated and trans-European connections are rare[22].

[19] Wydra S., Hüsing B., Jäger A., Lerch C., Pullmann L., Fischer, P. (2016). Progress Project Deliverable D 6.6: Final Conference report.
[20] Chatsko M. (2017). How to Make Money From Engineered Biology. Retrieved February 2020, from: https://www.fool.com/investing/2017/06/02/how-to-make-money-from-engineered-biology.aspx.
[21] Transparency Market research. (2017). Biotech Flavors Market– Global Industry Analysis, Size, Share, Growth, Trends, and Forecast, 2016–2024.
[22] Wydra S., Hüsing B., Jäger A., Lerch C., Pullmann L., Fischer, P. (2016). Progress Project Deliverable D 6.6: Final Conference report.

Section 3

3. Analysis of EU competitive positioning

Overall, Europe features a solid economic base with respect to biotech F&F as some key companies from the value chain are headquartered in the EU. Since the F&F sector is a mature industry, this can be considered as a strength as it proves the EU's competitive capacities. Nevertheless, biotech F&F still suffers from a lack of economies of scale. Although there is cross-continental cooperation, inner European networks are weak. Moreover, significant international competition plus unclear consumer acceptance makes a stronger engagement in biotechnological F&F production a risky endeavour. Nevertheless, biotechnology could help overcome the limitations of conventional F&F production to the profit of society and the economy.

Figure 2: Strengths, opportunities, challenges and risks for the biotechnology flavours and fragrances value chain

Source: Fraunhofer ISI

3.1 Strengths

Industrial basis. EU-based companies such as Mane, Symrise and Robertet are among the largest and most important firms in the F&F business. Moreover, Firmenich and Givaudan, two other leading F&F companies as well as some important biotechnology firms (e.g. Evolva) are headquartered in Switzerland. Hence, geographical proximity provides the potential to establish more regional value chains in Europe, which would be beneficial for actors from EU member states. Ultimately, with Anheuser-Busch InBev, L'Oréal and Unilever, the EU boasts some of the largest global consumer good companies. Europe is among the largest markets for biotech F&F worldwide. With regard to biotech flavours, it was ranked just behind North America in 2016, accounting for about an estimated 30%[23].

Strong technological competences. The EU possesses strong technological capabilities in biotechnological F&F with a highly diversified knowledge base. In general, European F&F companies feature a notable research intensity[24]. Hence, in combination with the strong industrial position this is a good starting point to develop, test and commercialise new applications in F&F relevant biotechnology.

[23] Transparency Market research. (2017). Biotech Flavors Market– Global Industry Analysis, Size, Share, Growth, Trends, and Forecast, 2016–2024.
[24] e.g. EFFA. (n. d.). Explore the industry. Retrieved February 2020, from: https://www.effa.eu/flavourings/explore-the-industry.

3.2 Opportunities

The F&F industry faces a variety of challenges such as to satisfy the increasing demand for natural ingredients (and end products) in the light of limited or waning global resources[25]. Biotechnology-based production technologies could contribute to successfully tackling corresponding difficulties as they allow for overcoming the limitations of conventional F&F production.

Improved Sustainability. Biotech F&F may come at smaller environmental footprints than chemically synthesised products or plant-derived natural ingredients, e.g. in cases where they require milder production conditions, emit fewer emissions or need less environmental inputs such as land[26]. Moreover, biotechnology can contribute to the EU's goal of a circular economy, since biotechnological production methods bear the potential to valorise low-value materials as inputs such as lignocellulose or residue fractions like terpenes in waste from fruit and vegetable processing[27].

Natural feedstock limitations. Biotech F&F products usually use feedstock substances (e.g. sugar, side streams of food production) that are not as rare as some flavours directly extracted from nature (e.g. vanilla planifolia). Hence biotech F&F are largely unaffected by the many liabilities of production methods that require the (agricultural) cultivation of those specific feedstock such as Vanilla planifolia and the corresponding extraction of its content. This is why changes in parameters like climate, soil quality or geo-policies would not translate into quantitative, qualitative and thus economic volatility for biotech F&F product.

Increased product range. Biotechnological production enables companies to extend their portfolios by the large amount of F&F that (i) are not or (ii) cannot yet be produced industrially. Moreover, biotechnology may allow producing novel compounds that are not found in nature[28].

Naturalness claims. Following EU and US legislation, flavour compounds produced from natural raw materials by biotechnological methods can be labelled as "natural". F&F firms may thus capture premium payments for natural products[29]. Moreover, naturalness also gains importance in other industries, such as cosmetics. Finally, making available novel F&F compounds via biotechnology means the production of potentially valuable intellectual property.

[25] Bomgardner M.(2019). How perfumers walk the fine line between natural and synthetic. Retrieved February 2020.
[26] Utroske D. (2018). 5 ways biotech is working for the fragrance industry. Retrieved January 202.
[27] Rodriguez Fernandez C. (2019). How the Biotech Industry is Making Flavors Healthier and Eco-Friendly. Retrieved January 2020, from: https://www.labiotech.eu/features/natural-flavors-biotech-industry/.
[28] Waltz E. (2015). Engineers of scent. Nature biotechnology 33 (4), pp. 329–332. DOI: 10.1038/nbt.3191.
Utroske D. (2018). 5 ways biotech is working for the fragrance industry. Retrieved January 2020
[29] Waltz E. (2015). Engineers of scent. Nature biotechnology 33 (4), pp. 329–332. DOI: 10.1038/nbt.3191.; Gallage, Nethaji J.; Møller, Birger Lindberg (2015): Vanillin-bioconversion and bioengineering of the most popular plant flavor and its de novo biosynthesis in the vanilla orchid. In Molecular plant 8 (1), pp. 40–57. DOI: 10.1016/j.molp.2014.11.008.; Bicas, J. L., Molina, G., Cavalcante B., Francisco F., Pastore, G, M, (2016): CHAPTER 12. Production of Aroma Compounds by White Biotechnology. In Maria Alice Z. Coelho, Bernado D. Ribeiro (Eds.): White biotechnology for sustainable chemistry. Cambridge, UK: Royal Society of Chemistry (RSC green chemistry, no. 45), pp. 310–332.

3.3 Risks

Unclear long-term consumer acceptance. Worldwide F&F markets are rather fragmented concerning regulation and (changing) consumer preferences. Yet there is a difference between flavours and fragrances. In particular, naturalness plays a minor role compared to attributes like price or sustainability for the fragrance industry[30], although it has gained importance in the recent years, e.g. for cosmetics. Instead in flavour business naturalness has constituted an important sales argument already for quite a time. In line with that, no notable regulation exists in major global economies like the EU or the USA regarding the specific labelling of biotechnologically produced fragrances in terms of production as synthetic, natural or the like, whereas the opposite applies to flavours. For the EU, Regulation (EC) No 1334/2008 allows the labelling of biotechnologically sourced substances as natural flavours. Moreover, such entitlements constitute a viable motivation for flavour companies to engage in biotechnology[31].

It should be noted that corresponding regulations could turn out detrimental for the further development of the biotech flavours sector. If framed correspondingly, end consumers may as well feel misled, e.g. by legislators or companies or the food industry at large. Currently, it remains unclear how realistic such a development is. On the one hand naturalness constitutes an important trait for consumers[32]. At the same time there are warnings that consumers may be ignorant or confused regarding the meaning of naturalness claims on food items[33]. For NGOs that criticise biotechnology-based food ingredients[34], this may make it easier to gather attention or generate momentum.

International competition. F&F companies from the EU face strong global competition, as is evident from the strong position of innovative US biotechnology companies like Amyris, Gingko Bioworks, Manus Bio, Conagen or Genomatica. Correspondingly, the USA are said to harbour major biotech activities, the creation of strong networks and the provision of significant public funding[35]. For example, Amyris announced a multi-year technology investment agreement with the USA Defense Advanced Research Projects Agency worth up to €29.8 m. The company intends to expand its portfolio by hundreds of molecules across multiple development platforms, which may be useable for F&F.

[30] Wydra S., Hüsing B., Jäger A., Lerch C., Pullmann L., Fischer, P. (2016). Progress Project Deliverable D 6.6: Final Conference report.
[31] Bicas, J. L., Molina, G., Cavalcante B., Francisco F., Pastore, G, M, (2016): CHAPTER 12. Production of Aroma Compounds by White Biotechnology. In Maria Alice Z. Coelho, Bernado D. Ribeiro (Eds.): White biotechnology for sustainable chemistry. Cambridge, UK: Royal Society of Chemistry (RSC green chemistry, no. 45), pp. 310–332.
Gallage, Nethaji J.; Møller, Birger Lindberg (2015): Vanillin-bioconversion and bioengineering of the most popular plant flavor and its de novo biosynthesis in the vanilla orchid..
[32] Román S., Sánchez-Siles L. M., Siegrist, M. (2017). The importance of food naturalness for consumers: Results of a systematic review. In Trends in Food Science & Technology 67, pp. 44–57. DOI: 10.1016/j.tifs.2017.06.010.
[33] Consumer Reports. (2016). Consumer Reports Survey Show 73 Percent of Consumers Look for 'Natural' Labels at Grocery Stores—and Many Are Unwittingly Misled.
[34] Ibid, Waltz E. (2015). Engineers of scent. Nature biotechnology 33 (4), pp. 329–332. DOI: 10.1038/nbt.3191. Hayden E. C. (2014). Synthetic-biology firms shift focus. In Nature (505), p. 598.
[35] Ibid

In addition to the US, there are also notable activities in China. Asia Pacific and China respectively are among the largest and most dynamic global markets for F&F. Likewise, it is projected to have the highest growth regarding biotechnologically-sourced flavours[36]. The Chinese government identified biotechnology and synthetic biology as major points of political interest[37]. For instance, the latest 5-year plan mandates biotechnology to exceed 4% of the Chinese gross domestic product by 2020.

Nonetheless, no F&F specific initiatives could be detected. Chinese interests seem to lie in other sectors than F&F[38]. However, due to the technological proximity between some medical applications and F&F manufacturing, public support might eventually benefit Chinese producers of biotech F&F nonetheless.

Hence, global competition in the biotechnological F&F industry is high. While this may on one hand be a risk for the developments in the EU, on the other hand experts also state that high competition may be a driver for the diffusion of biotechnological F&F innovations as the uptake of advanced technologies may get more and more necessary for all actors to remain competitive, which hold potentials for the biotech F&F industry development.

3.4 Challenges

Cost competiveness to fossil-based products. Currently, biotech F&F are mostly less cost-competitive than conventionally-sourced products[39]. While this disadvantage is mitigated in some cases by premium payments for natural products (see above), consumers' higher willingness-to-pay is limited nonetheless, especially outside the food and feed market with less specific regulations concerning naturalness. Therefore higher cost competitiveness of biotech F&F is of key importance. One issue is how to further increase the European technological advantage. Potential contributions to higher efficiency are expected by advanced technologies such as gene-editing and synthetic biology by the community. Here regulatory and acceptance issues have to be considered (see below). However, even if potential higher cost competiveness can be principally achieved, the established chemical industry already currently tries to defend existing market shares by their market power and potential influence on activities of actors, regulations, etc.

Upscaling and production capacities. Related to the challenge to achieve techno-economic competitiveness is the challenge to obtain a degree of technological maturity that allows for the necessary upscaling of production. Upscaling is thus crucial as it would enable companies to realise scale effects, which would mean a boost for the economic competitiveness of biotech F&F. In this respect hurdles pertain e.g. to the stability of enzymes, which can be used longer as well as the need for cheaper purification methods[40]. Regulatory hurdles in particular for smaller companies lie in complex regulations for products and processes. An industrial bottleneck in this respect are limited fermentation capacities in Europe, which hinders also the biotech F&F industry to transfer innovation into commercial production. Moreover, SMEs in the field of biotech F&F have higher difficulties to get access to finance, which is a critical bottleneck for these firms to build up or expand production capacities.

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Section 4

4. Conclusions & outlook

4.1 Conclusions

The F&F industry in the EU features companies that are key in the overall F&F value chain and in the development and production of biotech F&F, i.e. large F&F firms that engage in biotechnology, innovative biotech enterprises and multinational consumer good companies. Therefore, the EU biotech F&F sector disposes of valuable resources and considering significant technological and industrial potential a continuation of solid growth for biotech F&F industry is rather likely. Nevertheless, the deployment of biotechnology faces a variety of technological, economic and political challenges.

Regarding technology, the need to achieve sufficiently high production scales remains a crucial goal in order to render biotechnological F&F cost competitive vis-a-vis conventional production methods. Consequently, policies could support the development of the biotech F&F sector by supporting research and upscaling activities by recognising bio-based industries as an important field. In particular, the support for SMEs may be critical, which have less access to finance.

On the demand-side, gaining or maintaining consumer acceptance of biotechnologically produced F&F could turn into an important challenge, in particular regarding flavour substances. In this respect, the current regulatory environment in the EU can be judged a double-edged sword. By allowing the labelling of biotech flavours as natural ingredients current regulation enables companies to profit from increasing consumer demand and higher prices for clean label products. However, some accounts suggest that end consumers may be illiterate when it comes to food labelling. Given a partially differing understanding together with the perceived importance of naturalness, the situation could give room to public contestation, e.g. by NGOs that oppose biotechnology in food production.

As this seems a matter of information, one can conceive different ways by which policy may provide assistance. Examples would be instruments that target consumer food (labelling) literacy such as dialogues with consumers or consumer associations or other participatory approaches. Likewise, it is important that legislation proactively and credibly advocates transparency when it comes to food regulation. Overall, it seems advisable to reflect on the potential to develop food regulations in a way that the average consumer is able to grasp. Given that food regulation constitutes a complex, long-standing legal matter, this seems a difficult endeavour. Nevertheless, if policy manages to build and foster consumer trust, this may be to the larger benefit.

4.2 Outlook

The F&F industry is a promising opportunity for market entry of biotechnology firms, which can generate spill-overs for others. Moreover, all leading F&F firms have built up or acquired biotechnology competences, hence this is one of the most advanced product groups in this field. While the offer of naturalness according to regulation requirements is the key advantage of biotech F&F, an important issue for further development is how the trends and needs for sustainability will affect this rather low-volume, high value segment and whether it will become a key driver in the future.

Section 5

5. Annexes

5.1 List of interviewees

Interviewee	Company	Country
Peter Welters	Phytowelt GreenTechnologies	DE

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