KETs OBSERVATORY PHASE II

BIO-BASED AROMATICS
Report on promising KETs-based products nr. 2

Contract nr EASME/COSME/2015/026
Bio-based aromatics
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KETs Observatory Phase II
Contract nr EASME/COSME/2015/026

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European Union, August 2017.
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Executive summary

The current report aims to provide stakeholders with an analytical base helping to strengthen cross-regional cooperation mechanisms to boost the deployment of KETs in Europe. The report specifically aims to highlight the value chain structure, key players and constraints for the domain of bio-based aromatics in Europe. It also addresses the key strengths and potential of the EU regions, as well as promising business opportunities and key risks and challenges. Finally, the report elaborates on specific policy recommendations with both immediate focus and longer-term orientation.

The bio-based economy is steadily gaining ground as an alternative to fossil-based economy and represents a fundamental economic change with a far-reaching impact on current social and economic models. Bio-based aromatics – being a substantial component of the bio-based economy – have the potential to replace the fossil-based chemical building blocks, creating opportunities for better performing molecules and new materials with increased safety and environmental characteristics. Bio-based aromatics are also expected to address grand societal challenges related to the mitigation of climate change by considerably reducing CO\textsubscript{2} emissions.

Despite many benefits bio-aromatics bring, the European value chain is still at the R&D stage. Different constraints were identified. First of all, there is a value chain gap in the product development phase. This is caused by the lack of separation and conversion facilities that are reported to be expensive and risky to establish at the moment. Moreover, the facilities – crucial for experiments – are limited to few European regions and are not easily accessible to most of the SMEs. Secondly, there is a need for value chain optimisation with integration of manufacturing and supply chains as well as efficient cooperation between relevant stakeholders. Finally, sufficient feedstock needs to be ensured, coming from within and outside the EU at competitive prices.

European regions have the potential to successfully commercialise bio-based aromatics in the next decades. On the global arena, Europe stands out as a region with strong R&D environment, possessing know-how in the field of biotechnologies and extensive pool of required skills. The degree of success, however, will depend on how the EU overcomes number of challenges such as low technology readiness level, supply and investments in the bio-based aromatics. Additionally, there is a need to identify the most potential bio-based molecules for Europe and to ensure a systematic approach towards feedstock. The development of the bio-based aromatics will bring various opportunities to the EU, including development in rural areas and expansion of green chemicals market in Europe.

To conclude, the development and uptake of bio-based aromatics can be enhanced through long-term cooperation between European regions, enabling knowledge and technology, as well as the financial costs and risks to be shared among the different stakeholders. It further requires a campaign that will increase awareness, highlighting the positive impact on the advantages bio-based aromatics bring along. In the long run, there is a need to optimise the use of biomass for bio-based aromatics, as well as, the need for financial incentives to promote the investments in the production of bio-based chemical building blocks. Technology development for industrial use needs to be further stimulated. Moreover, new funds for the piloting of use-cases in bio-aromatics are needed, substantially reducing the financial risks and creating future outlook for the companies that wish to invest in the bio-based aromatics.
1. Introduction

The current report has been developed in the context of the second phase of the KETs Observatory initiative. The KETs Observatory represents an online monitoring tool that aims to provide quantitative and qualitative information on the deployment of Key Enabling Technologies\(^1\) (hereafter “KETs”) both within the EU-28 and in comparison, with other world regions. Specifically, the KETs Observatory represents a practical tool for the elaboration and implementation of Smart Specialisation Strategies in the EU regions.

1.1 Background

A key challenge for the EU competitiveness policy is to enable European industry to move to the higher end of the value chain and position itself on a competitive path that rests on more innovative and complex products. For many KETs, this implies a focus on more integrated technologies with the potential of connecting several KETs.

To this end, one of the key tasks of the KETs Observatory implies identifying and describing “promising KETs-based products” and their value chains, and recommending specific policy actions to help the EU industry stay ahead of global competition. Promising KETs-based products here can be defined as emerging or fast-growing KETs-based products with a strong potential to enhance manufacturing capacities in Europe. Such products correspond to KETs areas where Europe has the potential to maintain or establish global industrial leadership - leading to significant impacts in terms of growth and jobs.

1.2 Objectives of this report

In the context of the second phase of the KETs Observatory, in total, 12 promising KETs-based products will be selected for an in-depth analysis of their value chain, the associated EU competitive position and the corresponding policy implications. The selection of the topics stems from a bottom-up approach based on active engagement of regional, national and EU stakeholders through the S3 Platform for Industrial Modernisation\(^2\).

This report presents the results of the abovementioned in-depth analysis for one of the selected top-priority topics, namely bio-based aromatics. The analysis is based on desk-research and in-depth interviews with key stakeholders. The report aims to provide relevant stakeholders with an analytical base helping to establish or strengthen cross-regional cooperation mechanisms to boost the deployment of KETs in Europe.

1.3 Target audience

The report aims to provide key market insights for bio-aromatics and identify key directions for action in order to maintain Europe’s competitive position on the global market. The report specifically targets the EU, national and regional policy makers and business stakeholders who are currently involved in or consider engaging in cross-regional cooperation mechanisms. The report may also be relevant for other

\(^{1}\) Namely Nanotechnology, Micro-/Nanoelectronics, Photonics, Industrial Biotechnology, Advanced Materials and Advanced Manufacturing Technologies

\(^{2}\) http://s3platform.jrc.ec.europa.eu/industrial-modernisation
key stakeholder groups including academia, as well as different support structures such as cluster organisations, industry associations and funding providers.
2. Key product facts

In the current section, we provide a brief introduction to bio-based aromatics. We also elaborate on the market potential and the importance of this product for the EU competitiveness.

2.1 Introduction to the product

Today, commodity products largely derive from the fossil resources. However, fossil-based economy has two major implications: (1) a negative impact on the environment, with CO2 emissions and climate change, and (2) the dependency on crude oil that jeopardises economic stability due to fluctuations in prices and supply.

A growing alternative to the fossil-based economy is a ‘bio-based economy’, that - along with the products it produces - represents an economic shift that will have an extensive impact on society and current economic models. As a part of global efforts towards CO2 emissions reduction and the on-going shift towards a bio-based economy, recent developments in the field of aromatics have introduced the development of bio-based aromatics. Bio-based aromatics – derived from biomass – aim at replacing the traditional building blocks in the chemical industry, and to generate new green blocks with better and more sustainable functionalities. Traditional aromatics are hydrocarbons that derive from petroleum and in smaller quantities from coals. The application of traditional aromatics, being fossil-based products, creates a heavy dependence on crude oil and has a severe impact on the environment. Bio-based aromatics can serve as a drop-in replacement. Moreover, bio-based aromatics result in new innovative molecules that cannot be derived from petroleum origins. These new molecules are in general better performers and can lead to the development of new applications with enhanced safety, performance and environmental characteristics.

Bio-based aromatics can be split into the following two categories:

- **Drop-in aromatics:** aromatics coming from an alternative source such as biomass that are identical to the fossil-based chemicals and can thus be used in

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existing processes. This both shortens the transition to this alternative source and saves the cost of building new infrastructure and generating a new market. Drop-ins in most of the cases show lower greenhouse gas emissions in comparison to the petrochemical building blocks and the markets with high substitution potential already exist.

- The drop-in commodities do not differ greatly from their petrochemical counterparts as they do not provide any extra/new functionalities while being produced at a higher price than traditional petrochemical building blocks. In addition, the percentage of biomass that translates eventually in the final product varies from 25 to 50%, showing low efficiency and high waste of currently limited biomass.

- **Functionalised aromatics**: new chemicals with specific properties that retain as much of the inherent functionality of biomass as possible and thereby may lead to a promising business case. In other words, utilisation of the biomass is much higher, reaching up to 100% for starch polymers and cellulose derivatives. For the production of the functionalised aromatics, new advanced facilities and technologies are required.

Biomass that is used for the production of bio-based aromatics can be derived from various feedstocks. At the moment, most R&D in the EU concentrate on lignocellulosic (LC) biomass. Table 1 shows the main feedstock supply for LC biomass.

### TABLE 2.1: Feedstock for lignocellulosic biomass

<table>
<thead>
<tr>
<th>Origin of the feedstock</th>
<th>Type of feedstock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural supply</td>
<td>Straw, grain, chaff, cobs, starch or bagasse</td>
</tr>
<tr>
<td>Forestry supply and residues</td>
<td>Wood, branches, foliage, roots</td>
</tr>
<tr>
<td>Bio-waste streams</td>
<td>Municipal solid waste, food processing waste</td>
</tr>
</tbody>
</table>

2.2 Relevance to grand societal challenges

The shift to a bio-based economy needs to gradually and effectively address some of the major inter-connected societal challenges the world is facing today.

**Mitigating and adapting climate change**

It is estimated that a transition to raw materials coming from biomass and biological conversion methods could reduce the emission of up to 2.5 billion tons of CO2 by 2030. The decoupling of competitiveness and economic growth from environmental

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11 Ibid.
12 Lignocellulosic biomass refers to plant biomass that is composed of cellulose, hemicellulose, and lignin. http://www.biocore-europe.org/pagee027.html?optim=what-is-lignocellulosic-biomass--
13 Source http://www.biocore-europe.org/pagee027.html?optim=what-is-lignocellulosic-biomass-- Note that the presented list should not be considered exhaustive.
degradation can also be furthered through the development and application of bio-based aromatics\textsuperscript{14}.

**Reducing dependence on non-renewable resources**

The use of bio-based aromatics has the potential to unchain Europe’s industry from the heavy dependence on crude oil. The OECD reported the deepest fall in the exploration of new oil reserves in 60 years, as the bio-based economy took roots\textsuperscript{15}. Independence from fossil fuels and other non-renewable resources is expected to contribute to EU competitiveness and green economic growth. In addition, a low carbon Europe will benefit from increased economic stability by avoiding the impacts of oil price fluctuations and of possible political or social crises within oil exporting countries\textsuperscript{16}.

**Creating jobs**

Recent developments in bio-based aromatics are likely to lead to new markets and new bio-based products, which will have an impact on job creation - taking into consideration the entire value chain. Currently, the aromatics industry in Europe employs directly an estimated 20.0000 employees and indirectly creates over 1 million jobs in the wider industry value chain, being a part of a much bigger refinery-based employment\textsuperscript{17}. Moreover, research and development on the needed technologies will also result in additional jobs. For example, the direct research funding associated with the Bioeconomy Strategy can create around 130.000 jobs\textsuperscript{18} and increased bio-based chemical share will affect up to 400.000 jobs\textsuperscript{19}.

**2.3 Market potential**

The OECD has estimated the value of the global economic opportunities of the bio-based economy at 80 trillion USD\textsuperscript{20} by 2050 – with bio-aromatics accounting for a significant portion\textsuperscript{21}. For the EU specifically, business turnover in the bio-based economy already accounted for an estimated 2.1 trillion EUR in 2013\textsuperscript{22}. In the same period, the production of bio-based chemicals accounted for 48 billion EUR in business turnover\textsuperscript{23}.

\textsuperscript{15} Ibid.
\textsuperscript{20} 71 trillion EUR at current exchange rate (21/05/2017)
However, the bio-based share of the chemicals sector has grown rather slowly in the past several years. Between 2008 and 2013, it grew by only 2%, for the organic part. The market for aromatics has important potential to grow due to the wide range of applications, including in inks, paints, tires, textiles, wood panels and laminates, glues, adhesives, polymers, emulsifiers, coatings, fragrances and aromas, pharmaceuticals and fine chemicals. By 2030, the EU’s share of the bio-based chemicals market is expected to rise to 150 billion EUR annually.

The market growth and uptake of bio-based aromatics heavily depend on several factors, including the incentives and policies in place and the availability of the biomass. The use of bio-based aromatic molecules for the production of more sustainable products, such as bioplastics instead of bio-fuels, could result in better market potential for bio-based aromatics in the longer term.

2.4 Importance for the EU competitiveness

The global market for renewable chemicals is expected to rise up to 103 billion USD (about 90 billion EUR) in 2022 in comparison to 50 billion USD in 2016 (about 44 billion EUR). Europe is the largest market for bio-based chemicals followed by North America and Asia-Pacific. The regulations of the European Union on the use of fossil fuels and restrictions on the use of hazardous chemicals stimulate industries and researchers to look for safer alternatives. In addition, Europe has most of the major manufacturers such as DuPont, DSM and BASF, operating in the green chemistry that will further fuel the growth of the bio-based aromatics. In the field of bio-based aromatics, Europe has its unique position with outstanding knowhow, research and development of the bio-based molecules. Europe is also strong in the technology development, but at this stage, still at a small scale.

26 Ibid.
28 Ibid.
29 92 billion EUR at current exchange rate (17/06/2017)
30 47 billion EUR at current exchange rate (17/06/2017)
3. Value chain analysis

To cope with the shift to a bio-based economy, the chemicals industry will need to be ready for the change to alternative feedstock and to produce large quantities of the new chemical building blocks. In order to achieve this goal, considerable efforts are required to optimise the value chain, with a clear role for each of the actors along this chain\(^\text{32}\). The current section addresses the value chain structure, its key players as well as the key identified constraints.

In general, the European bio-based aromatics value chain today is still at the R&D stage. Greater technology development and upscaling is still needed before commercial-scale industrial production can be set up\(^\text{33}\). Currently, most of the activities along the value chain are taking place under the framework of cross-regional partnerships, but those partnerships are limited to a small number of regions. Therefore, there is a clear need for an expansion of this network and replication to other regions.

3.1 Value chain structure

Figure 3-1 demonstrates the value chain structure for bio-based aromatics, represented in three dimensions: (1) value-adding activities; (2) supply chain; and (3) enablers.

\[\text{FIGURE 3-1: Value chain for bio-based aromatics}^{34}\]

\(^{32}\) On track towards creating value with bio-aromatics (08/12/2016)


The first dimension represents seven co-related and complementary value-adding activities. Research and development includes not only technology development but also accelerating business uptake of the bio-based aromatics. Promotion and lobbying for a stronger bio-based environment with proactive role for regional, national and European governments are identified as other value-adding activities. Direct contact with financial institutions and access to funding as well as cross-regional and international partnerships are also among undertakings to be considered under this dimension.

In the second layer of the value chain, the main processes for the supply chain are reflected. The main input for the development of the bio-based aromatics is the lignocellulosic biomass. As a first step, biomass undergoes a separation process, unlocking biomass inputs into cellulose or hemicellulose. These molecules are further biochemically converted. Thermochemical conversion leads directly to the development of the drop-in molecules or can be further exploited for the production of the functionalised aromatics by adding fractionalising to the mixtures.

The other two possible biochemical conversions are catalytic depolymerisation and acid catalysed dehydration. These new technologies are still in R&D stage, but they allow the development of the functionalised aromatics such oligomers, dimers and monomers. The technology readiness level (TRL) of the functionalised aromatic products differs from case to case. Biorizon\(^{35}\) - for example - plans to realize a 40 ton/year scale in 2020 by reaching 5\(^{th}\) and 6\(^{th}\) levels of the technology readiness. It expects to commercialise its production by 2025\(^{36}\).

The application scope of bio-based aromatics is extensive, ranging from inks, paints, tires, textile, wood panels and laminates, glues, adhesives, polymers (polyesters, polyurethanes, polycarbonates, polyamides etc.), emulsifiers, coatings, fragrances and aromas, pharma and fine chemicals. Thus, market potential is large, however, at the moment, the supply of bio-based aromatics to the end-users is nihil. One impeding factor is the lack of large biomass quantity that is needed for commercialisation. Production of bio-based aromatics also requires technologies that are extremely limited at the moment and only available within R&D environment.

The third dimension represents actors that enable the bio-based ecosystem. These organisations support, feed and boost the supply chain. Knowledge and technology holders such as RTO’s, laboratories, technology parks and universities ensure the knowledge and technology development of the bio-based aromatics. Educational institutions such as vocational and education training centres, as well as universities teach the required skills to work within a bio-based environment. Governments of different levels foresee policies and provide support that is needed for effective and efficient development of the above described supply chain. SMEs play a crucial role along the entire ecosystem.

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\(^{35}\) Biorizon is a Shared Research Center with a focus on technology development for the production of biobased bulk aromatics (BTX) and functionalized biobased aromatics for performance materials, chemicals & coatings. Retrieved from: http://www.biorizon.eu/biorizon

\(^{36}\) Based on interview data
3.2 Key players

The following actors were identified for the European value chain on bio-aromatics:

- **Research and development centres**: these organisations are in charge of developing and testing different technologies for separation and biochemical conversion of the biomass into bio-aromatic molecules. They typically also offer testing and prototyping services. These organisations work out a roadmap for the future of bio-based aromatics accelerating and estimating the needed quantities of bio-based molecules to support the bio-economical approach.

- **Biomass suppliers**: one of the first steps for the development of the value chain is to ensure the large quantities of the biomass. There is a consensus on the fact that the uptake of the bio-aromatics will depend on the degree of optimisation of biomass supply in Europe. Suppliers can be local or from outside of Europe. Two approaches are complementary and will have to be both exploited in order to ensure enough availability at the best price. It will, on the one hand, allow to maximise diversification and flexibility of the supply chain, while, on the other hand, minimise dependence on exclusively local market and weather conditions or seasonal changes. It will also enable healthy demand and supply mechanisms, ensuring the best prices. For example, looking at the main feedstock suppliers for the biomass, Europe is a leader in wheat. For high-yield sugar cane, Brazil leads the global production, while the U.S. is the biggest supplier for corn crops and Canada for wood.

- **Biorefineries**: once biomass is supplied, biorefineries step in with the main task of separating and converting raw materials for industrial use. This process is by no means linear, as biomass transformation includes different technologies, including physical, chemical and biotechnological processes.
  - The concept of biorefineries is central to the value chain. While biomass can be imported at the world market prices, Europe has all the necessary conditions to make the conversions at home.
  - The location and setup of the biorefineries can play a strategic role in the future development of European bio-aromatics-based production. Biorefineries can be positioned within industrial clusters where all the necessary activities to convert biomass to bio-aromatics take place. In this case, location and proximity can play an important role, ensuring an optimal system of diverse industrial activities with shared facilities. For example, the proximity of biorefineries to ports would be supportive.

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39 European Chemical Industry Council CEFIC (2001) Aromatics: Improving the quality of your life; 40 Based on interview data
43 European Commission (2013) D2.3 – Report on the ‘Assessment of the bio-based products market potential for innovation; Based on interview data
idea is to concentrate the entire converting stage of the value chain and to share the required facilities.44

- There is a tendency for biorefineries to focus on drop-in commodity chemicals, mainly because the infrastructure and incentives are already present. However, in order to play an important role on the global market, the focus should be on building biorefineries that can cope with breaking down complex polymers.45 Future biorefineries will not only be technologically challenged, but they will also struggle to find the right focus that allows them to maximise the highest realistic biomass utilisation. As of today, a lot of biomass is often wasted. Therefore, Europe’s efforts need to be focussed on building and further developing efficient biorefineries that focus on biomass that has the highest utilisation potential and thus the lowest waste. This includes starch polymers and cellulose derivates.46

- At the moment, the biorefineries that are responsible for the treatment of the biomass and production of the first chemical building blocks are reported to be the weakest players of the value chain.47

**End-users:** these refer to companies that use bio-aromatics for the production of commodities. There is a lot of interest from end-users in bio-based products. Large companies, such as IKEA48, Coca-Cola49 and Lego50, are now working on products derived from bio-aromatic molecules. Large companies as end-users can accelerate the change to a bio-based economy and together with feedstock providers show more active and effective engagement in comparison to conversion industry.51 Nevertheless, the supply quantity that is currently produced is far what is needed for large scale production. As a result, many large companies are still on the sidelines.52

The table below showcases some examples of the organisations, SMEs and large companies involved in the bio-based aromatics value chain. Some of the listed private entities - mostly large companies – have headquarters outside of the EU; nevertheless, these companies are also included due to their active presence in the development of the bio-based aromatics value chain in Europe. This list should by no means considered exhaustive.

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44 Based on interview data
46 Ibid.
47 Based on interview data
51 Based on interview data
52 Ibid.
3 Value chain analysis

When looking on how different players of the value chain are interconnected in the European context, Bio-based Delta that connects different regions in the Netherlands, Germany and Belgium stands out as good practice example.

3.3 Key constraints

The identified constraints should be taken into consideration in the development of the value chain and as key industry players attempt to move on to the large-scale production of bio-based aromatics.

**Value chain gaps: lack of separation and conversion facilities and access to these facilities.**

Feedstock providers as well as the end-users are interested in participating in the bio-aromatics value chain. Despite this interest, the scale for production of green building blocks is too small and the prices are inhibitive. This is caused by the lack of separation and conversion facilities in the 'product development' segment (see FIGURE 3-1) since

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**TABLE 3-1: Mapping of key players**

<table>
<thead>
<tr>
<th>Research &amp; Development</th>
<th>Educational Institutions</th>
<th>Feedstock providers</th>
<th>Biorefineries:</th>
<th>End-Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>VITO (Belgium)</td>
<td>Polytechnical University of Madrid (Spain)</td>
<td>Sappi (South Africa)</td>
<td>Avantium (The Netherlands)</td>
<td>Foresa (Spain)</td>
</tr>
<tr>
<td>TNO (The Netherlands)</td>
<td>University of Delft (The Netherlands)</td>
<td>Metsä Fibre (Finland)</td>
<td>Andritz (Finland)</td>
<td>Bridgestone (Belgium)</td>
</tr>
<tr>
<td>Shared research centre Biorizon (Belgium-The Netherlands)</td>
<td>University of Leipzig (Germany)</td>
<td>KCPK (The Netherlands)</td>
<td>SAPPI Biotech Lignin</td>
<td>Beaulieu International (U.S.A.)</td>
</tr>
<tr>
<td>Green Chemistry Campus (The Netherlands)</td>
<td>University of Ghent (Belgium)</td>
<td>UPM (Finland)</td>
<td>Europe (Germany)</td>
<td>Altana, BYK (Germany)</td>
</tr>
<tr>
<td>Green Chemistry application centre (The Netherlands)</td>
<td>University of Wageningen (The Netherlands)</td>
<td>Suez (France)</td>
<td>Solvay (France, Germany, The Netherlands)</td>
<td>Henkel (Germany)</td>
</tr>
<tr>
<td>Bio Base Europe Pilot Plant (Belgium)</td>
<td>University of Antwerp (Belgium)</td>
<td>SuikerUnie (The Netherlands)</td>
<td>SABIC (The Netherlands)</td>
<td>Firmenich (Switzerland)</td>
</tr>
<tr>
<td>Bioprocess Pilot Facility (The Netherlands)</td>
<td></td>
<td>Lamb Weston (U.S.A.)</td>
<td>Zeeland Refinery (The Netherlands)</td>
<td>Lawter (U.S.A.)</td>
</tr>
<tr>
<td>European Forest Institute (EFI) (Spain)</td>
<td></td>
<td>McCain (Canada)</td>
<td>Covestro (Spain)</td>
<td>Sumitomo (Japan)</td>
</tr>
<tr>
<td>DSM (The Netherlands)</td>
<td></td>
<td>Cargill (U.S.A.)</td>
<td>BASF (Germany)</td>
<td>Alnex (Germany)</td>
</tr>
<tr>
<td>Brightlands Chemelot (The Netherlands)</td>
<td></td>
<td>Yara (Norway)</td>
<td>Laxness (Germany)</td>
<td>Nitto Europe (Belgium)</td>
</tr>
<tr>
<td>BioVale (UK)</td>
<td>Polytechnical University of Madrid (Spain)</td>
<td>Sappi (South Africa)</td>
<td>Avantium (The Netherlands)</td>
<td>Foresa (Spain)</td>
</tr>
<tr>
<td>Bio Economy Leuna (Germany)</td>
<td>University of Delft (The Netherlands)</td>
<td>Metsä Fibre (Finland)</td>
<td>Andritz (Finland)</td>
<td>Bridgestone (Belgium)</td>
</tr>
<tr>
<td>IAR (The French Bioeconomy cluster) (France)</td>
<td>University of Leipzig (Germany)</td>
<td>KCPK (The Netherlands)</td>
<td>SAPPI Biotech Lignin</td>
<td>Beaulieu International (U.S.A.)</td>
</tr>
<tr>
<td>3BI (France, Germany, the Netherlands, UK)</td>
<td>University of Ghent (Belgium)</td>
<td>UPM (Finland)</td>
<td>Europe (Germany)</td>
<td>Altana, BYK (Germany)</td>
</tr>
<tr>
<td>Bioeconomy cluster (Slovenia)</td>
<td>University of Wageningen (The Netherlands)</td>
<td>Suez (France)</td>
<td>Solvay (France, Germany, The Netherlands)</td>
<td>Henkel (Germany)</td>
</tr>
<tr>
<td>BIG-C Big Innovation Growth mega Cluster (Belgium Germany, The Netherlands)</td>
<td>University of Antwerp (Belgium)</td>
<td>SuikerUnie (The Netherlands)</td>
<td>SABIC (The Netherlands)</td>
<td>Firmenich (Switzerland)</td>
</tr>
<tr>
<td>Star-Colibri team</td>
<td></td>
<td>Lamb Weston (U.S.A.)</td>
<td>Zeeland Refinery (The Netherlands)</td>
<td>Lawter (U.S.A.)</td>
</tr>
</tbody>
</table>

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Feedstock providers as well as the end-users are interested in participating in the bio-aromatics value chain. Despite this interest, the scale for production of green building blocks is too small and the prices are inhibitive. This is caused by the lack of separation and conversion facilities in the 'product development' segment (see FIGURE 3-1) since

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53 The list of organisations presented in this table 3-1 should not be considered exhaustive. It is rather an illustrative representation of organisations currently active in the value chain of bio-based aromatics in Europe.
the establishment of a biorefinery is expensive and risky business at the moment\textsuperscript{54}. To have the capacity for the manufacturing of the bio-based products on a large scale, more biorefineries with available technologies are needed.

As of today, knowledge, technologies and separation/conversion facilities - crucial to experiment with bio-based aromatic molecules and demonstrate/pilot the use cases – are set up and as a result better accessible to a limited group consisting of universities, research and technology centres along with some large companies. Most of SMEs, on the contrary, cannot afford high investment risks to set up a biorefinery or to engage in the experimental production of the bio-based aromatic molecules. However, to meet the demand of the market, SMEs should be stimulated and involved in the process. Therefore, piloting and demonstration of use-cases should be further developed. Smaller companies should be also given a wider access to the existing biorefineries. Worth mentioning as a good practice case is BioBase Europe Pilot Plant in Belgium\textsuperscript{55}. This test facility – as a part of Bioriobozon - assists SMEs in overcoming the challenges with regard to the cost, capital equipment and expertise by offering various services such as process development, scale-up and custom manufacturing. Although a small number of similar examples already exist in Europe, more cases are needed. The extent of the scale to produce bio-based aromatics will thus depend on the availability and access to the separation and conversion facilities.

**Value chain optimisation**

There is a need for the integration of manufacturing and supply chains, with better and more efficient interaction and cooperation between innovative players from traditional sectors, building a crucial mass to engage policy makers, investors and young talents. This will increase the value added to biomass streams\textsuperscript{56}. This cooperation should also expand to the EU13 regions and countries. The current situation shows that efforts of the different ecosystems are often made in parallel, with little awareness of each other’s activities. The most active established partnerships that have been identified are concentrated in the Biobased Delta\textsuperscript{57}, where regions have a long tradition to work together. There are also smaller clusters scattered around Europe – in Italy, France, Spain, etc. However, there is hardly one pan-European way of approaching the discussed value chain.

**Supply chain optimisation needs**

To ensure the large quantities of required biomass are available, there is a need for an optimised supply chain with feedstock coming from within and outside the EU at competitive market prices. The biomass with the highest utilisation potential should be purchased\textsuperscript{58} at world market prices.

\textsuperscript{54} Based on interview data
\textsuperscript{55} Retrieved from: http://www.bbeu.org/pilotplant/
\textsuperscript{57} ARRA - The Antwerp Rotterdam Rhine Ruhr Area
4. Analysis of the EU competitive positioning

The following section analyses the positioning of the EU regions with regard to bio-based aromatics. It elaborates on the potential of the EU regions and estimates the main bottlenecks and opportunities. Europe has the potential for the development of a firm value chain, where the production processes can be covered exclusively by European companies.

At this point, European regions are notably strong in research and development of the technologies needed for the production of the bio-based aromatics with the leading centres. The manufacturing is small to non-existent, as it is also in other world regions.

4.1 Strengths and prospects of EU regions

In this sub-section, a short analysis is presented of the current and future position of the EU in bio-based aromatics, key competitive advantages of Europe, as well as regions that have the potential to be in the lead.

The current and future global position of the EU in bio-based aromatics

The development of the bio-based aromatics is closely linked to the chemical industry. Europe’s chemical industry holds a strong position worldwide despite facing low sales growth in the last years and increasing competition coming from Asia\textsuperscript{59}. That being said, Europe holds its firm place as one of the biggest markets and suppliers of the chemicals in the world. Europe’s leading regions, in particular, have the essential knowledge and technological capacity to secure a prominent position for the EU on the global bio-based aromatics market. Examples such as Bio-based Delta are considered to be global frontrunners in the development of the bio-based aromatics, gathering the main chemical clusters in the EU.

There is currently demand for the bio-based molecules – mostly coming from large companies. However, supply is insufficient and technology along with facilities is not in place. The bio-based chemicals sector is predicted to grow by 2030\textsuperscript{60}. The interviewed stakeholders are convinced that Europe should put all the necessary efforts in the development of this field; at the same time, they also stress that the development will depend on the sufficient supply of the bio-aromatic molecules.

There is also an expectation that the competition coming from the United States, Canada, Brazil and Asia will steadily increase. However, the location analysis\textsuperscript{61} has shown that globally, North-Western Europe and the United States come out as the most favourable business regions when compared with other world sugar providers such as Thailand and Brazil. One can conclude that despite sufficient feedstock in cheaper locations in Asia or Latin America, the development of the bio-based aromatics depends on additional factors such as availability of the research centres and high-tech

infrastructures, as well the political climate. Europe meets the above-mentioned conditions and has other competitive advantages that are summed up in the next section.

**Key competitive advantages of Europe**

Europe has the ecosystem and framework conditions in place conducive to R&D and innovation\(^\text{62}\). The following key competitive advantages were identified\(^\text{63}\):

- Strong and stable environment for R&D;
- Solid infrastructure for business support in comparison to the other regions worldwide (which may, however, still be insufficient to meet the demand);
- Know-how in the field of biotechnologies;
- Pool of required skills;
- Availability of the educational institutions to teach the required skills;
- Environmental consciousness and commitment;
- Legally stable environment in comparison to other global market such as Asian countries;
- Good reputation.

**Regions that could be in the lead**

At the moment, regions advancing the technology development for bio-based aromatics in Europe are concentrated in the Northern and Western parts of Europe. Flanders and various Dutch, German and Scandinavian regions are leading the way. France, Italy, Spain, Austria and the UK are also developing bio-based production facilities\(^\text{64}\).

Close cooperation among the Flemish, Dutch and German regions are facilitated under various frameworks such as, for example, Biorizon, Biobased Delta, where knowledge and financial costs are shared among different partners\(^\text{65}\).

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\(^{63}\) Based on interview data

\(^{64}\) Production facilities include headquarters (red), R&D sites (yellow), demonstration plants (blue) and production plants (green).

\(^{65}\) Based on interview data

\(^{66}\) (A) Location of the target population premises within the EU, showing headquarters (red), R&D sites (yellow), demonstration plants (blue) and production plants (green) Source: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC100357/jrc100357.pdf
This cooperation is located in the biggest chemical cluster in the world, with a favourable location to ensure large quantities of the feedstock and available knowledge and science to develop technologies that are needed for the production of the bio-based aromatics. All key players involved are present in the radius of 60 km and include some global chemical leaders such BASF, Bayer and Dow Chemicals.

These regions possess some of the largest ports in Europe, including Rotterdam and Antwerp, facilitating the imports of the needed feedstock. In addition, the proximity among the partners enables for cooperation and easy transportation. The findings of the JRC’s technical report on the EU bio-based industry (2016) are in line with this conclusion, indicating feedstock availability and proximity to R&D and commercial activities are strongly linked to the production facility location. The map in Figure 4-1 confirms that most of the facilities are concentrated in the harbours.

On a national level, one European Member State stands out not only in Europe but also on global arena: the Netherlands. According to the location analysis results, the Netherlands score above France, Belgium, Germany in Europe and higher than the United States globally.

4.2 Key risks and challenges

The following key risks and challenges for regions and regional stakeholders in the development of the bio-based aromatics market have been identified:

- **Lack of and incentives to encourage investment:** while a clear framework with incentives and support measures has been established for the development and uptake of biofuels and bioenergy, there is no specific framework for bio-based aromatics. The existing initiatives such as Bio-based Industries Joint-Undertaking (BBI JU) and the Investment Plan (EFSI) part on environment and resource efficiency cover the development of the biorefineries but have been repeatedly reported to be insufficient. In addition to biorefineries, interviewed stakeholders underlined the need for more demonstration and use-cases that will allow reduce the risks and boost the investments.

- **Low technology readiness and availability:** a considerable bottleneck in the uptake of bio-aromatics is technology development. To achieve the best results, an ecosystem has to be developed where different actors share knowledge, responsibilities and costs for the technological progress. In order for Europe to stay competitive, it is important to leap over the valley of death and achieve the TRL 8 – 9 in the shortest time possible.

- **Lack of investments in biorefineries and technologies for functionalised aromatics:** there is a tendency to limit the focus on biorefineries for the...
production of drop-in molecules\textsuperscript{72}. Facilities for the production of complex functionalised bio-aromatics require larger investments and highly innovative technologies. However, considering the immense potential of functionalised aromatics, extensive public support is merited\textsuperscript{73}.

- **Lack of a systematic approach towards feedstock:**
  - EU agriculture, forestry, fisheries and aquaculture capacities and activities are not extensive enough to ensure the right amount supply of biomass not only for industrial purposes but also for food for the coming years\textsuperscript{74}. There should be a well-designed setup of new production structures with minimal greenhouse gas emissions and mechanisms to mitigate droughts and floods.
  - At the moment, the cultivation of feedstock not yet strongly linked to the bio-based industry and crops are grown for food and feed production. In addition, the cultivation of the feedstock for the chemical industry is not sufficiently combined with the feedstock aimed for food production. Good practices where the two practices are combined exist in Europe, albeit on a small scale, and should be followed\textsuperscript{75}.
  - Due to the utilisation of large amounts of biomass for bioenergy and biofuels in particular, prices for feedstock have gone up, making it difficult for bio-aromatics producers to purchase feedstock at affordable prices\textsuperscript{76}.

- **Potential complications for small companies in the context of REACH\textsuperscript{77} registration:** As of June 2018, REACH will require registration of all substances that come on the market and/or are used in quantities that exceed 1 ton per year. The interviewed stakeholders, however, expressed their concern about the affordability of REACH registration for new types of bio-based aromatics and suggested that it could create a bottleneck for small companies\textsuperscript{78}.

- **A need to select the most promising bio-aromatics:** drop-in molecules require less transition efforts and can be adapted much quicker than the functionalised aromatics\textsuperscript{79}. In the longer term, however, functionalised aromatics allow the production of materials with new functions. Therefore, within the group of functionalised molecules, there is a need to identify building blocks with the highest industry and market potential\textsuperscript{80}.

\textsuperscript{72} European Commission (2013) D2.3 – Report on the 'Assessment of the bio-based products market potential for innovation


\textsuperscript{75} The Italian company AEP Polymers is using cashew nut shell liquid for the production of bio-aromatics. Cashew trees have a very long lifespan of 70-80 years and are known for high CO2 absorption. http://www.aeppolymers.com/funded-r-d-projects-en-002.html; Based on interview data

\textsuperscript{76} Based on interview data

\textsuperscript{77} REACH is a regulation of the European Union, adopted to improve the protection of human health and the environment from the risks that can be posed by chemicals, while enhancing the competitiveness of the EU chemicals industry. It also promotes alternative methods for the hazard assessment of substances in order to reduce the number of tests on animals. Retrieved from: https://echa.europa.eu/regulations/reach

\textsuperscript{78} Ibid.

\textsuperscript{79} Based on interview data

\textsuperscript{80} Ibid.
Lack of willingness and the hesitations of European industry regarding the use of bio-based products\textsuperscript{81}: in the current situation, many companies, large and small, still opt to produce traditional aromatics, as it implies less risk and investments\textsuperscript{82}.

4.3 Opportunities for Europe's regions

The development of bio-aromatics in the European Union will bring the following opportunities for the regional key players:

- **Growing market demand**: the European market demand for chemicals is known to be high and thriving\textsuperscript{83} and has to be further supplied. The bio-based share of the chemical production is also expected to grow, reaching estimated 30% of the total share globally\textsuperscript{84}. These prospects offer significant opportunities for green chemicals\textsuperscript{85} in Europe.
- **Access to skilled labour force**: with the availability of outstanding educational institutions, Europe can count on an extensive pool of highly-skilled labour in operations, management, science and technology\textsuperscript{86}.
- **Development of rural areas**: feedstock supply coming from Europe will be grown in the rural areas, which could attract new investments and employment for these regions\textsuperscript{87}. As an example, EUROSTAT reported that in 2013, for the production of the bio-based chemicals and chemical products, equal percentage of employers in agriculture and forestry and in manufacturing was involved. Specifically, to produce bio-based chemicals out of 1 million tonnes of dry matter of feedstock, 10,000 workers were employed in agriculture and forestry sector as well as 10,000 in manufacturing division\textsuperscript{88}.
- **CO2 reduction and increased safety**: replacing traditional chemicals with new bio-aromatics can reduce CO2 emissions, protect the environment and improve the safety and health of employees in the chemicals industry and of the general public\textsuperscript{89}. It is estimated that a transition to raw materials coming from biomass and biological conversion methods could reduce the emission of up to 2.5 billion tons of CO2 by 2030\textsuperscript{90}.

\textsuperscript{81} Based on interview data
\textsuperscript{82} Ibid.
\textsuperscript{85} European Chemical Industry Council CEFIC (2001) Aromatics: Improving the quality of your life
\textsuperscript{86} Based on interview data
\textsuperscript{87} European Commission (2013) D2.3 – Report on the ‘Assessment of the bio-based products market potential for innovation
\textsuperscript{89} COP. What’s it all about? Retrieved from http://www.cop21paris.org/about/cop21
4.4 Available support measures

Industry players are still hesitant to further embrace bio-based production and address the immature nature of the value chain. There is a need for clear incentives and public support measures.

At the moment, six EU Member States have elaborated a national strategy dedicated to bioeconomy: Finland, Germany, Sweden, Denmark, The Netherlands and Belgium. These strategies are often defined by the availability of natural resources and industry inheritance and traits.

At the European level, in 2012, the European Commission has published the Bioeconomy Strategy that aims to streamline existing policy and direct Europe’s efforts for fostering the production of renewable biological resources, based on key recommendations to addresses the transition from the use of fossil fuels to sustainable alternatives. The document aims to help the EU Member States with the development of the bioeconomy strategies.

In 2014, the public-private partnership between a consortium of bio-based industries and the European Union was set up. The 3.7 billion EUR Bio-based Industries Joint Undertaking (BBI JU) focuses on: (1) the development of new bio-refining technologies to convert biomass into bio-based products, materials and fuels in a sustainable way; (2) building new supply chains of feedstock; and (3) developing the market and policy framework. BBI JU focuses on the entire value-chain of bio-based industry. In 2016, it launched various calls directed at strengthening the value chain of innovative chemical blocks, such as a call on ‘Converting bio-based feedstocks via chemical building blocks into advanced materials for market applications’.

In 2016, 6 EU ‘model demonstrator regions’ were selected to receive consultancy support for the development of a sustainable chemical production in Europe. The European Sustainable Chemical Support Service – led by the European Commission and Centre for Intelligent Research in Crystal Engineering (CIRCE) aims at stimulating investments in sustainable chemicals production in Europe as a contribution to the development of the circular economy. The selected regions are Andalusia (Spain), Groningen-Drenthe (The Netherlands), Kosice (Slovakia), Scotland (United Kingdom), South and Eastern Ireland, and Wallonia (Belgium). The project, among others, will: (1) contribute to the reduction of the fossil-based feedstock imports; (2) engage regional authorities in the development of sustainable chemicals industry; (3) boost the creation of new companies and employment numbers and (4) improve the economy in rural areas.

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91 Based on interview data
92 Source: http://bioenergyconnection.org/article/bioeconomy-everywhere
5. Policy implications

The current section aims to present specific policy recommendations on what needs to be done in order to strengthen the EU competitive position regarding this product in the coming years, and specifically on how to enable European industry to move to the higher end of the value chain.

5.1 Measures with immediate focus

The following measures with immediate focus have been identified:

- **EU-coordinated actions focused on supporting and strengthening inter-regional cooperation and its value chain complementarities**: the shift towards bio-based aromatics requires inter-regional cooperation and shared investments in the development of technologies and facilities, bringing opportunities to the regions to engage in joint projects and initiatives. These actions should focus on the creation of long term inter-regional cooperation between relevant stakeholders in developing the bio-aromatics infrastructures, products and market.
  - The Smart Specialisation Strategy Partnerships and the Vanguard Initiative are good examples of ongoing inter-regional cooperation. Infrastructure and technologies required for the development and production of the bio-aromatics is not easy-accessible and is seen as a risky investment. **Sharing technologies and facilities among different regions will allow to achieve higher results and reduce risks.**
  - Biorizon – shared research centre - is a good practice example of inter-regional research, which could be replicated or scaled up in other parts of Europe.

- **Expanding the number of demonstration and testing facilities**: aiming at accelerating the shift towards bio-based production and filling in the gap in the product development stage of the value chain in particular, more infrastructure should be created in Europe. Testbeds should allow the companies experiment, test and apply new technologies without a need of uncertain investments in setting up bio-refineries. To reduce the costs, facilities should be setup within the interregional cooperation.
  - Bio-base Europe Pilot Plant assists SMEs in overcoming challenges related to technologies, expertise, equipment and others. Similar facilities - within an interregional framework – should be made available to the European businesses.

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100 Based on interview data
5 Policy implications

- **New funds for the piloting and demonstration of use-cases in bio-based aromatics**: before the companies can engage in the development of bio-aromatics and apply new technologies, more pilot projects and demonstration use cases are needed. This will considerably reduce the financial risks and create a future outlook with greater certainty and stability for the stakeholder companies.\(^{101}\)

- **Further developing EU standards**, the EU is working towards the development of the standards and regulations for the bio-based products. SRAT4BBI\(^{102}\) analyses the regulatory and standards framework impacting the bio-based industry in Europe. Within the EU policy, Lead Market Initiative supports bio-based products with policy instruments, including public procurement, regulation and standardisation. Under the framework of the initiative, the EC gave a mandate to European Committee for Standardisation (CEN)\(^{103}\), that works towards the development of the standards in the fields of bio-lubricants, bio-surfactants, bio-solvents and bio-polymers. In the meantime, CEN has already generated horizontal standards as well as standards for specific types of products in a format of European Norms, Technical Reports and Technical Specifications related to common terminology, methods to determine bio-based content, test methods and others.\(^{104}\)

- **Campaigns to raise awareness of the benefits and opportunities of the transition to bio-based chemicals**\(^{105}\): currently, there is a good understanding on the benefits of biofuels and bioenergy for the environment and the economy. As the benefits coming from bio-aromatics are expected to create even greater impact, it is important to ensure that European industries and the entire community in general can correctly estimate the positive impact. In combination with financial and regulatory incentives, the awareness raising campaigns are likely to create an environment with more actors willing to make a shift to bio-based production.\(^{106}\)

### 5.2 Measures with longer-term focus

The following measures with longer-term focus have been identified:

- **To stimulate technology development for industrial scale**\(^{107}\): as the bio-aromatics are still at the R&D stage in Europe, it is important to ensure a rapid development of the technologies that will allow for the production of large quantities of new bio-based aromatics to further manufacture bio-aromatic-based commodities and materials. It is of a crucial importance that Europe identifies and invests in the most promising technologies and the production of the bio-aromatic molecules with a great potential and industrial applications.

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\(^{101}\) Based on interview data

\(^{102}\) Retrieved from: http://www.biobasedeconomy.eu/research/star4bbi/

\(^{103}\) Retrieved from: https://www.cen.eu/work/areas/pages/default.aspx


\(^{105}\) Based on interview data

\(^{106}\) Ibid.

\(^{107}\) Ibid.
• **Reductions in the use of biomass for bioenergy**\(^{108}\):  
  o At the moment, much of the biomass is often wasted to produce biofuels and bioenergy. A more sustainable approach is needed in which biomass is used in the production of bio-aromatic molecules.  
  o Companies responsible for the delivery of biofuels and bioenergy could be stimulated by subsidies for the production of biomass to be used in bio-aromatics.

• **Financial incentives to promote investments in the production of bio-based chemical building blocks**: there is a strong need for financial and policy incentives to foster general interest in the production of bio-based chemical building blocks that will stimulate the technology development. More key players should be involved at every stage of the value chain with specific focus on the conversion and separation facilities. The provision of the financial framework will reduce the risks for companies and trigger greater participation to engage into bio-based development, scale up and production\(^{109}\).

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\(^{109}\) Based on interview data
Annex A: List of interviewees

Table A-1: Overview of the interviewed stakeholders

<table>
<thead>
<tr>
<th>Nr</th>
<th>Name</th>
<th>Position</th>
<th>Organisation</th>
<th>Country</th>
<th>Stakeholder type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ludo Diels</td>
<td>Professor; Scientific manager</td>
<td>Vito, Biorizon</td>
<td>Belgium</td>
<td>R&amp;D</td>
</tr>
<tr>
<td>2</td>
<td>Joop Groen</td>
<td>Business Development Manager</td>
<td>TNO, Biorizon</td>
<td>The Netherlands</td>
<td>R&amp;D</td>
</tr>
<tr>
<td>3</td>
<td>Thomas David</td>
<td>Senior Scientist</td>
<td>VTT</td>
<td>Finland</td>
<td>R&amp;D</td>
</tr>
<tr>
<td>4</td>
<td>Andrea Minigher</td>
<td>Head of Business Development Department</td>
<td>AEP Polymers</td>
<td>Italy</td>
<td>SME</td>
</tr>
<tr>
<td>5</td>
<td>Berend Vreugdenhil</td>
<td>Scientist</td>
<td>Energy research Centre of the Netherlands</td>
<td>The Netherlands</td>
<td>R&amp;D</td>
</tr>
<tr>
<td>6</td>
<td>Emilia Moisio</td>
<td>Sales Director</td>
<td>Metsa Fibre</td>
<td>Finland</td>
<td>Large company</td>
</tr>
<tr>
<td>7</td>
<td>Mikel Irujo Amezaga</td>
<td>Head of Delegation</td>
<td>Delegation of the Government of Navarra</td>
<td>Spain</td>
<td>Regional authority</td>
</tr>
</tbody>
</table>

Acknowledgments

We would like to express our gratitude to Ludo Diels, Joop Groen, Thomas David, Andrea Minigher, Berend Vreugdenhil, Emilia Moisio and Mikel Irujo Amezaga for their fruitful insights and expert opinions essential for drafting this case study report.