Bio-based Building Blocks and Polymers

Global Capacities and Trends 2016–2021

Bio-based polymers: Evolution of worldwide production capacities from 2011 to 2021

Authors: Florence Aeschelmann (nova-Institute), Michael Carus (nova-institute) and ten renowned international experts

This is the short version of the full market study (about 500 pages, €4,750). Both are available at www.bio-based.eu/markets.
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Bio-based Building Blocks and Polymers – Global Capacities and Trends 2016–2021

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Michael Carus (V.i.S.d.P.)

nova-Institut GmbH
Chemiepark Knapsack
Industriestraße 300
50354 Hürth, Germany

Authors of the short version
Florence Aeschelmann (nova-Institute)
florence.aeschelmann@nova-institut.de,

Michael Carus (nova-Institute)
michael.carus@nova-institut.de

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All European Bioplastics graphs can be downloaded at www.european-bioplastics.org/market

Please find the table of contents of the full report with market data, trend reports and company data, containing about 500 pages and 200 tables and figures, on pages 19–21.
European Bioplastics (EUBP), the European association representing the interests of the bioplastics industry along the entire value chain, serves as both knowledge partner and business network for companies, experts, and all relevant stakeholder groups of the industry. Our primary task is to raise awareness and inform policy makers, businesses, and the interested public about the properties, benefits, and potentials of bioplastics for a sustainable society. We therefore provide comprehensive information on all relevant topics surrounding bioplastics, including an annual global market data update, for which we rely on the longstanding market research expertise of the nova-Institute. Our market data update 2016 has been conducted together with the nova-Institute and is based on the study ‘Bio-based Building Blocks and Polymers’, from which we extract the data for our defined scope of new economy bioplastics. For more information, please visit www.european-bioplastics.org/market

We offer a €1,000 discount on the first year’s membership fee for organisations that join EUBP in connection with the purchase of this study by nova-Institute.

If you would like to know more about our activities, our members, or the benefits of becoming a member of European Bioplastics, go to our website www.european-bioplastics.org or contact us directly at info@european-bioplastics.org.

Kind regards,
Hasso von Pogrell,
Managing Director of European Bioplastics

A warm welcome to all readers of our free summary of our comprehensive market study on “Bio-based Building Blocks and Polymers”.

The full report is unique and gives you the most comprehensive insight in the bio-based world market with latest data on capacities and applications and trend reports for all relevant bio-based building blocks and polymers. What makes the report unique?

- We have formed a high-level expert group from Asia, Europe and the US with direct contact to the leading bio-based building block and polymer producers in the world.
- We show real data for the year 2016 and forecast for 2021.
- We are updating our data every year, so we have now continuous data for the last 5 years.
- The trend reports give in-depth information that you cannot normally find in reports.
- The high and outstanding quality of our market study is proved by three facts:
  - European Bioplastics decided to use only data from our expert team.
  - Leading brands are buying our report year by year.
  - If you are not satisfied with our report, you can give it back and will get your money back – so far nobody did!

Don’t miss the future of building blocks and polymers – stay informed with the nova market report on “Bio-based Building Blocks and Polymers”.

Enjoy our solid data and analysis, we are looking forward to your feedback.

Michael Carus & Florence Aeschelmann
Bio-based polymers’ growth rates at same level as global polymers: Worldwide production capacity is forecasted to increase from 6.6 million tonnes in 2016 to 8.5 million tonnes in 2021. In contrast to a 10% annual growth between 2012 and 2014, the capacity growth data now show a 4% annual growth rate from 2015 to 2021 – which is almost the same as for the overall global polymer capacity. The main reasons for this slow increase in capacity are low oil prices, low political support and a slower than expected growth of the capacity utilization rate.

The new fourth edition of the most comprehensive market study of bio-based building blocks and polymers will be available in January 2017. It includes consistent data from the year 2012 to the latest data of 2016 and the recently published data from European Bioplastics, the association representing the interests of Europe’s bioplastics industry. This update expands the market study’s range, including further bio-based building blocks as precursor of bio-based polymers. The nova-Institute carried out this study in collaboration with renowned international experts from the field of bio-based building blocks and polymers.

The study investigates every kind of bio-based polymer and major building blocks produced around the world.

The annual capacity growth rate for bio-based polymers has been slowed down sharply since it has been reduced by more than half since 2015. The lower annual growth rate is due to several factors: the low oil prices, the unfavourable political framework in most countries, a slower than expected growth of the capacity utilization rate and the populist debates about using food crops for industry use.

Figure 1: Pathways to bio-based polymers (nova-Institute 2016)
However, some bio-based polymers are still showing an impressive growth. The new polymer PHA, the high-performance PA and bio-based drop-in PET show the fastest rates of market growth. The bio-based polymer turnover is about € 13 billion worldwide in 2016 compared to € 11 billion in 2014.

**Share of bio-based polymers in the total polymer market**

The bio-based share of overall polymer capacity had grown over the years: it was 1.4% in 2011. In recent years, the bio-based share has been stagnating at approximately 2%. The bio-based polymer annual capacity growth rate is currently similar to the global polymer annual capacity growth rate of 3–4%.

This study focuses exclusively on bio-based building block and polymer producers, and the market data therefore does not cover the bio-based plastics branch. We must clearly differentiate between these two terms. A polymer is a chemical compound consisting of repeating structural units (monomers) synthesized through a polymerization or fermentation process, whereas a plastic material constitutes a blend of polymers, additives and fillers, whose granulates are ready for use for the industry. Only a strict differentiation can avoid double counting.

Table 1 gives an overview on the covered bio-based polymers and the producing companies with their locations and production capacities from 2012 to 2016 with corresponding growth rates. Detailed data for 2015 and 2016 are available in the full study.

<table>
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<tbody>
<tr>
<td>Cellulose acetate</td>
<td>CA</td>
<td>50%</td>
<td>16</td>
<td>19</td>
<td>835,000</td>
<td>860,000</td>
<td>1%</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Epoxies</td>
<td>–</td>
<td>30%</td>
<td>–</td>
<td>–</td>
<td>1,000,000</td>
<td>1,500,000</td>
<td>22%</td>
<td>–</td>
</tr>
<tr>
<td>Ethylene propylene diene monomer rubber</td>
<td>EPDM</td>
<td>50% to 70%</td>
<td>1</td>
<td>1</td>
<td>45,000</td>
<td>45,000</td>
<td>0%</td>
<td>–</td>
</tr>
<tr>
<td>Polyamides</td>
<td>PA</td>
<td>40% to 100%</td>
<td>9</td>
<td>13</td>
<td>75,000</td>
<td>105,000</td>
<td>18%</td>
<td>1,000,000</td>
</tr>
<tr>
<td>Poly(butylene adipate-co-terephthalate)</td>
<td>PBAT</td>
<td>Up to 50%**</td>
<td>4</td>
<td>4</td>
<td>75,000</td>
<td>100,000</td>
<td>15%</td>
<td>1,100,000</td>
</tr>
<tr>
<td>Polybutylene succinate</td>
<td>PBS</td>
<td>Up to 100%**</td>
<td>8</td>
<td>8</td>
<td>125,000</td>
<td>125,000</td>
<td>0%</td>
<td>1,400,000</td>
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<tr>
<td>Polyethylene</td>
<td>PE</td>
<td>100%</td>
<td>1</td>
<td>1</td>
<td>200,000</td>
<td>200,000</td>
<td>0%</td>
<td>1,100,000</td>
</tr>
<tr>
<td>Polyethylene terephthalate</td>
<td>PET</td>
<td>20%</td>
<td>4</td>
<td>5</td>
<td>800,000</td>
<td>1,000,000</td>
<td>12%</td>
<td>800,000</td>
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<td>Polyhydroxyalkanoates</td>
<td>PHA</td>
<td>100%</td>
<td>19</td>
<td>21</td>
<td>30,000</td>
<td>35,000</td>
<td>8%</td>
<td>30,000</td>
</tr>
<tr>
<td>Poly(lactic acid)</td>
<td>PLA</td>
<td>100%</td>
<td>26</td>
<td>32</td>
<td>180,000</td>
<td>195,000</td>
<td>4%</td>
<td>180,000</td>
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<td>Polytrimethylene terephthalate</td>
<td>PTT</td>
<td>27%</td>
<td>2</td>
<td>3</td>
<td>90,000</td>
<td>120,000</td>
<td>15%</td>
<td>90,000</td>
</tr>
<tr>
<td>Polyurethanes</td>
<td>PUR</td>
<td>10% to 100%</td>
<td>–</td>
<td>–</td>
<td>1,100,000</td>
<td>1,400,000</td>
<td>13%</td>
<td>1,100,000</td>
</tr>
<tr>
<td>Starch blends***</td>
<td>–</td>
<td>25% to 100%</td>
<td>16</td>
<td>17</td>
<td>365,000</td>
<td>395,000</td>
<td>4%</td>
<td>395,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>106</td>
<td>124</td>
<td>4,020,000</td>
<td>6,080,000</td>
<td>11%</td>
<td>6,555,000</td>
</tr>
</tbody>
</table>

* Bio-based carbon content: fraction of carbon derived from biomass in a product (EN 16575 Bio-based products – Vocabulary)

** Currently still mostly fossil-based with existing drop-in solutions and a steady upward trend

*** Starch in plastic compound

Green: Growth over the previous year

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Bio-based polymers

In 2016, the association “European Bioplastics” used exclusively nova-Institute’s market study as its data source for their recently published market data. European Bioplastics’s selection of bio-based polymers and time span differ from nova-Institute’s. nova-Institute decided to cover further bio-based polymers by including further bio-based thermosets (epoxies and ethylene propylene diene monomer rubber (EPDM)) and cellulose acetate (CA).

Figure 2 shows European Bioplastics’s growth projection of bio-based polymers production; these could grow from 4.2 million tonnes in 2016 to 6.1 million tonnes in 2021 in absolute terms.¹ The market is clearly dominated by bio-based and non-biodegradable polymers. Bio-based polyurethanes (PUR) and drop-in bio-based polyethylene terephthalate (PET) lead this category. Drop-in bio-based polymers are chemically identical to their petrochemical counterparts but at least partially derived from biomass. European Bioplastics uses plastic as a synonym for polymer.

The global capacities in 2016 and 2021 have been split by material type in Figures 3 and 4 respectively. Bio-based PUR and PET are the overall market leaders. PUR share is expected to remain stable and PET share is expected to grow from 22.8% in 2016 to 28.2% in 2021. As a

¹ Market data graphs are available for download in English and German: www.european-bioplastics.org/market
Global production capacities of bioplastics 2016 (by material type)

- **Other (bio-based/non-biodegradable)**: 4.6%
- **PET**: 22.8%
- **PA**: 3.5%
- **PEF**: 0.0%
- **PE**: 4.8%
- **PUR**: 41.2%
- **Total**: 4.16 million tonnes

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Percentage</th>
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</thead>
<tbody>
<tr>
<td>PBAT</td>
<td>2.5%</td>
</tr>
<tr>
<td>PBS</td>
<td>2.8%</td>
</tr>
<tr>
<td>PLA</td>
<td>5.1%</td>
</tr>
<tr>
<td>PHA</td>
<td>1.6%</td>
</tr>
<tr>
<td>Starch blends</td>
<td>10.3%</td>
</tr>
<tr>
<td>Other (biodegradable)</td>
<td>0.8%</td>
</tr>
<tr>
<td><strong>Bio-based/non-biodegradable</strong></td>
<td>76.8%</td>
</tr>
<tr>
<td><strong>Biodegradable</strong></td>
<td>23.2%</td>
</tr>
</tbody>
</table>

*PEF is currently in development and predicted to be available in commercial scale in 2020.

More information: [www.bio-based.eu/markets](http://www.bio-based.eu/markets) and [www.european-bioplastics.org/market](http://www.european-bioplastics.org/market)

Figure 3: Global production capacities of bioplastics 2016 (by material type) (European Bioplastics 2016)

Global production capacities of bioplastics 2021 (by material type)

- **Other (bio-based/non-biodegradable)**: 3.1%
- **PET**: 28.2%
- **PA**: 4.4%
- **PEF**: 1.1%
- **PE**: 3.3%
- **PUR**: 39.3%
- **Total**: 6.11 million tonnes

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBAT</td>
<td>1.7%</td>
</tr>
<tr>
<td>PBS</td>
<td>1.9%</td>
</tr>
<tr>
<td>PLA</td>
<td>5.3%</td>
</tr>
<tr>
<td>PHA</td>
<td>4.1%</td>
</tr>
<tr>
<td>Starch blends</td>
<td>7.1%</td>
</tr>
<tr>
<td>Other (biodegradable)</td>
<td>0.5%</td>
</tr>
<tr>
<td><strong>Bio-based/non-biodegradable</strong></td>
<td>79.4%</td>
</tr>
<tr>
<td><strong>Biodegradable</strong></td>
<td>20.6%</td>
</tr>
</tbody>
</table>

More information: [www.bio-based.eu/markets](http://www.bio-based.eu/markets) and [www.european-bioplastics.org/market](http://www.european-bioplastics.org/market)

Figure 4: Global production capacities of bioplastics 2021 (by material type) (European Bioplastics 2016)
consequence, the bio-based non-biodegradable polymers market is expected to grow further since bio-based PUR and PET are part of this category. In 2016 and in 2021 distant runner-ups behind bio-based PUR and PET are starch blends and polylactic acid (PLA).

Figures 5 and 6 show the main results of nova-Institute’s survey and market analysis. Production capacity of bio-based polymers is forecasted to increase from 6.6 million tonnes in 2016 to 8.5 million tonnes by 2021. In recent years, the development of production capacity for bio-based polymers showed a compound annual growth rate (CAGR) of 4%, which is very similar to petrochemical polymers. Due to their broader scope, nova-Institute’s projected production capacities are much higher than those projected by European Bioplastics.

The 6.6 million tonnes bio-based polymer production capacity represent approximately a bio-based polymer turnover of about €13 billion (6.6 Mio. t (production capacity) x €2.50/kg (estimated average bio-based polymer price) x 0.8 (capacity utilization rate)).

The most dynamic development is foreseen for the new bio-based polymers polyhydroxyalkanoates (PHA), which is a big family of different polymers. PHA production capacity is still small in 2016 and is projected to almost triple by 2021. The second most dynamic development is foreseen for polyamides (PA), whose production capacity is expected to almost double by 2021. Bio-based drop-in PET and new bio-based polymer PLA are showing interesting growth as well with an approximately 10% annual growth rate.
Bio-based epoxies, PUR, CA and PET have huge production capacities with a well-established market in comparison with other bio-based polymers. However, other bio-based polymers listed on Figure 6 show strong growth as well. Figure 6 shows the evolution of worldwide production capacities only for selected bio-based polymers (without bio-based epoxies, PUR, CA and PET). Some of these polymers are brand new bio-based polymers. That is why their markets are smaller and need to be developed correspondingly.

Here are some details on each bio-based polymer covered in the report by alphabetical order:

**Aliphatic polycarbonates (APC)** are a big family of polymers. Most of the bio-based APC are still in an early stage development. The most well-known bio-based APC is probably DURABIO™ from Mitsubishi. This isosorbide-based polymer can be used in screens and automotive interior parts since it features high transparency and very good optical properties.

**Cellulose acetate (CA)** is 50% bio-based (only bio-based carbon content\(^2\) considered in this report). This market is similar to that of epoxies: well established, for example cigarette filters and frames for glasses are made from CA.

**Epoxies** are approximately 30% bio-based and are produced out of bio-based epichlorohydrin, which is produced from glycerol, a by-product of the biodiesel industry. The market is well established since epoxies have already been partly bio-based for a long time. Production capacities of bio-based epoxies and epichlorohydrin are expected to remain steady until 2021. Further epichlorohydrin projects are currently placed on hold due to the low oil prices.

**Ethylene propylene diene monomer rubber (EPDM)** is made out of bio-based ethylene and can be 50% to 70% bio-based. Specialty chemicals company Lanxess is currently producing bio-based EPDM in Brazil. The market is small but a steady growth is expected in the coming years through the development of new grades and new applications.

**Polyamides (PA)** are a big family since there are many different types of polyamides. This explains the wide range of bio-based carbon content: from 40% to 100%. Polyamides are generally based on sebacic acid, which is produced from castor oil. Evonik has recently developed a polyamide based on palm kernel oil. Production is expected to almost double by 2021. The market is headed by one big player, Arkema. Cathay Industrial Biotech entered the market in 2015 and planned an expansion in the coming years.

**Poly(butylene adipate-co-terephthalate) (PBAT)** is also currently mostly fossil-based. PBAT is produced from 1,4-butanediol (1,4-BDO), terephthalic acid (TPA) and adipic acid (AA). PBAT is biodegradable. PBAT can theoretically be up to 50% bio-based since bio-based adipic acid is not available yet. It is currently still at the research stage. PBAT has mostly been produced by one big company, BASF, but a new player, Jinhui Zhaolong High Technology, entered the market in 2014.

**Polybutylene succinate (PBS)** is biodegradable and currently mostly fossil-based but could in theory be 100% bio-based. PBS is produced from 1,4-BDO, succinic acid and often in combination with a third monomer. The building blocks are available bio-based but 1,4-BDO entered the market only in 2016. PBS is currently produced exclusively in Asia. In 2016, PTT MCC Biochem opened its new facility in Thailand. Further new projects are not expected in the coming years due to the low oil prices.

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2 Bio-based carbon content: fraction of carbon derived in a product (EN 16575 Bio-based products from biomass – Vocabulary)
Polyethylene (PE) is a 100% bio-based drop-in polymer. The bio-based building block needed is bio-based ethylene, which is made out of sugar cane. Brazilian petrochemical company Braskem produces bio-based PE in Brazil. Bio-based PE has been on the market for a few years but its production capacity has hitherto remained the same. Further developments have been slowed down because of the shale gas boom.

Polyethylene furanoate (PEF) is 100% bio-based and is produced out of bio-based 2,5-furandicarboxylic acid (2,5-FDCA) and monoethylene glycol (MEG). PEF is a brand new polymer, which is expected to enter the market in 2020. PEF is comparable to PET. PET is used in bottle production and PEF is intended to be used for this application as well. However, PEF is said to have better properties, such as better barrier properties, than PET. Several companies are active on the monomer and polymer developments for this product.

Polyethylene terephthalate (PET) is currently 20% bio-based and produced out of bio-based MEG and TPA as a drop-in bio-based polymer. TPA is currently still petro-based but subject to ongoing R&D, small amounts of bio-based TPA can already be produced at pilot scale. Most bio-based PET and MEG are produced in Asia. Bio-based PET is one of the leaders of the bio-based polymers market. This is largely due to the Plant PET Technology Collaborative (PTC) initiative launched by The Coca Cola Company. However, PET development has recently sharply slowed down due to decision of the stakeholders. For this reason, the current forecast strongly differs from the forecast in our last report from December 2015.
Polyhydroxyalkanoates (PHA) are 100% bio-based and biodegradable even in cold sea water. PHA are produced through a fermentation process mainly by specific bacteria. Many different companies are involved in the production of many different PHA products, which cannot be compared to each other. The market is currently small but is expected to grow tremendously. PHA are brand new polymers, which means their market still needs time to fully develop. Nevertheless, PHA producers and several new players are optimistic and see potential in PHA. Therefore, production capacity is expected to have grown threefold by 2021. Several sugar companies are investing in PHA.

Polylactic acid (PLA) is 100% bio-based and biodegradable but only under certain conditions: PLA is industrially compostable. Produced by numerous companies worldwide, with NatureWorks as market leader, PLA is the most well established new bio-based polymer. However, the PLA market is still expected to grow further, with a projected annual growth rate of 10% until 2021. PLA can already be found at near-comparable prices to fossil-based polymers. Corbion, one leading producer of lactic acid, will build its first PLA plant in the coming years in Thailand.

Polytrimethylene terephthalate (PTT) is 27% bio-based and made out of bio-based 1,3-propanediol (1,3-PDO) and currently petro-based TPA. PTT is comparable to PET since both have TPA as precursor. Bio-based PTT and 1,3-PDO are produced by DuPont. The market is well established and production capacity increased in 2016 due to the very good market acceptance.

Polyurethanes (PUR) can be 10% to 100% bio-based. PUR can be produced from natural oil polyols (NOP), but also from APC based polyols and the first bio-based isocyanate. Bio-based succinic acid can be used to replace adipic acid. The global PUR market (including petro-based PUR) is continuously growing but the bio-based PUR market is expected to grow faster.

Starch blends are completely biodegradable and 25% to 100% bio-based, with starch added to one or several polymers. Many players are involved in the production of starch blends but Italian company Novamont is currently market leader. Production capacity is expected to remain steady. In 2015, Roquette decided to stop the production of starch blends due to the decrease of oil prices and the delay in the implementation of a favourable legislative and regulatory environment in Europe. However, the French market became attractive in 2016 for starch blend producers through the new French law on bags.

In short, the most dynamic development is expected for new bio-based polymer PHA, with a significant projected production capacity by 2021, which means a threefold growth. Second is PA with an almost twofold growth until 2021. Bio-based drop-in PET and new bio-based polymer PLA are showing interesting growth as well with an approximately 10% annual growth rate.

Detailed information on the development of bio-based polymers can be found in the full study, in the data part as well as in specific trend reports.

Bio-based building blocks as a precursor of bio-based polymers
The market study’s range has been expanded by including further bio-based building blocks as precursor of bio-based polymers. Seven new bio-based building blocks are included in the study, which brings the number of reported building blocks to seventeen. The total production capacity of the bio-based building blocks reviewed in this study is 2.4 million tonnes in 2016 and is expected to reach 3.5 million tonnes in 2021, which means a CAGR of 8%.

The bio-based building block annual capacity growth rate is twice as high as the bio-based polymer annual capacity growth rate. The most dynamic developments are spearheaded by succinic acid and 1,4-BDO, with MEG as a distant runner-up. Bio-based MEG, L-lactic acid (L-LA), ethylene and epichlorohydrin are relatively well established on the market.
These bio-based building blocks cover most of the total production capacity. They are expected to keep on growing, especially bio-based MEG, whereas L-LA, bio-based ethylene and epichlorohydrin are projected to grow at lower rate or even to stagnate. However, the most dynamic developments are spearheaded by succinic acid and 1,4-BDO. Both are brand new drop-in bio-based building blocks on the market. The first facilities are currently running and more will be built in the coming years. Figure 7 shows the evolution of worldwide production capacities for some major building blocks.

Here are some details on each bio-based building block covered in the report by alphabetical order:

**Adipic acid (AA)** is a very important building block for a wide range of polymers such as polyamides and polyurethanes. Bio-based AA is not available yet but a lot of companies are developing bio-based routes to adipic acid. R&D has slowed down due to low prices for petro-based AA. The first demonstration plant is expected to be built in the coming years.

**11-Aminoundecanoic acid (11-AA)** is an eleven carbon atoms dicarboxylic acid and is produced by Arkema. 11-AA is used for the production of long chain polyamides with unique properties. Capacity production is small and stable.

**1,4-Butanediol (1,4-BDO)** is a versatile building block. 1,4-BDO can directly be produced from biomass or indirectly from succinic acid. The first producers of bio-based 1,4-BDO have recently entered the market. In October 2016, Novamont opened its first industrial plant for the production of bio-based 1,4-BDO via direct fermentation in Italy.

**Dodecanedioic acid (DDDA)** is a twelve carbon atoms dicarboxylic acid. DDDA is used for the production of long chain polyamides such as PA 6,12 and lubricants. Current production capacity is small but further investments are expected.

**Epichlorohydrin** is one of the building blocks of epoxies. Glycerin, which is a by-product of the production of biodiesel, is used as feedstock. Production capacities of bio-based epoxies and epichlorohydrin are expected to remain steady until 2021. Further epichlorohydrin projects are currently placed on hold due to the low oil prices.

**Ethylene** is PE’s building block. Bio-based ethylene is currently made from sugar cane in Brazil. Further developments have slowed down because of an extreme price drop in petro-based ethylene that happened, among other things, due to the shale gas boom.

**2,5-Furandicarboxylic acid (2,5-FDCA)** can be combined with MEG to produce polyethylene furanoate (PEF). 2,5-FDCA is a brand new building block which is expected to come to the market in 2020. Avantium is deeply involved in 2,5-FDCA but others such as AVA-CO2 are also showing interest. In October 2016, Avantium and BASF announced the formation of the joint venture Synvina for the production and marketing of 2,5-FDCA and the marketing of PEF.

**Isosorbide** is produced from sorbitol by the company Roquette. Isosorbide can be used for the production of aliphatic polycarbonates as a substitute for bisphenol A. Other possibilities are the use of isosorbide for epoxy resins and plasticizers. Production capacity is small but Roquette expanded its capacity in 2015.

**L-Lactic acid (L-LA)** is PLA’s building block, together with **D-lactic acid (D-LA)**. Both are optical isomers of LA. **Lactide** is an intermediate between LA and PLA. It can be bought as such to produce PLA. A lot of different companies are involved in this business worldwide since most LA has long been used in the food industry mainly as a food preservative, pH regulator and flavouring agent. The production capacities do not only include LA used for polymer production, but also for the food industry. It is estimated that more than a half of LA is used by the food industry.
Monoethylene glycol (MEG) is one of PET's building blocks. Bio-based MEG is a drop-in which is mostly produced in Asia. The fast increase in bio-based PET production has had a considerable impact on the production capacities of bio-based MEG. Bio-based PET is actually one of the leading bio-based polymers, which is largely due to the Plant PET Technology Collaborative (PTC) initiative launched by The Coca-Cola Company. However, PET development has recently sharply slowed down due to decision of the main stakeholders.

Monopropylene glycol (MPG) is mostly produced from biodiesel by-product glycerin. MPG can be used in a wide range of applications such as antifreeze, de-icing fluids, resins, detergents and cosmetics. Production capacity is expected to grow to some extent since a new project is in the pipeline.

1,5-Pentamethylenediamine (DN5) is a five carbon atoms diamine and is one of the rare bio-based diamines available on the market. This building block is widely used in the production of polyamides such as PA 5,6, PA 5,11 and PA 5,12. PA 5,6 is intended for the fabrication of textile fibres. Production capacity of DN5 is currently small but is expected to grow in the coming years.

1,3-Propanediol (1,3-PDO) is one of PTT’s building blocks. 1,3-PDO is mostly produced from corn by DuPont Tate & Lyle Bio Products. The market is well established. Production capacity is expected to remain steady in the coming years.

Sebacic acid is a ten carbon atoms dicarboxylic acid, which is produced from castor oil. This building block is widely used in the production of
long chain polyamides such as PA 4,10, PA 6,10 and PA 10,10. It can also be used in personal care and lubricants. Production capacity, which is mostly based in Asia, is well established.

**Succinic acid** is a very versatile building block. Bio-based polymers such as PBS can be made of succinic acid but also other bio-based building blocks such as 1,4-BDO. It can be used as well in PUR to replace adipic acid. However, the market is still in the early stage of development. Petro-based succinic acid is not a big market since petro-based succinic acid is relatively expensive. Bio-based succinic acid is actually much cheaper to produce than its petro-based counterpart. The first facilities have been running since 2012, in 2015 BioAmber opened its new facility in Canada and additional plants from different investors are already in the pipeline.

Detailed information on the development of bio-based building blocks and the producing companies can be found in the full study.

**Investment by region**

Most investment in new bio-based polymer capacities will take place in Asia because of better access to feedstock and a favourable political framework. Figures 8 and 9 show the 2016 and 2021 global production capacities for bio-based polymers repartitioned by region. European Bioplastics published these market data, which take into account fewer types of bio-based polymers than the full report. Due to the complexity of the manufacturing value chain structure of epoxies and cellulose acetate, the repartitions by region cannot be reliably determined for all bio-based polymers. As a result, a graph representing the repartition by region with the full scope is not provided in the report, but only for the subgroup selected by European Bioplastics.

Europe’s share and North America’s share are projected to remain almost stable, from 27.1% to 26.0%, and from 23.4% to 22.5% respectively, whereas Asia’s is predicted to increase from

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Figure 8: Global production capacities of bioplastics in 2016 (by region) (European Bioplastics 2016)

Figure 9: Global production capacities of bioplastics in 2021 (by region) (European Bioplastics 2016)
43.4% to 46.9%. South America is set to fall from 5.9% to 4.4%. In other words, world market shares are expected to remain relatively stable. All regions are predicted to experience developments in the field of bio-based building block and polymer production.

**Production capacities in Europe**

Figure 10 shows the evolution of production capacities in Europe without bio-based thermosets (epoxies and PUR) and cellulose acetate. Europe’s position in producing bio-based polymers is limited to a few polymers. Europe has so far established a solid position mainly in the field of starch blends and is expected to remain strong in this sector for the next few years. This can be traced back to Italy’s Novamont, a leading company in this field. Bio-based PA production is partly based in Europe and is likely to continue supplying for the growing markets of the building and construction and automotive sectors. Europe does have industrial production facilities for PBAT which is still fully fossil-based. However, judging by industry announcements and the ever-increasing capacity of its bio-based precursors, PBAT is expected to be increasingly bio-based. In Europe, PLA production facilities are not only small in size but also small in number. Asia produces most of the bio-based PET but Europe also produces this polymer to a lesser extent. Nevertheless, a number of developments and investments are foreseen in Europe. PHA is currently not produced in Europe but the first industrial PHA plants are expected to be built in Europe in the coming years. Production of PEF, which is expected to enter the market in 2020, is intended to take place in Europe.

One noteworthy finding of demand studies is that Europe shows the strongest demand for bio-based polymers, while production tends to take place elsewhere, namely in Asia. Housing the leading chemical corporations, Europe is particularly strong and has great potential in the
fields of high value fine chemicals and building blocks. However, only few specific, large-scale plans for bio-based building blocks incorporating concrete plans for the production of bio-based polymers have been announced to date.

The European Union’s relatively weak position in the production of bio-based polymers is largely the consequence of an unfavourable political framework. In contrast to bioenergy and biofuels, there is no European policy framework to support bio-based chemicals and polymers, whereas bioenergy and biofuels receive strong and ongoing support during commercial production (quotas, tax incentives, green electricity regulations, market introduction programs, etc.). Without comparable support, bio-based chemicals and polymers will suffer further from underinvestment by the private sector. It is currently much safer and much more attractive to invest in bio-based polymers in Asia and even North America.

**Market segments**

The packaging industry consumes most petro-based polymers. For bio-based polymers, the same trend can be observed: the major part of this as rigid packaging (bottles and others) and the rest as flexible packaging (films and others). These uses cannot come as a surprise, since bio-based PET is one of the biggest bio-based polymers in terms of capacity and is mostly used for the production of bottles. On the other hand, the packaging industry has a considerable interest in biodegradability since packaging is only needed for short times but in big quantities, which contributes to the accumulation of waste. It should be understood that not all bio-based polymers are biodegradable, but some important ones are e.g. PHA, PLA and starch blends. The biodegradation takes place in different environments; some polymers need industrial composting, others work also in home composting and a limited number also in soil, sweet water or even in the ocean. This

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**Figure 11: Global production capacities of bioplastics 2016 (by market segment)**


Figure 11: Global production capacities of bioplastics 2016 (by market segments) (European Bioplastics 2016)
feature can also be interesting for agriculture and horticulture applications (mulch films for example). However, bio-based polymers are also used in many different other market segments such as high-performance durable applications. Figures 11 and 12 show the global production of bio-based polymers by market segment in 2016 and 2021. The order of importance of the market segments is expected to stay the same between 2016 and 2021. Rigid packaging is supposed to keep its first place by growing almost twofold. This is again due to the development of bio-based PET. Consumer goods, automotive & transport and building & construction are also showing interesting developments.

Figure 13 shows the worldwide shares of bio-based polymers production in different market segments in 2016 and 2021 for nova-Institute’s scope of bio-based polymers (with epoxies, EPDM and cellulose acetate included). The same statement can be made regarding the packaging sector: packaging (rigid and flexible together) is the leader, with a clear advantage for rigid packaging, which is slated to grow. On the other hand, automotive and transports, building and construction, textiles and consumer goods have similar shares because bio-based epoxies, polyurethanes and cellulose acetate are used in these sectors. The smallest market segments are agriculture and functional polymers. Functional polymers are used in adhesives, coatings and inks, which require relatively small quantities of polymers. In agriculture, applications are mostly limited to biodegradable polymers (mulch films), which is clearly not a market leader in terms of capacities – but depending on future policy on plastic microparticles, mulch films and other biodegradable applications could grow strongly. The nova-Institute published the first comprehensive market study on the consumption of biodegradable and compostable plastic products in Europe. The short version and the full market study are available at www.bio-based.eu/markets.
Content of the full report

The full 500-page report presents the findings of nova-Institute’s market study, which is made up of three parts: “market data”, “trend reports” and “company profiles”.

The “market data” section presents market data about total production capacities and the main application fields for selected bio-based polymers worldwide (status quo in 2011–2016, trends and investments towards 2021). This section provides exclusive insight into CO₂-based polymers, bio-based thermosets and cellulose acetate with three independent articles by experts in the field who present and discuss their views on current and potential market development. However, this part not only covers bio-based polymers, but also investigates the current bio-based building block platform.

The “trend reports” section contains a total of twelve independent articles by leading experts in the field of bio-based building blocks and polymers. These trend reports cover in detail every recent issue in the worldwide bio-based building block and polymer market.

The final “company profiles” section includes company profiles with specific data including locations, bio-based building blocks and polymers, feedstocks and production capacities (actual data for 2011–2016 and forecast for 2021). The profiles also encompass basic information on the companies (joint ventures, partnerships, technology and bio-based products). A company index by bio-based building blocks and polymers, with list of acronyms, follows.
Table of contents

(about 500 pages and 200 tables and figures)

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<table>
<thead>
<tr>
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<tbody>
<tr>
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<td></td>
</tr>
<tr>
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<tr>
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</tr>
<tr>
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</tr>
<tr>
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</tr>
<tr>
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<td>€600</td>
</tr>
<tr>
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<td>with market and environmental potential (January 2017)</td>
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<tr>
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<td></td>
</tr>
<tr>
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<td>Roland Essel</td>
<td>€400</td>
</tr>
</tbody>
</table>
Bio-based building block and polymer producers – Company profiles
(January 2017)
(129 pages, 96 company profiles)
Florence Aeschelmann, Michael Carus, Wolfgang Baltus, Doris de Guzman, Harald Käb and Jan Ravenstijn

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Company profiles
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BioAmber Inc.
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Cathay Industrial Biotech, Ltd.
Cellulac
Chengdu Dikang Biomedical Co., Ltd.
China New Materials Holdings Ltd.
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Corbion Purac
Covestro Deutschland AG
DaniMer Scientific LLC
DSM N.V.
DuPont
DuPont Tate & Lyle Bio Products Company, LLC
Evonik Industries AG
Far Eastern New Century Corporation
Futerro
Galactic
Genomatica, Inc.
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Yunan Fuji Bio-Material Technology Co., Ltd.
Zhejiang Hangzhou Xinfu Pharmaceutical Co., Ltd.
Zhejiang Hisun Biomaterials Co., Ltd.
Main authors of the study

Florence Aeschelmann (MSc) (Germany), materials engineer, is a staff scientist in the Technology & Markets department at nova-Institute. Her main focus is on bio-based materials, especially bio-based polymers. She is well acquainted with the global market for bio-based polymers and building blocks.

Michael Carus (MSc) (Germany), physicist, founder and managing director of the nova-Institute, has worked in the field of Bio-based Economy for over 20 years with a special focus on market and policy development.

Wolfgang Baltus (PhD) (Thailand) worked for BASF for 15 years and was responsible for the business development of environmental friendly coatings in Asia. From 2008 until 2015, Baltus worked for the National Innovation Agency (NIA) and for Precise Corporation in Bangkok. In 2016, he founded his own independent consultancy, Wobalt Expedition Consultancy. He is regarded as one of the leading experts on bio-based polymer markets and policy in Asia.

Dirk Carrez (PhD) (Belgium) is one of the leading policy consultants on a Bio-based Economy in Brussels. He was Director Industrial Biotechnology at EuropaBio, the European Association for Bioindustries, until 2011. He is now Managing Director of Clever Consult, Brussels. In 2013 he became the Executive Director of the Bio-based Industries Consortium (BIC).

Doris de Guzman (BSChE) (USA) joined UK-based Tecnon OrbiChem in March 2013 as a senior consultant covering bio-based chemicals feedstocks for the company’s Bio-Materials Chemical Business Focus newsletter published every month. Doris has been covering the business of green chemistry for more than 16 years and provides expertise on oleochemicals, biofuels, biopolymers, industrial biotechnology and other renewable chemical products as creator and author of the Green Chemicals Blog. The blog has an average 15,000 to 20,000 unique readers per month.

Harald Käb (PhD) (Germany) is a chemist and has an unblemished 20-year “bio-based chemistry and plastics” track record. From 1999 to 2009 he chaired the board and developed “European Bioplastics”, the association representing the bioplastics industry in Europe. Since 1998 he has been working as an independent consultant, servicing green pioneers and international brands to develop and implement smart business, media and policy strategies for bio-based chemicals and plastics.
Jim Philp (PhD) (France) is a microbiologist who has been a policy analyst at the Organisation for Economic Cooperation and Development (OECD) in Paris since 2011, where he specializes in industrial biotechnology, synthetic biology and biomass sustainability.

Jan Ravenstijn (MSc) (The Netherlands) has more than 35 years of experience in the chemical industry (Dow Chemical and DSM), including 15 years in executive global R&D positions in engineering plastics, thermosets and elastomers, based in Europe and in the USA. He is currently a consultant to producers, investors and consulting companies involved in bio-based monomer or polymer activities, member of the Scientific Advisory Board of the Aachen-Maastricht Biomaterials Institute and has published several papers and articles on the market development of bio-based monomers and polymers. He is regarded as one of the world’s leading experts in his field.

Further contributions from:

Constance Ißbrücker
European Bioplastics, Germany

Kristy-Barbara Lange
European Bioplastics, Germany

Hasso von Pogrell
European Bioplastics, Germany

Stefan Zepnik
Fraunhofer UMSICHT, Germany
The nova-Institut GmbH was founded as a private and independent institute in 1994. It is located in the Chemical Park Knapsack in Huerth, which lies at the heart of the chemical industry around Cologne (Germany).

For the last two decades, nova-Institute has been globally active in feedstock supply, techno-economic and environmental evaluation, market research, dissemination, project management and policy for a sustainable bio-based economy.

**Key questions regarding nova activities**

What are the most promising building-blocks, polymers and applications in the Bio-based Economy? What are the challenges and latest trends, how will policy and markets develop?

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**nova-Institut GmbH**

Chemiepark Knapsack
Industriestraße 300
50354 Hürth, Germany

**T** +49 (0) 22 33/48 14-40
**F** +49 (0) 22 33/48 14-50

contact@nova-institut.de
www.nova-institut.eu

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