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Top emerging bio-based products, their properties and industrial applications

Research and Innovation

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TABLE OF CONTENT

ABSTRACT

This study was performed for the EC-DG RTD under the framework of the BIOSPRI tender "Study on support to R&I policy in the area of bio-based products (BBPs) and services", implemented by the University of Bologna (Italy) and the Fraunhofer ISI (Germany) as part of a consortium led by COWI A/S. The study mapped the most relevant value chains currently under development that originate from different kinds of large-volume biomass components (natural rubber, vegetable fibres, lignin, renewable oils and fats) and low-volume high-value (LVHV) biomass components (terpenes, natural polyelectrolytes) as well as urban wastes. More than 100 innovative BBPs were monitored; lignin was found to generate the highest number of innovative products, together with terpenes and urban wastes. More than 30 innovative BBPs are approaching full availability on the market, and more than 20 products are now at the pilot plant level. Through an assessment of the active marketplace, EU-based development, innovation degree and market potential, the top 20 most innovative BBPs holding the greatest promise for commercial deployment within the next 5–10 years were identified. This selection includes engineering materials, new bioplastics, high added-value products for demanding applications in the pharmaceutical and biomedical fields as well as sustainable substitutes for critical raw materials. Detailed case studies on these top 20 innovative BBPs were prepared.

INTRODUCTION

Building new value chains through the utilisation of large-volume and LVHV biomass components for the development of innovative BBPs aimed at specific market sectors will accelerate the transition from traditional production technologies to the concept of biorefineries.

New technologies and traditional methods coupled with biotechnologies applied to biomass feedstocks and waste streams from various sources, such as urban waste or agricultural residues or wastes from food and feed streams, will convert renewable resources into high added-value sustainable BBPs.

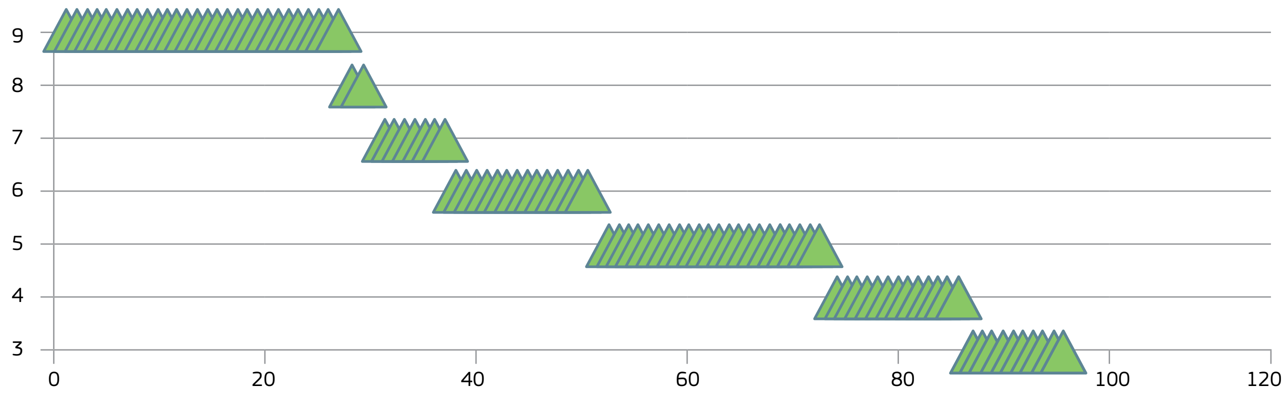
This study was aimed at mapping innovative BBPs currently at any stage of development that are derived from the biomass components listed in Table 1 below. The table reports the number of related products identified.

In Figure 1 (next page), the spread of TRL values achieved by each of the BBPs mapped in the study is shown. This graphical representation allows a visualisation of how many products are close to commercialization and how many have reached the most advanced stage of technical development. As the figure clearly shows, almost one third of the products are already

TABLE 1: BIOMASS COMPONENTS INCLUDED IN THE STUDY AND RESPECTIVE NUMBER OF INNOVATIVE BBPS MAPPED

Category	Main biomass components	Number of innovative BBPs mapped
Large-volume biomass components	Natural rubber	5
	Vegetable fibres	17
	Renewable oils and fats	19
	Lignin	23
Low volume high value (LVHV) biomass components	Terpenes	18
	Polyelectrolytes	6
Urban biowastes	Urban biowastes	19

FIGURE 1: TRL DISTRIBUTION FOR THE BBPS MAPPED IN THE STUDY



at a very advanced level of development, approaching full availability on the market. More than 20 products are now at the pilot plant level (TRL 5), but there are very few products between TRL 7 and 8.

Through an assessment of the active marketplace, EU-based development, innovation degree and market potential, the TOP20 most innovative BBPs holding the greatest promise for commercial deployment within the next 5–10 years were identified.

This selection of BBPs is shown in Table 2 below, organized by the biomass category that is the origin of their value chain.

The outcome of the selection of the top 20 BBPs reveals important information on general trends in the bio-based industry.

- First of all, the greatest attention is focused on the industrial development of new bio-based materials targeted at advanced technical applications. **Engineering materials** with elevated thermomechanical properties suitable for the

TABLE 2: TOP 20 BBPS UNDER DEVELOPMENT AND HOLDING THE GREATEST PROMISE FOR COMMERCIAL DEPLOYMENT IN THE NEXT 5–10 YEARS

Biomass category	Most promising BBPs under development
Natural rubber	Guayule Rubber
Vegetable fibres	Lignin biocomposites reinforced with natural fibres Microfibrillated cellulose Thermoplastic biopolymers reinforced with natural fibres Natural fibres reinforced bioresin pre-pregs Self-binding composite non-woven natural fibres
Renewable oils and fats	Biolubricants PHAs from renewable oils and fats Bio-based polyamide 12
Lignin	Lignin-based carbon nanofibres Bio-Btx aromatics Lignin bio-oil High-purity Lignin Bio-based phenol and alkylphenols Lignin-based phenolic resins
Terpenes	Limonene-based engineering polymers
Polyelectrolytes	Bacterial biosurfactants Biotechnological chitosan
Urban biowastes	PHAs from urban wastes Volatile fatty acids (VFAs) mixtures

automotive and construction fields, such as biopolyesters, biopolyamides, matrices and fillers for reinforced biocomposites, but also biolubricants, represent the vast majority of the top 20 innovative bio-based products. More than 13 can be attributed to this category.

- Bio-based innovative solutions that are related in any way to the **plastics** sector clearly occupy the most relevant position. Plastics are perceived as modern and versatile, but polluting, materials in relation to their relatively low durability and priority eligibility as disposables. Sustainable solutions, either just bio-based or bio-based and biodegradable, are therefore being intensely investigated. More than 10 of the top 20 selected products are related to plastics. Both thermosets and thermoplastics innovative plastic materials are currently under development, and innovation lays either in the synthesis of completely new polymeric structures (for example, limonene-based engineering polymers: polyurethanes, polycarbonates, polyamides) or in the development of drop-in substitutes derived from renewable resources (for example, biophenolic resins). Polyhydroxyalkanoates (PHAs) are rigorously being explored as promising biodegradable substitutes for a number of commodity polymers, such as HDPE, PP and others. The fact that PHAs can be obtained by a purely biotechnological route starting from a variety of carbon-rich biomass feedstocks, including agricultural wastes, organic fractions of solid municipal waste and urban wastewater, makes them particularly attractive. At present, the development of PHAs based on renewable oils and fats and urban biowastes (OFMSW and UWW) is at TRL 6–7. These production routes nevertheless compete with the one based on sugars, which is more advanced, presently at TRL 9.

- Innovative bio-based products for commercial solutions having a **high added value** due to their peculiar specificity, also hold a relevant position. As an example, the anti-bacterial, anti-fungal and anti-cancer activity of 3rd generation chitosan attracts a lot of attention for highly demanding applications in the pharmaceutical and biomedical fields.

- The chemical platform related to **lignin** is the one giving rise to the highest number of innovative products at present. Its natural abundance and global availability certainly represent the main reasons for the persistent attempts at its exploitation beyond its actual relevant role as a bioenergy source, though its chemical versatility and uniqueness as a source of aromatic building blocks also play a role. Aromatics, in general, are only available from fossil oil, and very often associated with highly polluting chemicals that are harmful to people and the environment.

  The essential role of aromatics in numerous industrial sectors, including fuels, solvents and lubricants and plastic materials makes them very attractive if derived from renewable resources.

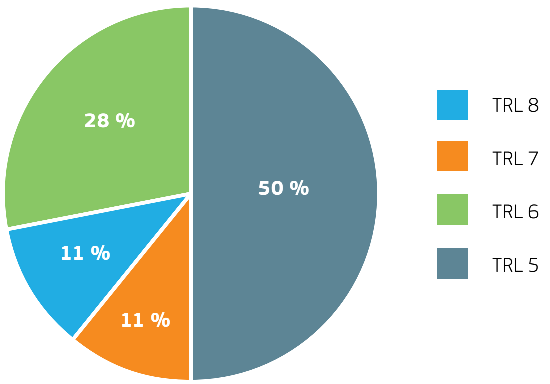
  Innovative products derived from lignin range from fundamental chemical building blocks, such as BTX aromatics, to materials for advanced applications in technical fields like construction engineering, where for instance both carbon fibres and thermoset resins play a major role but are currently not available from renewable sources. Indeed, seven of the top 20 selected bio-based products are derived from lignin.

- Europe's complete dependency on importing natural rubber sourced from the rubber tree Hevea Brasiliensis in southeast Asia has motivated the recent inclusion of this elastomer in the list of **critical raw materials** for the EU. The need to develop solid alternative routes of provision for natural rubber, based on regional biomass feedstock availability, supports the current research on natural rubber from guayule and Russian dandelion as well as rubber derived from the polymerization of the bio-based isoprene monomer.

- The **TRL distribution** for the top 20 selected innovative bio-based products shows that half of them currently have the related technology validated in the relevant environment (TRL 5), while just approximately 10% have the system fully developed and qualified (TRL 8). The picture below (Figure 2) shows TRL distribution for the selected top 20 products.

This booklet collects 20 infographics for the selected most innovative BBPs holding the greatest promise for commercial deployment in the next 5 to 10 years. They have been elaborated on the basis of data reported in the respective detailed case studies available in the full version of the study report.

FIGURE 2: TRLS DISTRIBUTION FOR THE SELECTED TOP 20 PRODUCTS.



GUAYULE RUBBER

Guayule is a source for natural rubber (NR). Guayule rubber is similar to and can substitute natural latex from Hevea Br. in almost all kinds of applications. Its latex is hypoallergenic because it does not contain the proteins that can cause severe allergic reactions (e.g. for medical rubber gloves and medical items).

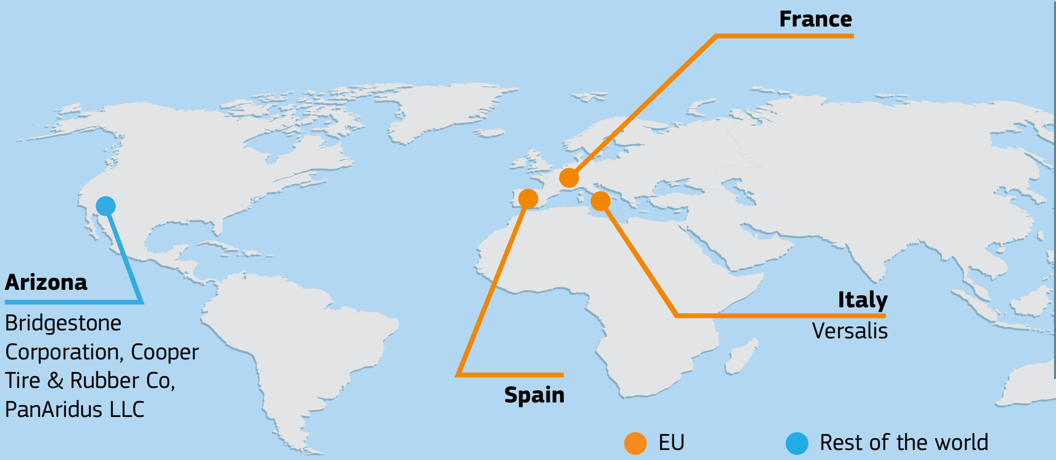
Guayule is considered the most promising plant specie for the next-generation of NR sources.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtC & BtB

BIOMASS PLATFORM
Natural Rubber

TECHNOLOGY READINESS LEVEL (TRL)
6 (YULEX, USA)

MAIN ACTORS AND POTENTIAL CUSTOMERS



MAIN APPLICATIONS

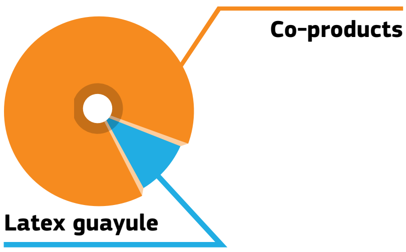
- Truck and airplane tires
- Car parts
- R2® wetsuit
- Gloves and other material for the health sector
- Other rubbery goods
- Not "food-based" biofuel in building and energy industries

PRODUCT EVALUATION

VALUE PROPOSITION

USE OF GUAYULE

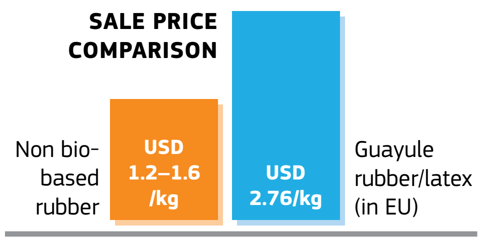
±88% of residual plant material (E.g.: flavor, fragrance, cosmetics, pharmaceuticals, paints and adhesive markets, jet fuel).



±12% of total dry biomass

PRODUCTION VOLUME/VALUE

Around 27 million tonnes of natural rubber are produced naturally or synthetically on an annual basis.



PRODUCT SAFETY

The absence of IgE latex allergic reactions makes Guayule rubber particularly suitable for medical applications, unlike natural rubber derived from the Hevea Brasiliensis tree.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:
No need for pesticides, low fertilisation requirements, more sustainable processing. (e.g.: the production of a guayule-based tire generates 6 to 30 % lower emissions compared to a conventional tire.)

IMPACTS ON HEALTH:
Guayule latex is much less allergenic than Heavea rubber.

MICROFIBRILLATED CELLULOSE

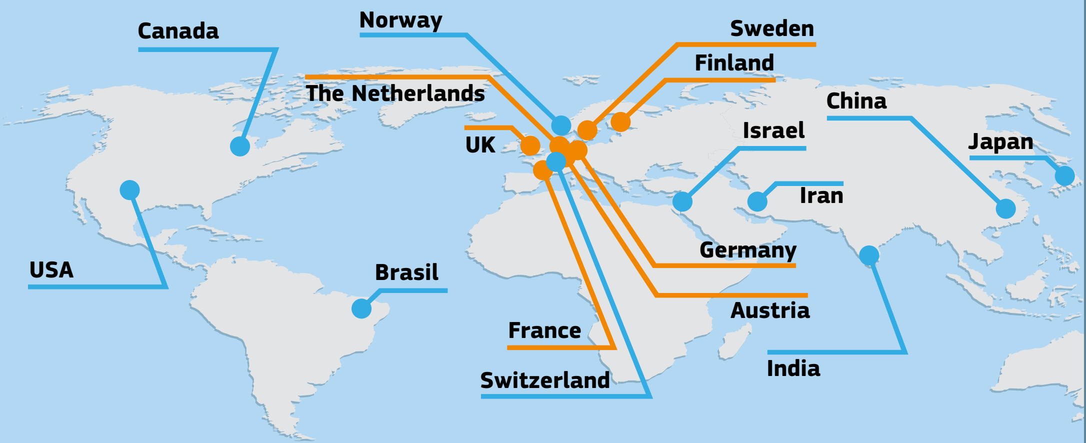
Microfibrillated cellulose (MFC), also commonly named nanocellulose, is obtained by delaminating cellulosic fibres in high-pressure, high-temperature and high-velocity impact homogenization, grinding or microfluidization. The fibrillation of cellulose fibres creates an increased surface area and gives the fibril product new characteristics. Fully delaminated nanocellulose consists of long microfibrils and has the appearance of a highly viscous, shear-thinning transparent gel. It is a pseudo-plastic and exhibits thixotropy properties.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtB

BIOMASS PLATFORM
Vegetable fibres

TECHNOLOGY READINESS LEVEL (TRL)
8

MAIN ACTORS AND POTENTIAL CUSTOMERS



- EU: **UK** (CelluComp, FiberLean Technologies, ZelfoTechnology GmbH) **France** (Imerys, InTechFibres), **Sweden** (INNVENTIA AB, Ahlstrom-Munksjö), **Austria** (Lenzing Group), **Germany** (JRS, J. RETTENMAIER & Söhne Group, BASF), **The Netherlands** (AkzoNobel, Sappi group), **Finland** (Stora Enso, UPM-Kymmene OYJ)
- Rest of the world: **Norway** (Borregaard), **Switzerland** (WEIDMANN Fiber Technology), **Japan** (Daicel Finechem Ltd., Dai-ichi Kogyo Seiyaku Co., Ltd., Daio Paper, Sugino Machine, Chuetsu Pulp & Paper, Nippon Paper Industries, Oji Paper, Asahi Kasei, Seiko PMC, DIC Corporation, Tokushu Tokai Paper), **China** (Tianjin Haojia Cellulose Co., Ltd.), **Canada** (FP Innovation, BioVision, CelluForce, Alberta Innovates, Kruger Inc.), **USA** (Forest prod Lab, American Process Inc., ITT Rayonnier, UMaine Nanomaterial Pilot Plant, Southworth Company/Paperlogic), **India** (Indian Council of Agricultural Research – Central Institute for Research on Cotton Technology, Aditya Birla Group), **Israel** (Melodea Ltd.), **Iran** (Nano Novin Polymer Co), **Brazil** (Suzano)

MAIN APPLICATIONS

- Non-woven binders
- In food and paints as a reinforcement for plastic composites
- Piezoelectric sensors, high barrier packaging also for food
- Foams with high insulating and fireproof properties for building,
- Paper additive
- Filters or membranes
- Hygiene or pharmaceutical and cosmetic applications
- Reinforcement for thermoplastics and thermosets
- In the medical field for antimicrobial films to foster bone regeneration and for non-woven products or tissues

PRODUCT EVALUATION

VALUE PROPOSITION

PRODUCTION VOLUME/VALUE

Since 2014, microfibrillated cellulose has accounted for the largest share (over **50 %**) of the global cellulose additives composite market.

SALE PRICE

- MCF price varies according to the market place and the specific format and characteristics of the bio-material being sold.
- Cellulose nanofibrils cost between USD 2/g and USD 6/g depending on the form.
- Cationic- and anionic-type cellulose nanofibrils cost between USD 20/g and USD 25/g.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:

- Nanocellulose is a 100% natural raw material obtained from fully biodegradable sources.
- MFC can replace non-biodegradable materials and many fossil fuels-based products at a lower cost.
- MFC-based products are less carbon intensive (greener carbon footprint) than non-bio-based products, and they are recyclable, reusable and compostable.

IMPACTS ON HEALTH:

Nanocellulose can improve public health through the development of new healthcare products.

THERMOPLASTIC BIOPOLYMERS REINFORCED WITH NATURAL FIBRES

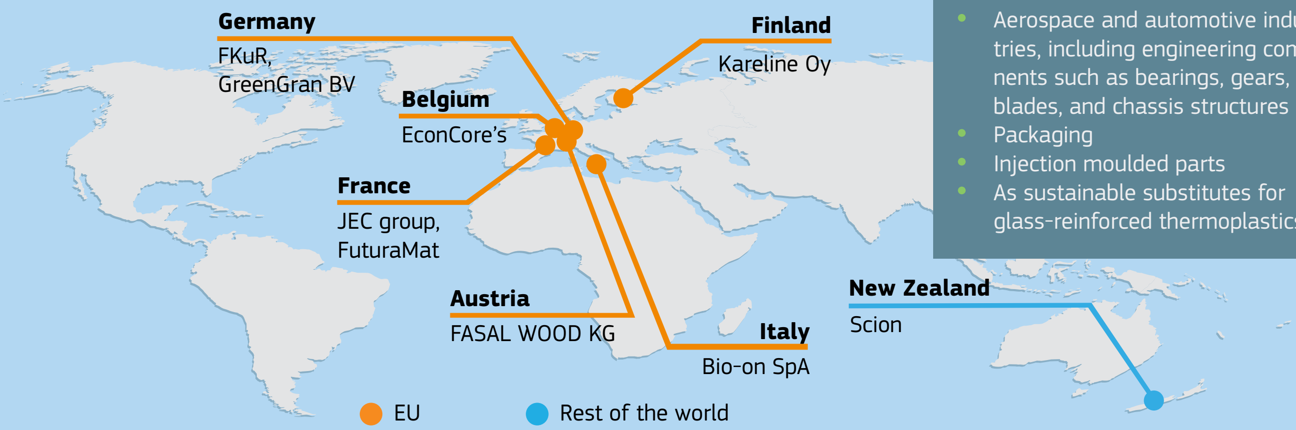
Thermoplastic biopolymers reinforced with natural fibres (NF) actually represent a fully renewable version of the widely diffused short-fibre reinforced thermoplastics. The latter have been developed to increase the physical and thermomechanical properties of standard plastics, such as polypropilene (PP) reinforced with glass or carbon fibres. These reinforced bio-composites can keep the formulation 100 % biodegradable and bio-compostable.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtB

BIOMASS PLATFORM
Vegetable Fibre

TECHNOLOGY READINESS LEVEL (TRL)
5

MAIN ACTORS AND POTENTIAL CUSTOMERS



MAIN APPLICATIONS

- Aerospace and automotive industries, including engineering components such as bearings, gears, fan blades, and chassis structures
- Packaging
- Injection moulded parts
- As sustainable substitutes for glass-reinforced thermoplastics

PRODUCT EVALUATION

VALUE PROPOSITION

SALE PRICE

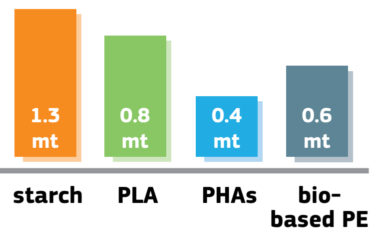
NF usable as reinforcements for thermoplastic matrices are less expensive than synthetic alternatives (glass and carbon).

Currently, NF are priced at one third or less of the cost of glass fibre.

In contrast, bio-plastics remain expensive if compared with synthetic alternatives because plastic prices are correlated with oil prices and volatility.

PRODUCTION VOLUME/VALUE

By 2020 the most important bio-based polymers will be:



PRODUCTION COSTS

The use of NF rather than glass or carbon fibres for reinforcing thermoplastic matrices reduces production costs.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:
The biodegradability and biological degradation of the whole composite makes it environmental friendly.

PRODUCT SAFETY

- The benefits of the bioplastics blended with NF include safety in the automotive sector.
- NF provide better vibration damping than glass or carbon fibres.
- NF provide better acoustic and thermal insulation.

PRODUCT PROSPECTS & OUTLOOK

The market of NF as reinforcements for thermoplastic matrices shows a Compound Annual Growth Rate (CAGR) of 11 % from 2016, which will be confirmed over the next three years.

The market is mainly driven by the increasing use of natural fiber composites in automotive applications.

NATURAL FIBRES REINFORCED BIORESIN PRE-PREGS

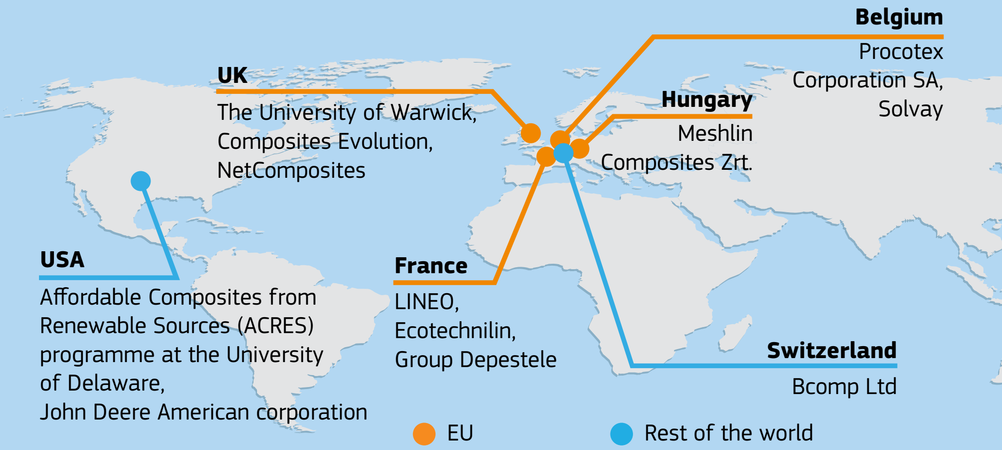
Natural fibres reinforced bioresin pre-pregs are fabricated by pre-impregnation of vegetable fibers, mainly flax, with a curable bio-based resin, to have semi-finished products suitable for advanced composites lamination. The aim is to maximize the proportion of renewable resources used while getting outstanding material properties, suitable for technical and load-bearing applications. In this respect, fully bio-based composites could be produced by using bio-based resins, in replacing traditional thermosets, which are coming under increasing restrictions due to tightening environmental exposure regulations.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtB

BIOMASS PLATFORM
Vegetable Fibres

TECHNOLOGY READINESS LEVEL (TRL)
9

MAIN ACTORS AND POTENTIAL CUSTOMERS



MAIN APPLICATIONS

- Automotive and aeronautical applications (mass transportation)
- Light-weight and high-strength construction parts
- Construction sector
- Marine and offshore sector

The application of vegetable fibres remains limited due to difficult reproducibility in the manufacturing process.

PRODUCT EVALUATION

VALUE PROPOSITION

With respect to glass and carbon fibers reinforcements, Natural fibres reinforced bioresin pre-pregs present:

- improved vibration damping
- reduced costs for the same performance
- reduced weight of parts
- natural look
- excellent fire performance

SALE PRICE

Applications to the automotive and aeronautic sectors and in the construction industry could cost between **EUR 8–20/sqm**.

PRODUCTION COSTS

Final production cost is a function of the rising cost of feedstock and oil price instability combined with the increased cost of compliance with environmental and safety legislation.

Moreover, the market growth strictly depends on industrial availability and development of bio-based polymer matrices.

PRODUCTION VOLUME/VALUE

By 2021, the Natural Fiber Composites Market will be worth **USD 6.50 billions**.

In 2012 the European automotive industry used **90,000 tonnes** of natural fibre composites.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:

- Low emission of toxic fumes when subjected to heat and during incineration at end of life.
- Energy consumption related to the natural fibre separation process is lower than that of synthetic fibre production processes.

IMPACTS ON HEALTH:

Natural fibres reinforced bioresin pre-pregs are non-toxic, and the use of bio-composites reinforced with natural materials ensure no skin irritation for workers.

PRODUCT SAFETY

- Natural fibres reinforced bioresin pre-pregs are similar to a phenolic pre-pregs but with lower formaldehyde and VOC emissions.
- Natural fibres reinforced bioresin pre-pregs have fire retardant properties, high chemical and thermal stability.

SELF-BINDING COMPOSITE NON-WOVEN NATURAL FIBRES

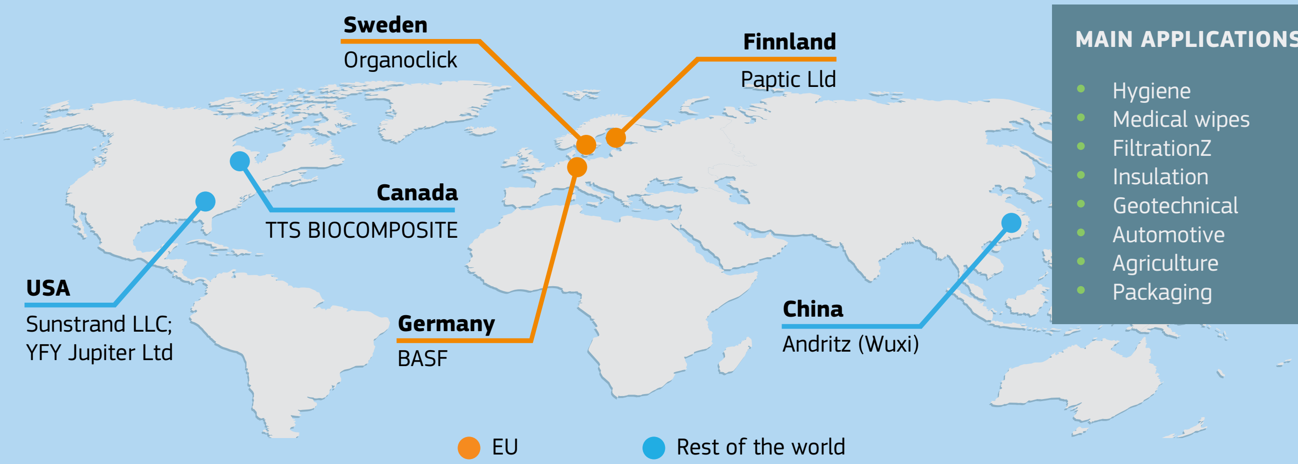
In self-binding composite non-woven natural fibres, natural fibres are surface-modified by the deposition of a layer of polymer or polymer-precursor that induces thermoplasticity in the fibres themselves. When the polymer-surface-modified natural fibres are heated, the thermoplastic coating melts (or reacts) and generates a matrix that binds the fibres together. One of the most innovative materials is thermoplastic paper, such as PAPTIC®.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtB

BIOMASS PLATFORM
Vegetable fibres

TECHNOLOGY READINESS LEVEL (TRL)
7

MAIN ACTORS AND POTENTIAL CUSTOMERS

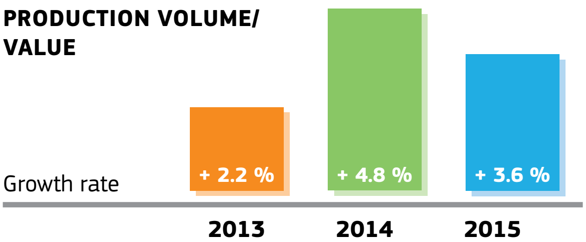


MAIN APPLICATIONS

- Hygiene
- Medical wipes
- FiltrationZ
- Insulation
- Geotechnical
- Automotive
- Agriculture
- Packaging

PRODUCT EVALUATION

VALUE PROPOSITION



The European non-woven goods industry has an estimated turnover of **EUR 7,471 million**.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:

- The advantages of natural fibres-reinforced materials include a reduced dependence on non-renewable energy and material sources as well as lower pollutant and greenhouse emissions
- Enhanced energy recovery, CO_2 neutrality when burned, biodegradability
- The material is fully recyclable

IMPACTS ON HEALTH:

- Surgical gowns and drapes help prevent infection during operations
- Short-use protective suits and masks protect against hazardous dusts and chemicals.
- Nonwoven filtration media improve indoor air quality.
- The material is lightweight, soft, breathable.

LIGNIN BIOCOMPOSITES REINFORCED WITH NATURAL FIBRES

Mixing lignin with natural fibres and natural additives produces a fibre composite that can be processed at raised temperatures and be made into mouldings, plates or slabs on conventional plastics processing machines.

Many of these composites are "green" alternatives to petroleum-based plastics. Lignin mixed in plastics or bioplastics reinforced with vegetal fibres improves the physical-mechanical properties and processability of the fibre-reinforced material.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtB

BIOMASS PLATFORM
Vegetable Fibres

TECHNOLOGY READINESS LEVEL (TRL)
6

MAIN ACTORS AND POTENTIAL CUSTOMERS

MAIN APPLICATIONS

- As thermoplastics to be processed in standard injection moulding machines
- Construction industry
- Use in the automotive sector to produce technical parts, furniture and interiors, sport and leisure, packaging and clothing
- Toys
- Garden supplies
- As a sustainable substitute for standard fossil fuel-based thermoplastics

PRODUCT EVALUATION

VALUE PROPOSITION

PRODUCTION VOLUME/VALUE

Lignin biocomposites with natural fibres behave like standard thermoplastics, with mechanical properties ranging from standard commodities such as PP, PE and PS to technical polymers such as PAs.

The global market of lignin biocomposites produces between **1 and 1,1 million** tonnes per year.

SALE PRICE

The price is circa **10 cents/lb** of lignin feedstock. Therefore, lignin could be price competitive alongside oil-based commodity plastics.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:

- Natural fibres and composites exhibit low emissions of toxic fumes when subjected to heat and during incineration at the end of life.
- Vegetable fibres-reinforced biocomposites make the construction industry more sustainable by reducing the use of non-renewable resources and CO_2 emissions.
- The properties of lignin (e.g., abundance, low weight, CO_2 neutrality, antioxidant, antimicrobial and biodegradable nature) make it suitable for new composite materials development. The global warming potential for producing lignin is much lower compared to a number of common polymers.

IMPACTS ON HEALTH:

The use of bio-composites reinforced with natural materials ensures no skin irritation for workers.

PRODUCT PROSPECTS & OUTLOOK

- There is modest growth in the demand for these products.
- The annual rate of growth (CAGR) for these products is around 2 % annually.

HIGH-PURITY LIGNIN

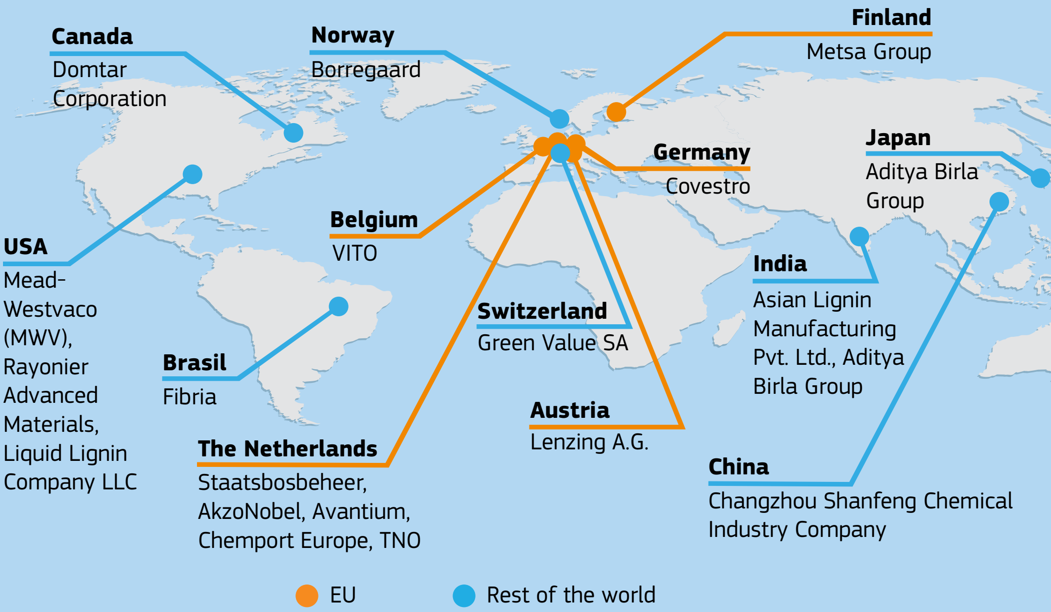
High-purity lignin, also named high-grade lignin, is the starting point for the development of further formulations suited for use as raw chemicals and advanced materials. It can be considered a platform chemical from which a wide variety of high-added-value products can be derived.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtB

BIOMASS PLATFORM
Lignin

TECHNOLOGY READINESS LEVEL (TRL)
5

MAIN ACTORS AND POTENTIAL CUSTOMERS



MAIN APPLICATIONS

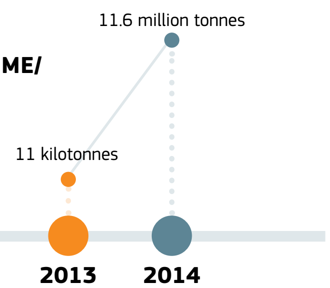
- Carbon-based materials
- Macromolecular applications
- Fine- and specialty chemicals
- Bulk chemicals (e.g. aromatics and acids)
- Raw chemicals (e.g. vanillin, benzene toluene and xylene aromatics, food and beverage additives
- Advanced materials (e.g.: carbon fibres for reinforced composites, adhesive binders, resins and coatings, PU-based foams, films, paints and plastics)
- Higher value fuel additives

PRODUCT EVALUATION

VALUE PROPOSITION

PRODUCTION VOLUME/ VALUE

The lignin market value is more than USD 4 million.



SALE PRICE COMPARISON

Prices range between **USD 650/t** and **USD 1,000/t**.

High-purity lignin-based products can reach a value of **USD 1,300–USD 6,500/t**.

PRODUCTION COSTS

Despite ongoing research, the cost of extracting high-purity lignin from plants is rather high.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:

- Lignin-based products outperform their synthetic alternatives in terms of environmental impact and sustainability.
- High-purity lignin applications can be more easily recycled, reused and composted.

IMPACTS ON HEALTH:

Natural materials and technologies have been developed to increase health and safety, reduce emission of volatile organic compounds, energy consumption and toxicity from manufacturing.

PRODUCT SAFETY

Lignin is a renewable, wood-based and non-toxic alternative to fossil-based materials.

LIGNIN-BASED CARBON NANOFIBRES

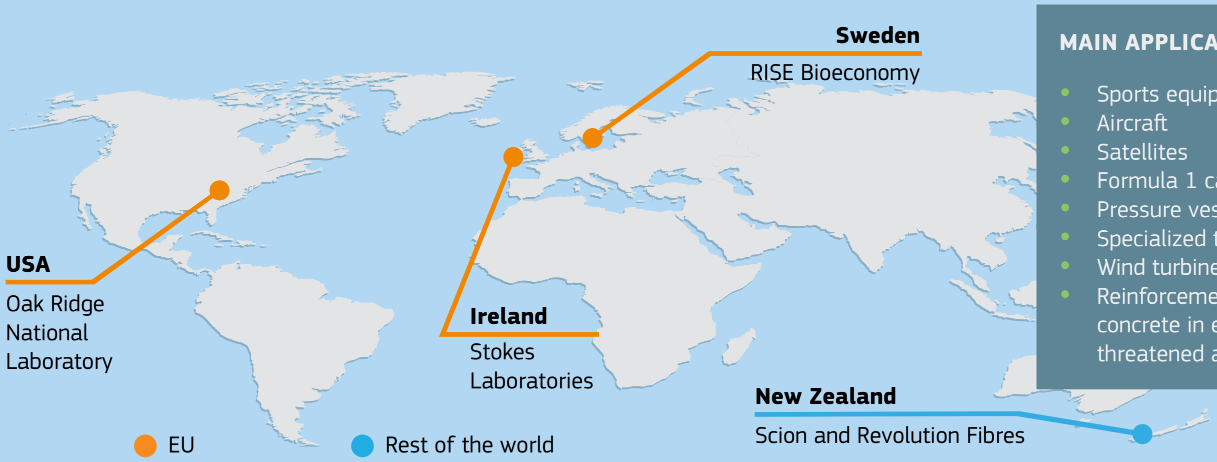
Lignin permits the production of low-cost carbon fibres and high-performance carbon fibre-reinforced polymers (CRFP), thus contributing to increased energy efficiency, reduced environmental emissions and the use of renewable raw materials. There is no commercial production of lignin carbon fibres yet.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtB

BIOMASS PLATFORM
Lignin

TECHNOLOGY READINESS LEVEL (TRL)
5–6 (RISE, Research Institutes of Sweden)

MAIN ACTORS AND POTENTIAL CUSTOMERS



MAIN APPLICATIONS

- Sports equipment
- Aircraft
- Satellites
- Formula 1 cars
- Pressure vessels
- Specialized tools
- Wind turbine components
- Reinforcement element of concrete in earthquake-threatened areas

PRODUCT EVALUATION

VALUE PROPOSITION

PRODUCTION VOLUME/VALUE

In 2017, the global production of carbon fibre was approximately **80,000 t**.

In 2015, its market size was estimated to be approximately **USD 2.5 billion**.

SALE PRICE

Lignin has an average gross price of **USD 660/t** dry solid (in 2013). Non-aerospace-grade carbon fibre is around **USD 20–30/kg**.

It is assumed that lignin fibres would be less expensive because of the low cost precursor lignin (**~USD 2–3/kg**).

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:

- The use of low-cost lignin-based carbon nanofibres enables a broader use of lightweight materials in the automotive and aerospace industries. Carbon fibre composites can reduce the weight of a vehicle by up to 50 % and improve fuel efficiency.
- Up to now, carbon fibre has not shown itself to be recyclable like other materials,
- GHG emissions targets: the carbon dioxide-equivalent emissions are estimated to be 24 kg/kg of lignin- and 31 kg/kg of PAN-based carbon fibres (highly dependent on the scope of the LCA).

IMPACTS ON THE ECONOMY:

Low-cost carbon fibres can have positive effects on:

- sectors that involve thermal insulation at high temperatures,
- batteries that use commercial carbon fibres as active electrodes or for storage of hydrogen gas

LIGNIN BIO-OIL

Lignin Bio-oil is the fluid product of the chemo-thermal conversion of biomass that contains lignin.

It constitutes a complex mixture of hundreds of organic compounds like acids, ketones, phenols, lignin-derived oligomers and solid particles for example.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)

BtB (maybe eventually BtC)

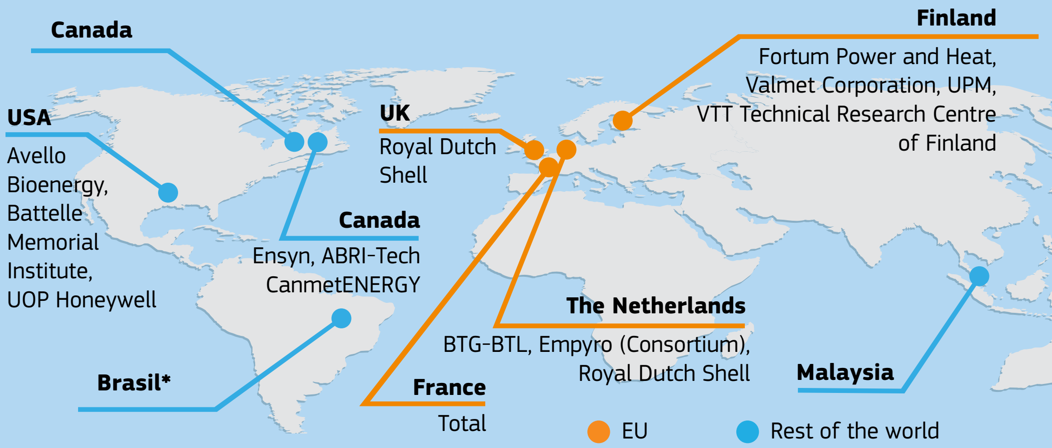
BIOMASS PLATFORM

Lignin

TECHNOLOGY READINESS LEVEL (TRL)

Max. 5

MAIN ACTORS AND POTENTIAL CUSTOMERS



MAIN APPLICATIONS

- Substitute for fossil fuels and chemical feedstock, i.e.
  - Fuel applications (e.g. for fuel oil)
  - Chemicals for food production (e.g. flavouring agents)
- **Co-products**: bio-char and gas (energy generation)

PRODUCT EVALUATION

VALUE PROPOSITION

PRODUCTION VOLUME/VALUE

Pyrolysis oil production (as an indicator for bio-oil) is estimated to exceed **500,000 t** by **2018**, with a potential market volume of about **USD 114 million**.

2014 PRICE OF COMPARABLE PRODUCT (CANADIAN PYROLYTIC OIL) **USD 228/t**

PRODUCTION COSTS

Presently, bio-oil cannot be considered cost competitive compared to its petroleum equivalents for various reasons, for instance the lack of economy of scales or feedstock prices.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:
Carbon neutral combustion, no production of any SOx (depending on production feedstock), bio oil stems from a renewable feedstock, bio oil production does not necessarily compete with food production, waste valorisation possible.

GHG EMISSIONS TARGETS:
Lignin Bio-oil apparently fares better than its petroleum counterparts in terms of global warming potential.

PRODUCT SAFETY

A 2005 comprehensive study on the (eco) toxicity of bio oil found no significant health, environmental or safety risk (reviewing 21 oils from most commercial producers worldwide and evaluating a representative bio oil).

*Not yet operational

LIGNIN-BASED PHENOLIC RESINS

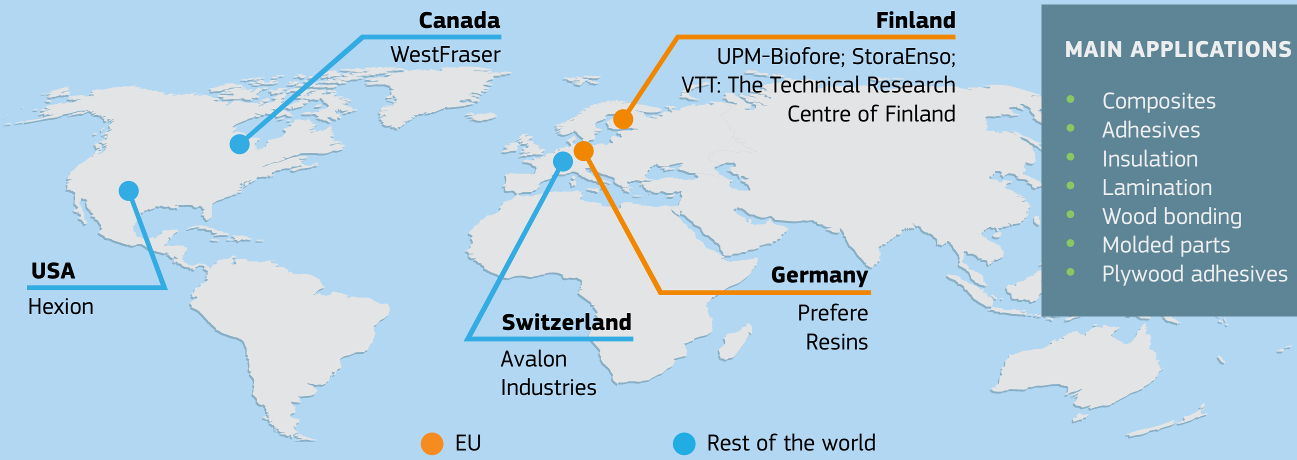
Lignin-based phenolic resins, also called phenol-formaldehyde resins, are a group of very versatile polymers with excellent physical characteristics (e.g. low flammability, high temperature resistance and low humidity absorption). Phenolic resins are divided between two groups: novolacs and resoles, which are both widely used polymers in different industries.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtB

BIOMASS PLATFORM
Lignin

TECHNOLOGY READINESS LEVEL (TRL)
8

MAIN ACTORS AND POTENTIAL CUSTOMERS



MAIN APPLICATIONS

- Composites
- Adhesives
- Insulation
- Lamination
- Wood bonding
- Molded parts
- Plywood adhesives

PRODUCT EVALUATION

VALUE PROPOSITION

PRODUCTION VOLUME/VALUE

Phenolic resins are produced globally with a volume of **6 mt** annually.

UPM has recently announced **100%** lignin-based phenolic resin production on a commercial scale, a technology called **WISA BioBond**.

SALE PRICE

Market price of phenolic resins:

USD 1,100/t–USD 2,300/t

Depending on the purity, quality and application of the final resin.

PRODUCTION COSTS

Current price of LBP resins is publicly not available. It is estimated that technology improvements could make LBP resins cost less than phenolic resins.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:

- Reduced toxicity, lower energy consumption.
- It can be estimated that every tonne of lignin substituted in phenolic resins production prevents the generation of a tonne of CO2 emissions.

PRODUCT SAFETY

The incorporation of lignin, which has a very low toxicity, into the production processes of phenolic resins results in improved worker health and safety as well as in the production of safer end-use products for consumers.

BIO-BTX AROMATICS

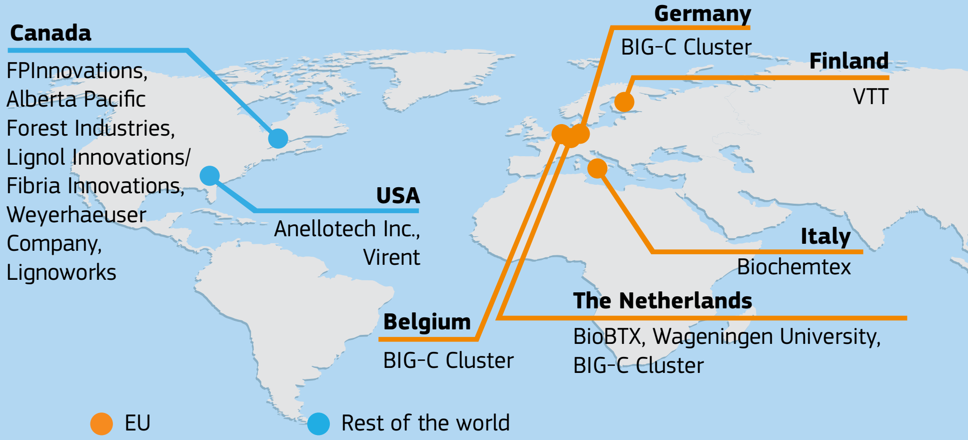
BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtB

BIOMASS PLATFORM
Lignin

TECHNOLOGY READINESS LEVEL (TRL)
6

Benzene, toluene and xylenes (BTX) are basic aromatics that are produced globally in very large volumes. They are highly important intermediates and used as starting materials for a wide variety of end-products in different industries. Currently, all lignin-based BTX aromatics are still in the R&D phase, and experts indicate that commercial scale production could begin within 10–20 years.

MAIN ACTORS AND POTENTIAL CUSTOMERS



MAIN APPLICATIONS

- Healthcare and pharmaceuticals
- Automotive industry (car parts)
- Packaging
- Electronics (DVDs, keyboards, mobile phones etc.),
- Textiles (e.g.: innovative fibres),
- Sports equipment Construction industry (e.g. insulation, piping materials and window frames)
- **Co-products**: fuel, crude oil asphaltene fraction applications, heat and power generation

PRODUCT EVALUATION

VALUE PROPOSITION

PRODUCTION VOLUME/VALUE

In 2012, the annual production of BTX Aromatics was around **103 mt**.

SALE PRICE COMPARISON

*estimation, as no actual products are on the market yet

PRODUCTION COSTS

The prices of BTX aromatics range between **EUR 0.52/l** and **EUR 0.86/l**.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:

- Sustainable production of BTX aromatics would help to reduce the footprint of industrial processes.
- Lower greenhouse gas emissions in comparison to the petrochemical building blocks
- The high performance of materials has positive environmental impacts in the long-term

PRODUCT PROSPECTS & OUTLOOK

BioBTX production on commercial scale will be ready after 2025

BIO-BASED PHENOL AND ALKYLPHENOLS

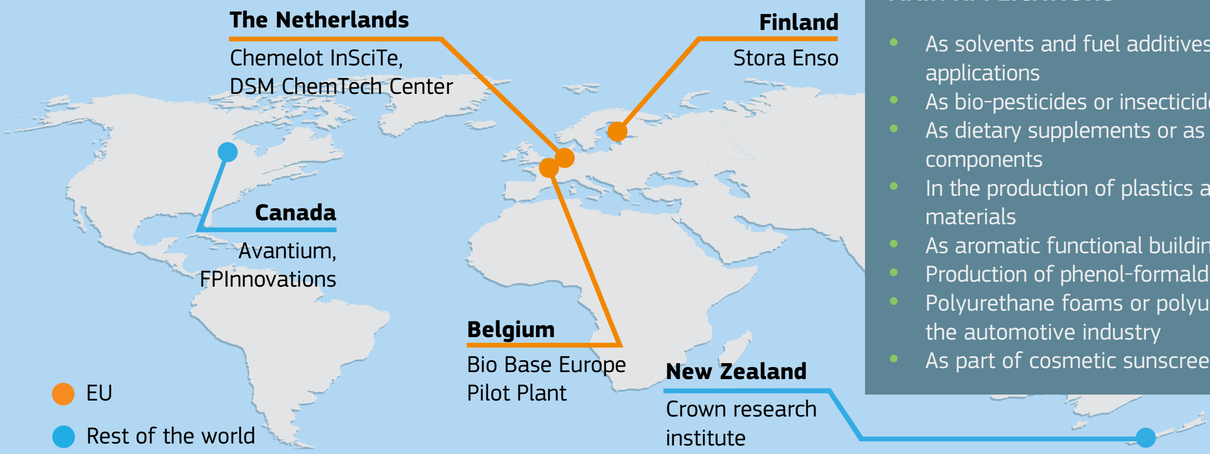
Lignin is a high molecular-weight polymer composed of alkylphenol units. It is regarded as a rich source of phenols. Lignin currently represents a residue in the production of bio-ethanol from cellulose and hemicellulose.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtB

BIOMASS PLATFORM
Lignin

TECHNOLOGY READINESS LEVEL (TRL)
5

MAIN ACTORS AND POTENTIAL CUSTOMERS



MAIN APPLICATIONS

- As solvents and fuel additives for industrial applications
- As bio-pesticides or insecticides
- As dietary supplements or as drug components
- In the production of plastics and other materials
- As aromatic functional building blocks
- Production of phenol-formaldehyde resins
- Polyurethane foams or polyurethanes for the automotive industry
- As part of cosmetic sunscreen formulas

PRODUCT EVALUATION

VALUE PROPOSITION

PRODUCTION VOLUME/VALUE

8 million tonnes per year with a market value around **USD 1,500/t**.

SALE PRICE

The price of Phenol is volatile due to fluctuations in the oil price and can cost from **USD 1,000/mt** to **USD 2,000/mt**.

PRODUCTION COSTS

Lignin costs about **USD 330/t**.

Phenols extracted from lignin that has a yield of **40 %** would induce a raw material price of about **USD 800/t** specifically for the lignin-based phenol.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:

Environmental impacts depend on the energy demand for cracking the lignin, as well as on the catalysts and solvents needed in the production process.

Bio-derived methoxylated alkylphenols are promising alternatives to traditional alkylphenols as their toxicity is significantly lower. Furthermore, methoxylated alkylphenols from lignin can possess unsaturated alkyl chain (i.e. eugenol). The unsaturation is also proposed to benefit the biodegradability of the alkylphenol, as unsaturated compounds often degrade faster in various environments than their saturated counterparts.

BIO-BASED POLYAMIDE 12

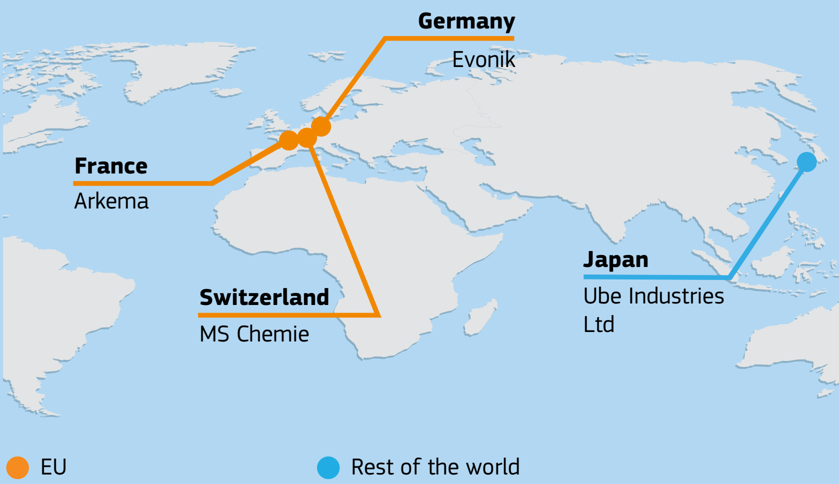
Bio-based polyamide 12 (PA12) is a long-chain linear polyamide belonging to the aliphatic polyamides group. Polyamides became the first truly synthetic fiber to be commercialized. Fatty-acids from renewable resources can be used to synthesize polymers for bio-plastics production, and PA12 represents a high-performance member of the bio-plastics family.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtB

BIOMASS PLATFORM
Renewable oils & fats

TECHNOLOGY READINESS LEVEL (TRL)
5

MAIN ACTORS AND POTENTIAL CUSTOMERS



MAIN APPLICATIONS

- Automotive, construction, electronics, food and medical industries
- Cable ties, wire insulation, flexible hosing, nozzles, damping cogwheels, flexible cover caps, sheet gaskets, sealing rings
- Fuel line applications for the automotive/transportation market
- Metal coatings
- High resistance to abrasion allows the realization of movable part connections like gears or hinges
- Advanced medical material for prosthetic devices
- 3D printing, additive manufacturing
- Filaments such as bristles for toothbrushes, shoe soles for high-quality sport shoes, cable housings, etc.
- Co-products = palm-based food and oleo- chemical industries

PRODUCT EVALUATION

VALUE PROPOSITION

Highly technical thermoplastic polymer.

Exceptionally strong even when temperatures fall below freezing.

High strength, stiffness and strong resistance to cracking under stress, and excellent long-term consistency.

A low concentration of amide moieties compared to other commercially available polyamides. PA12 absorbs very little moisture, has excellent resistance to chemicals (e.g., hydraulic fluids, oil, fuels, etc.), dampens noise and vibration and is highly processable.

PRODUCTION VALUE

In 2016, the bio-based polyamide market was valued at **USD 110.5 million**.

SALE PRICE

Rises in oil price will make fossil-based polymers more expensive, favouring the production of bio-based substitutes.

This trend will be additionally supported by increasing environmental awareness and stricter environmental policies.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT

PRODUCT SAFETY

PA12 is a durable, highly stable technical plastic with no safety concerns. Even if PA12 is suitable for medical applications, it is not intended for internal and long-term implant use.

BIOLUBRICANTS

Lubricant is a collective term for substances that reduce friction and (mechanical) stress on counteracting or moving machine parts. Lubrication reduces energy consumption and material wear and acts as a coolant. Biolubricants are derived from vegetable oils and other renewable sources.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)

BtC & BtB

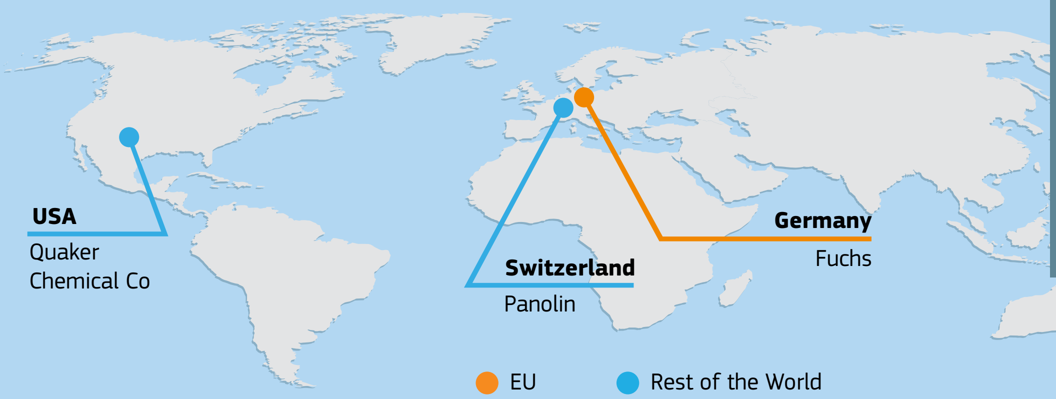
BIOMASS PLATFORM

Oils & Fats

TECHNOLOGY READINESS LEVEL (TRL)

7–8

MAIN ACTORS AND POTENTIAL CUSTOMERS



MAIN APPLICATIONS

- Transmission fluids
- Gearbox oils
- Hydraulic fluids turbine and compressor oils
- Chainsaw oil and specialty oils such as oil for track switches
- **Co-products**: Glycerin

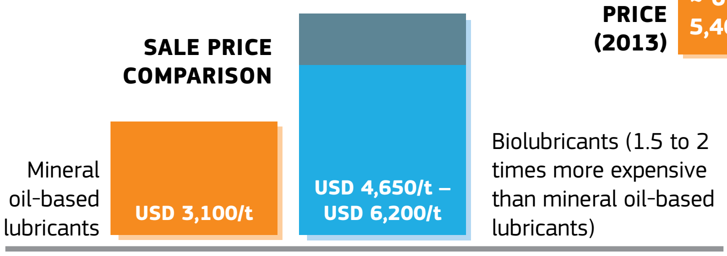
PRODUCT EVALUATION

VALUE PROPOSITION

PRODUCTION VOLUME/VALUE

The total lubricant market in 2013 comprised around **39.4 mt**, **1.5 %** of which (approx. **0.6 mt**) consisted of biolubricants.

AVERAGE PRICE (2013) ≈ USD 5,400/t



ENVIRONMENTAL CRITERIA

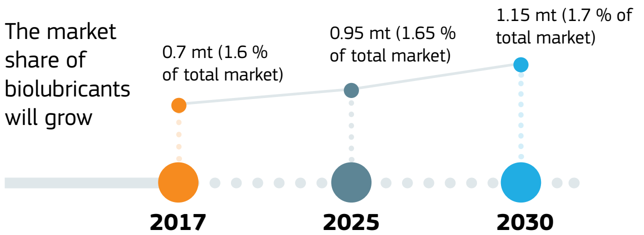
IMPACTS ON THE ENVIRONMENT:

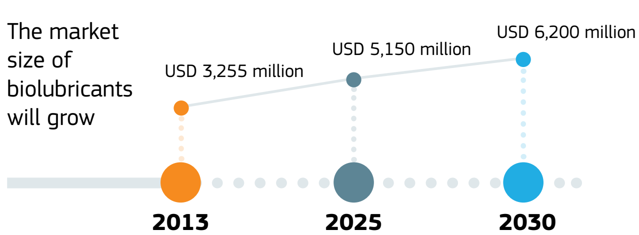
- Biolubricants are more biodegradable than normal lubricants, therefore less dangerous in case of spillage and evaporation.
- Carbon dioxide-equivalent emissions are 1.3 kg/l for biolubricants and 4.8 kg/l for fossil-based lubricants.

PRODUCT SAFETY

Biolubricants are less toxic than normal lubricants (highly dependent on the scope of the LCA).

PRODUCT PROSPECTS & OUTLOOK





PHAs FROM RENEWABLE OILS AND FATS

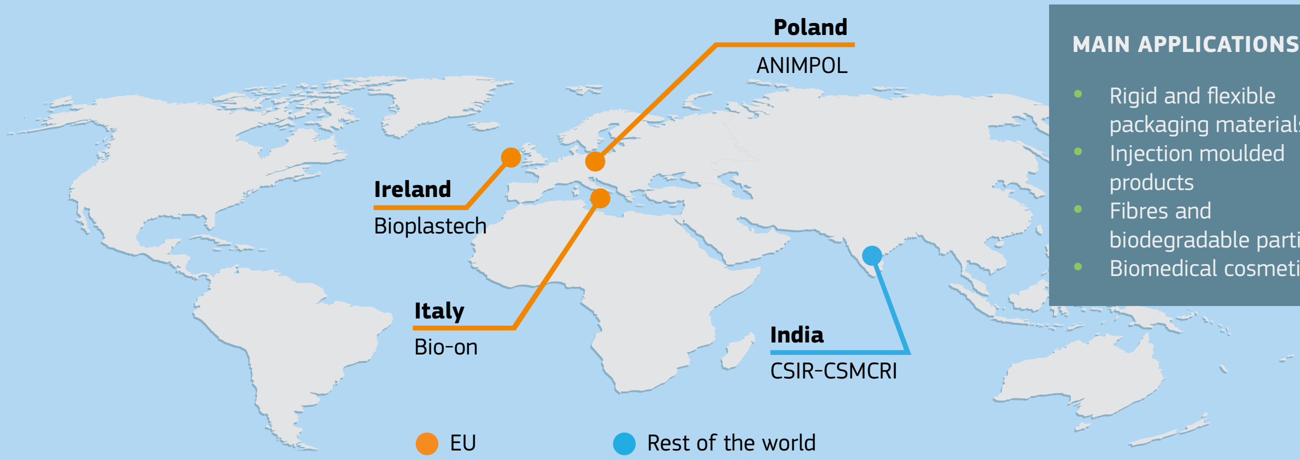
Polyhydroxyalkanoates (PHAs) are bio-polyesters that are synthetized and accumulated like carbon or energy storage by various microorganisms. The homopolymer poly(3-hydroxybutyrate) (PHB) and its copolymers containing valerate units (PHBV) or hexanoate units (PHBH) represent the most diffused types of PHAs. PHA macromolecular chains can be synthesized from numerous carbon-rich substrates by the biosynthetic action of selected prokaryotic microorganisms.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtB

BIOMASS PLATFORM
Renewable oils & fats

TECHNOLOGY READINESS LEVEL (TRL)
6

MAIN ACTORS AND POTENTIAL CUSTOMERS



MAIN APPLICATIONS

- Rigid and flexible packaging materials
- Injection moulded products
- Fibres and biodegradable particles
- Biomedical cosmetics

PRODUCT EVALUATION

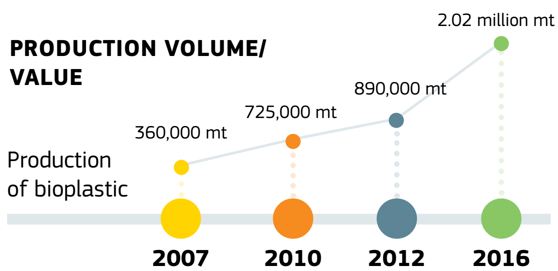
VALUE PROPOSITION

SALE PRICE

The PHA price depends on substrate cost and the bacteria used to influence the PHA yield and efficiency. The 2016 price was higher than **USD 7.2/kg**.

The commercially viable price should come to **USD 3–5/kg**, comparable to other biodegradable plastic materials.

PRODUCTION VOLUME/ VALUE



PRODUCTION COSTS

Production costs depend on:

- bacterial stream selected
- carbon source
- production technology applied
- recovery technology applied
- producing PHA from sugars is actually the less expensive option, and technology is at TRL9.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:

- PHA are spontaneously degraded in oceanic conditions (Open waters, seas, rivers, wetlands, etc).
- PHA will not contribute to plastic litter in the seas.
- PHA are the only bioplastics that spontaneously degrade in open waters.
- PHA powders and abrasives particles in detergents formulation do not have negative environmental impacts.
- The environmental impacts of PHA production depend on the carbon substrate used. If the latter is a waste by-product stream, little to no land competition impact is registered.

PRODUCT SAFETY

PHA is biocompatible and bioresorbable. Its bio-medical applications include bone-marrow scaffolds, cardiovascular patches, nerve repair devices and bone graft substitutes.

PRODUCT PROSPECTS & OUTLOOK

The production volume of bioplastic is projected to reach up to **4.4 million mt** by 2020, growing at a CAGR of 12 %.

LIMONENE-BASED ENGINEERING POLYMERS

Limonene is the main element of the essential oils present in citrus fruit peels. It is mainly derived from the oil and peels of citrus fruits (e.g.: lemon, orange, mandarin)and is a clear colourless liquid at room temperature.

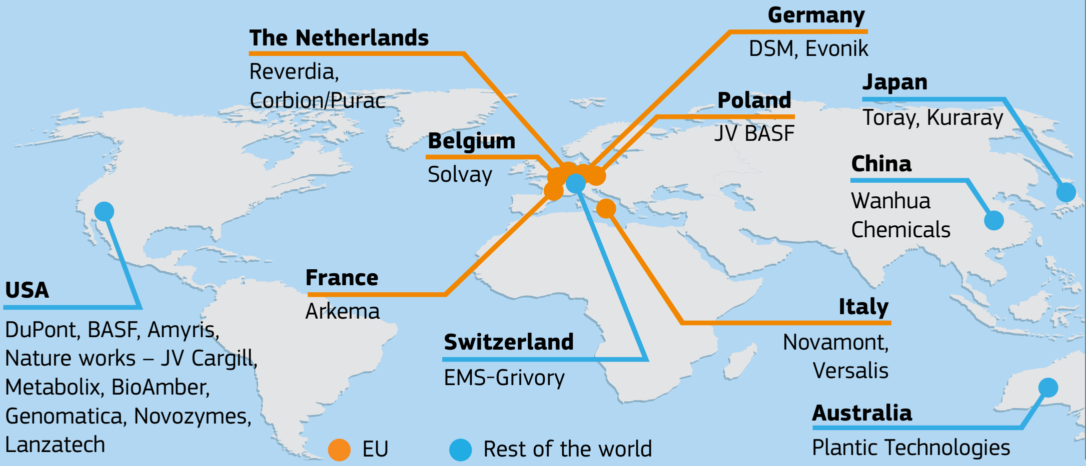
Technical polymers that are sourced from limonene and have elevated thermomechanical properties for engineering use are currently under development. Beyond being an aromatic moiety that induces elevated molecular stiffness in polymer chains, its minimal environmental and health impacts make it attractive for the substitution of traditional monomers.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtB

BIOMASS PLATFORM
Terpenes

TECHNOLOGY READINESS LEVEL (TRL)
5

MAIN ACTORS AND POTENTIAL CUSTOMERS



MAIN APPLICATIONS

- Tubing,
- Footwear,
- Industrial machinery,
- Coatings and paints,
- Elastic fibres,
- Rigid insulations,
- Soft flexible foam,
- Medical devices,
- Protective coatings as well as optically clear sheets and films
- construction engineering and automotive industry

PRODUCT EVALUATION

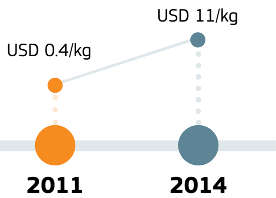
VALUE PROPOSITION

PRODUCTION VOLUME/VALUE

Limonene worldwide production exceeds **70,000 tonnes** per year.

SALE PRICE

D-Limonene exhibits price volatility in the market just like any other agricultural product.



USE OF LIMONENE-BASED ENGINEERING POLYMERS

(R)-enantiomer constitutes **90–96 %** of citrus peel oil and accounts for circa **49,895–74,843 tonnes** per year.

Since limonene is also the main component of orange oil, it is a quite abundant alicyclic terpene, resulting in a capacity of more than **520,000 tonnes** per year (estimated from **70 million tonnes** of oranges produced per year), of which **70,000 tonnes** are extracted each year.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:
D-Limonene has a zero net global warming potential and is an environmentally preferable product (EPP). Limonen-based technical polymers are durable plastics that can substitute traditional fossil-based counterparts, with similar properties and applications, but wih reduced environmental impact.

IMPACTS ON HEALTH:
D-limonene has been used clinically to dissolve cholesterol-containing gallstones and to relieve heartburn.

PRODUCT SAFETY

Limonene-based polyols are safe bio-based alternatives for traditional Mannich polyols as nonyl-phenol is considered estrogenic and toxic, especially for aquatic life.

BACTERIAL BIOSURFACTANTS

Biosurfactants, widely known as biological surface-active compounds or microbial surface-active agents, are a structurally diverse group of molecules synthesized by microorganisms. They all have an amphiphilic character. In the last five decades, they have occupied a market niche as alternatives to chemical surfactants. Among the various categories of biosurfactants, sophorolipids and rhamnolipids belong to the class of microbial glycolipids.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtB

BIOMASS PLATFORM
Natural Polyelectrolytes

TECHNOLOGY READINESS LEVEL (TRL)
7

MAIN ACTORS AND POTENTIAL CUSTOMERS

MAIN APPLICATIONS

- In agricultural industries as phytopathogens control and as an adjuvant in the formulation of herbicides
- In the pharmaceutical, cosmetics, and textile industries
- In the food industry bioremediation medium for oil recovery from contaminated soils
- In biomedicine for their anti-microbial, antitumor, antiviral and immune-modulating characteristics
- In detergents and cleaners

PRODUCT EVALUATION

VALUE PROPOSITION

PRODUCTION COSTS

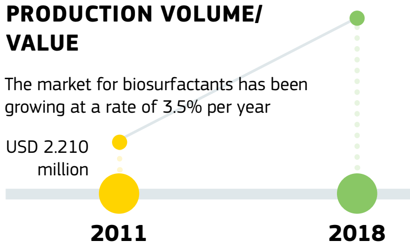
The cost of a commercialized biosurfactant is between USD 10/mg (98 % pure Surfactin used in medical research) and USD 24/kg (formula used in the early 1980s for the cleaning of oil tanks and/or advanced oil recovery).

The economics of production hinders the commercialization of rhamnolipids and other biosurfactants.

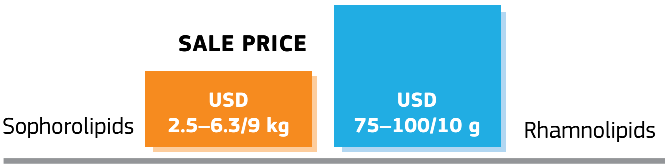
No downstream technology allows to recover and purify rhamnolipids at industrial scale (e.g., Downstream processing of biosurfactant production accounts for 70–80 % of all production costs).

PRODUCTION VOLUME/ VALUE

The market for biosurfactants has been growing at a rate of 3.5% per year



SALE PRICE



ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:

- They have a significantly lower environmental impact vis-a-vis chemical surfactants.
- They are characterized by a low toxicity and a biodegradable nature and specificity, which is in line with the European Surfactant Directive.
- Biosurfactants' biodegradability, in conjunction with their low environmental toxicity, allow these products to be an effective alternative to surfactants that are non-compliant with EU regulations.

PRODUCT SAFETY

Biosurfactants are safe products suitable for pharmaceutical applications; they even have therapeutic applications given their large number of bioactivities.

BIOTECHNOLOGICAL CHITOSAN

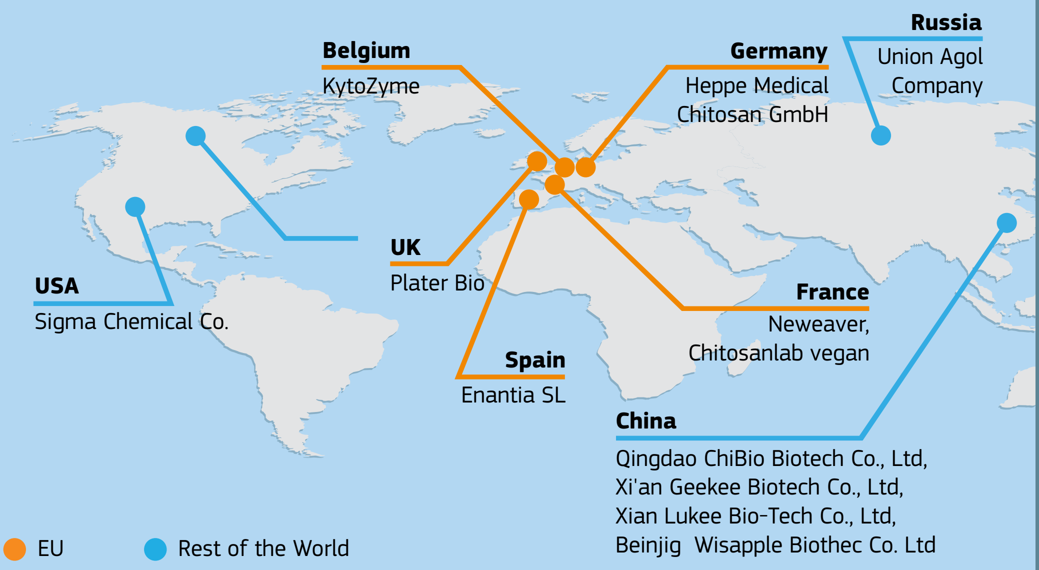
Chitin is a natural biopolymer that has limited large scale use due to its water and solvent insolubility. Water-soluble derivatives have been produced in its place, such as chitosan. Third generation chitosan is derived from algae, bacteria and fungi, and the available biomass is represented by wastes from agro-alimentary industries. Microalgae fermentation already exists at industrial scale, and this could be the first commercial source of non-animal chitosan that is derived chemically.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)
BtB

BIOMASS PLATFORM
Natural Polyelectrolytes

TECHNOLOGY READINESS LEVEL (TRL)
7

MAIN ACTORS AND POTENTIAL CUSTOMERS



MAIN APPLICATIONS

- Antibacterial lining for bandages and wound dressings,
- Development of artificial skin and cartilage regeneration,
- Reconstruction of periodontal tissues,
- Hemodialysis membranes
- Drug targeting
- Coating for seeds to boost disease resistance,
- Agent to prevent spoilage in winemaking,
- Food safety and quality enhancer, food preservative and lengthener of shelf-life
- Water treatment
- Paper and textile industries

PRODUCT EVALUATION

VALUE PROPOSITION

PRODUCTION VOLUME/VALUE

Most of the chitosan commercially available is produced from **shrimp** or **crab shell wastes**, rather than from **fungi** and **algae**.

In 2018, small quantities of these molecules have been made available on the market at prohibitively high prices.

SALE PRICE

Chitin	Chitosan
≈ EUR 500/kg	≈ EUR 1,100/kg–1,200/kg

The final price depends on:

- The source of chitosan derivation
- The degree and pattern of deacetylation

PRODUCTION COSTS

Different extraction methods (either chemical or biological) yield different processing costs. While chitin-degrading enzymes represent high-cost low-volume products, deacetylase-producing bacteria may represent a more efficient solution.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:

- Chitosan is used in wastewater treatment to remove heavy metals to polluted sediment.
- Chitosan can lower food waste, as it helps extend the shelf life of refrigerated fish fillets.

PRODUCT SAFETY

Bacterial chitosan (3rd generation chitosan) is highly pure and has a well-controlled molecular structure.

It's fully biocompatible and bioresorbable.

These features make it suitable for highly demanding applications, mainly in the medical and pharmaceutical sectors.

PHAs FROM URBAN WASTES

Polyhydroxyalkanoates (PHAs) are bio-polyesters synthetized and accumulated like carbon or energy storage by various microorganisms. A variety of waste streams has been utilized in the last decades to produce PHAs. Activated sludge, municipal waste water treatment plants (WWTP), urban wastewater sludge (UWWS) and organic municipality solid waste (OFMSW) are all economically viable carbon substrates for its production.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)

BtB

BIOMASS PLATFORM

Urban biowaste

TECHNOLOGY READINESS LEVEL (TRL)

6

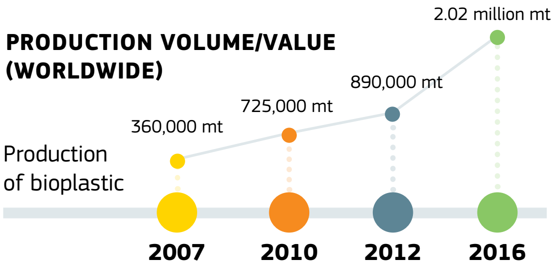
MAIN ACTORS AND POTENTIAL CUSTOMERS

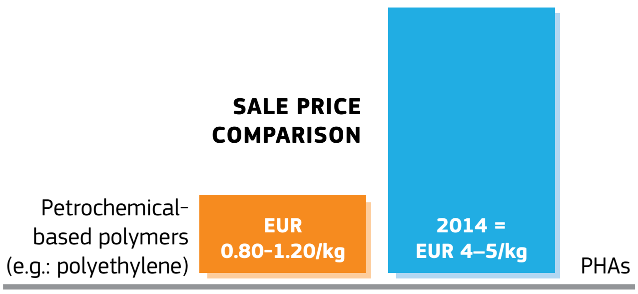
MAIN APPLICATIONS

- Rigid and flexible packaging materials,
- Injection moulded products,
- Fibres,
- Biodegradable particles,
- Biomedical cosmetics

PRODUCT EVALUATION

VALUE PROPOSITION





PRODUCTION COSTS

Raw material costs represent 50 % of production costs.
PHA production generates extensive biomass waste and, as consequence, high disposal costs.
Five kilograms of raw material are needed to obtain 1 kg of product.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:

- PHA are spontaneously degraded in oceanic conditions (Open waters, seas, rivers, wetlands, etc).
- PHA will not contribute to plastic litter in the seas.
- PHA are the only bioplastics that spontaneously degrade in open waters.
- PHA powders and abrasives particles in detergents formulation do not have negative environmental impacts.
- The environmental impacts of PHA production depend on the carbon substrate used. If the latter is a waste by-product stream, little to no land competition impact is registered.

PRODUCT SAFETY

PHA is biocompatible and bioresorbable. Its bio-medical applications include bone-marrow scaffolds, cardiovascular patches, nerve repair devices and bone graft substitutes.

VOLATILE FATTY ACIDS (VFAs) MIXTURES

Volatile fatty acids (VFAs) include short and medium chain saturated carboxylic acids. They can be produced both via microbial fermentation and biological routes, utilisizing renewable carbon sources as a raw material. A large varieties of organic waste streams could be converted to VFAs by the application of conventional biotechnological anaerobic fermentations. VFAs are a performing start material for the entire chemical industry and represent suitable precursors for the production of biopolymers.

BUSINESS TO BUSINESS (BTB) OR BUSINESS TO CONSUMER (BTC)

BtB

BIOMASS PLATFORM

Urban biowaste

TECHNOLOGY READINESS LEVEL (TRL)

7

MAIN ACTORS AND POTENTIAL CUSTOMERS

MAIN APPLICATIONS

- Polymers (PVA, PET, biodegradable)
- Inks, paints, coatings
- Textile (CA), intermediates, pigments, dyes
- Foods
- Plastics
- Leather tanning processes
- Flavours, drug preparation
- Propylene, glycol, acrylates, propylene oxide
- Plasticisers, food processing packaging
- Poly-L-lactates (plant growth regulators)
- Cosmetics & toiletries
- **Co-products**: biopolymers (PHAs) and other valuable products, such as biofuels, alcohols, aldehydes or ketones

PRODUCT EVALUATION

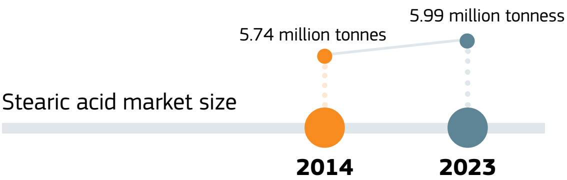
VALUE PROPOSITION

PRODUCTION VOLUME/VALUE

Among VFAs, acetic acid is most commercialized, with a global production of circa **6.5–7 mt** per year.

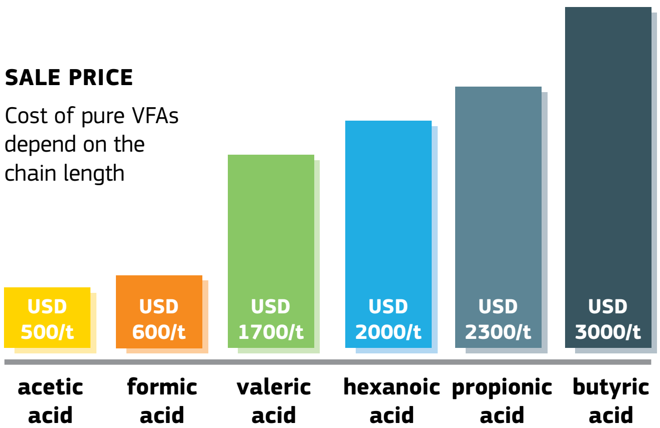
Estimations for VFAs production is **1.7 mt** per year.

Growth of personal care industry is likely to support fatty acids market size growth.



SALE PRICE

Cost of pure VFAs depend on the chain length



VFAs recovered from biowaste will presumably have a higher price, up to USD 5000/t.

PRODUCTION COSTS

One of the disadvantages of VFAs are the production costs associated with the separation and purification of downstream processes.

ENVIRONMENTAL CRITERIA

IMPACTS ON THE ENVIRONMENT:

VFAs can replace fossil carbon substances with more sustainable sources such as waste and biomass.