FONDAZIONE ISTITUTO ITALIANO DI TECNOLOGIA

A TECHNOLOGY TEASER

BIOPLASTICS AND BIOELASTOMERS

ISTITUTO ITALIANO DI TECNOLOGIA

Released on March 2015

NEW MATERIALS

Istituto Italiano di Tecnologia – Mission and History

The Foundation is intended to promote Italy's technological development and advanced education, consistent with national policies for scientific and technological development, thus strengthening the national production system.

For this purpose, the Foundation:

- helps and accelerates the development, within the national research system, of scientific and technological skills able to facilitate state of the art technological advancements of the national production system;

- develops innovative methods and know-how, in order to facilitate new high-level practices and positive competitive mechanisms in the field of national research;

- promotes and develops scientific and technological excellence, both directly, through its multi-disciplinary research laboratories, and indirectly, through a wide collaboration with national and international laboratories and research teams;

- carries out advanced training programs as a part of wider multi-disciplinary projects and programs;

- fosters a culture based on sharing and valuing results, to be used in order to improve production and for welfare-related purposes, both internally and in relation to the entire national research system;

- creates technological understanding about components, methods, processes and techniques to be used for the implementation and interconnection of innovative products and services, in strategic areas for the competitiveness of the national production system;

- pools research scientists operating in various research institutes and establishes cooperation agreements with high-level, specialized centers;

- promotes interactions between basic research and applied research facilities, encouraging experimental development;

- spreads transparent, merit-based selection mechanisms for research scientists and projects, in compliance with globally approved and established criteria.

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EXECUTIVE SUMMARY

Although plastics are indispensable tools for our daily life, most of the plastics we use today are made up of non-degrading petroleum based resources. Lack of degradability and the closing of landfill sites as well as growing water and land pollution problems have led to serious global concern about plastics. Processed vegetables and cereals produce large amounts of waste rich in cellulose all over the world. Such waste was directly transformed into green plastics.

Two different technologies have been developed at IIT for the fabrication of bioplastics from agro-waste and starch. The first one is the direct transformation of inedible agro-waste (Figure 1) into bioplastics and the second one is elastomerization of agro-waste or starch into robust bio-elastomers. The first process uses an organic acid to transform the cellulosic agro-waste into amorphous plastics. The acid can be recycled in closed system of production. The second process uses micronized agro-waste powders including starch dispersed in silicone-based polymer precursors to produce bio-elastomers containing not less than 50% vegetable based ingredient by weight. Typical agro-waste products that can be used are parsley and spinach stems, cacao pod husks, rice hulls, oat hulls, orange peels, and starch.

These technologies represent a unique chance for companies interested in bioplastics market or willing to branch out to this market. IIT assets appear well positioned for an out-licensing strategy, providing the licensee partner with the ability to take care of the late stage development, CE certification, scale-up and production process. The licensee should guarantee a high probability of market success based on consolidated marketing & distribution organization. A typical licensing strategy based on entry fee and subsequent royalties on net sales can be envisaged.

INTELLECTUAL PROPERTY

PCT International Application #	PCT/IB2014/062919 - 07 July 2014
Priority Application #	TO2013A000570 - 08 July 2013
Regional Patent Applications filed	**EP** 14759297.6, **US** 14/90378, **KR** 2016-7003275, **CN** 201480039021.2
Applicant	Fondazione Istituto Italiano di Tecnologia
Inventors	Ilker S. BAYER, Elisa MELE, Despina FRAGOULI, Roberto CINGOLANI, Athanasia ATHANASIOU
Title	Process For Producing A Hydrophobic Composite Bioelastomer Comprising Starch

Short Description

The present invention relates to a process for producing hydrophobic composite bioelastomers comprising a cross-linked bioelastomer matrix, in which an organic phase is dispersed. In particular the invention relates to composite bioelastomers comprising a polysiloxane as cross-linked matrix polymer and starch as dispersed phase.

PCT International Application #	PCT/IB2014/065688 - 29 October 2014
Priority Application #	TO2013A000874 - 29 October 2013
Regional Patent Applications filed	**EP 14812604.8,** pending requests in US, BR, CN and JP
Applicant	Fondazione Istituto Italiano di Tecnologia
Inventors	Ilker S. BAYER, Elisa MELE, Despina FRAGOULI, Roberto CINGOLANI, Athanasia ATHANASIOU
Title	Process for the production of a biodegradable plastic material, obtained from vegetable waste materials

Short Description

This invention relates to a process for the production of biodegradable plastics materials and biodegradable composite plastics materials using cellulose plant wastes, particularly those deriving from edible herbs, greens and cereals.

IIT TECHNOLOGY

Bioplastics

The first technology is the direct transformation of inedible agro-waste (Figure 1) into bioplastics.

Figure 1. Examples of agro-waste raw materials that can be used to produce bioplastics

The production process is relatively simple and can be scaled up for continuous production with solvent recycle facilities. Depending on the plant origin, the dry micronized agro-waste powders can take from three days to two weeks for complete dissolution. After full dissolution, the solutions can be cast into proper molds to make the bioplastics after solvent evaporation as shown in Figure 2.

Figure 2. Bioplastics obtained from zein powder (corn protein), parsley stems and cacao pod husks

Depending of the source raw material, the mechanical properties bioplastics can significantly vary. For instance, bioplastics obtained from rice husks are very rigid whereas spinach stems produce rather soft and stretchable films (Figure 3). It is possible blend the solutions in order to reach a desired plastic property. In this technology, we demonstrated for the first time that industrially processed wastes from edible cereals and vegetables rich in cellulose can be transformed into bio-plastics by simply aging them in simple organic acid solutions regardless of their bio-origin. Depending on the plant species, biopolymers can be made to display diverse mechanical properties ranging from brittle and rigid to soft and stretchable. Blending these vegetable waste solutions with the similar organic acid solutions of pure cellulose, all-natural plasticization of amorphous cellulose is achieved. These new bio-plastics can replace many non-degrading plastics, preserving the environment, and open up new avenues towards tailoring mechanical properties of cellulose for applications in packaging and biomedicine as well as designing new feedstock for biofuel synthesis.

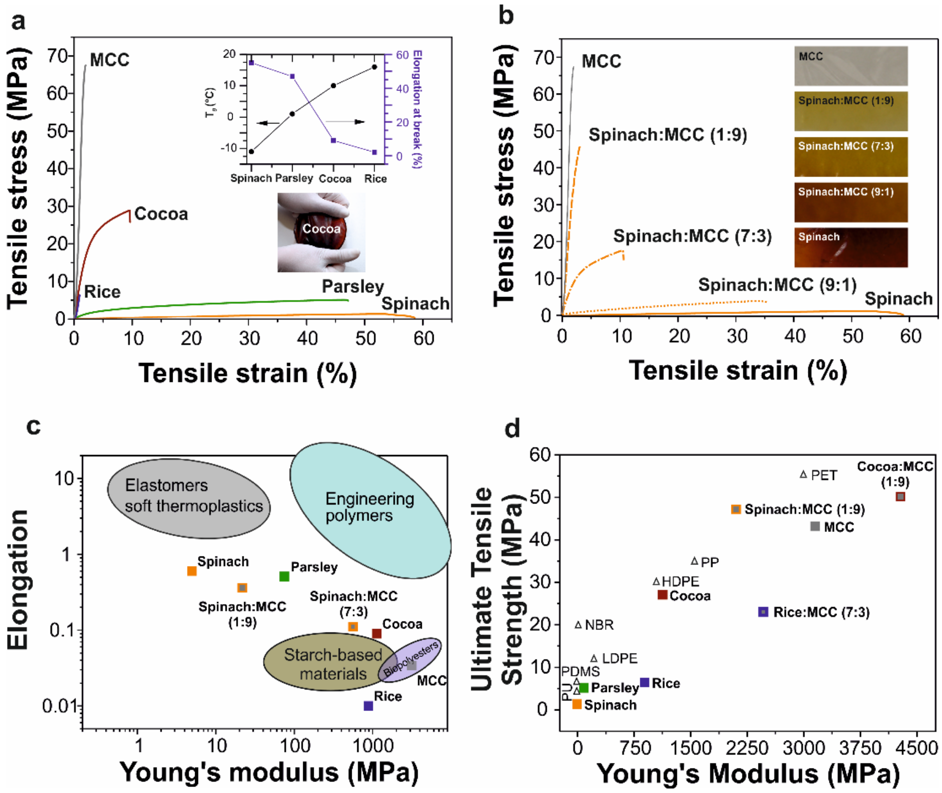


Figure 3. Mechanical properties of pure cellulose and inedible plant bio-plastics: **a**, Typical stress-strain curves for pure cellulose, cocoa, rice, parsley and spinach films. An important set of different mechanical properties is observed. In the upper inset the relationship between the glass transition temperature and the elongation at break is displayed. The bottom photography shows a stretched film from cocoa pod husk waste. **b**, Typical stress-strain curves for MCC:spinach blends. Intermediate tensile behaviors between pure cellulose and spinach waste bio-plastics are achieved. The appearance of tested samples is also shown. **c**, Elongation versus Young's modulus graph where the domains of elastomers/soft thermoplastics (PU, PDMS, NR, etc.), engineering polymers (PET, PP, PE, etc.), biopolyesters (PHB, PLA, etc.) and starch-based materials (thermoplastic starch (TPS), TPS/PCL, LDPE/starch, etc.) are highlighted. Pure cellulose, plant waste and blend samples are located among these groups. **d**, Ultimate tensile strength versus Young's modulus graph. Pure cellulose, plant waste and blend bio-plastics cover a wide range.

Bioelastomers

Designing starch or vegetable-based biopolymers and biodegradable composites with durable mechanical properties and good resistance to water is still a challenging task. Although thermoplastic (destructured) starch has been an emerging alternative to petroleum based polymers, its poor dimensional stability under humid and dry conditions extensively hinders its use as a biopolymer of choice in many applications. In this technology, we produced a biodegradable elastomer by incorporating large amounts of unmodified corn starch or micronized vegetable waste powders such as parsley, spinach or cacao-exceeding 80% by volume-in silicone-based thermosets to produce mechanically robust and hydrophobic bio-elastomers. The naturally adsorbed moisture on starch or micronized vegetable powder surface enables auto-catalytic rapid hydrolysis of the polyorganosiloxane forming Si–O–Si networks. Depending on the amount of micronized granules, the mechanical properties of the bio-elastomers can be easily tuned with high elastic recovery rates. Moreover, for instance, starch granules lowered the surface friction coefficient of the polyorganosiloxane network considerably. Stress relaxation measurements indicated that the bio-elastomers have lower strain energy dissipation factors than conventional rubbers rendering them promising green substitutes for plastic mechanical energy dampeners. The corn starch granules also have excellent compatibility with addition-cure polysiloxane chemistry that is used extensively in micro-fabrication. Regardless of the starch or micronized vegetable powder concentrations, all the developed bio-elastomers have hydrophobic surfaces with low friction coefficient and much less water uptake capacity than thermoplastic starch. The bio-elastomers are biocompatible and are estimated to biodegrade in the Mediterranean Seawater within three to six years. The bio-elastomers are quite robust and can be handled easily as seen in Figure 4.

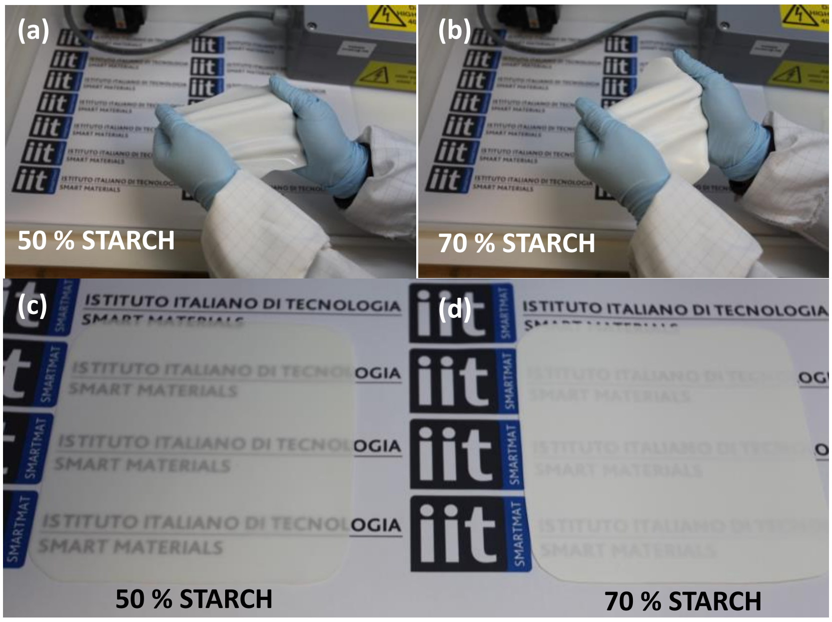
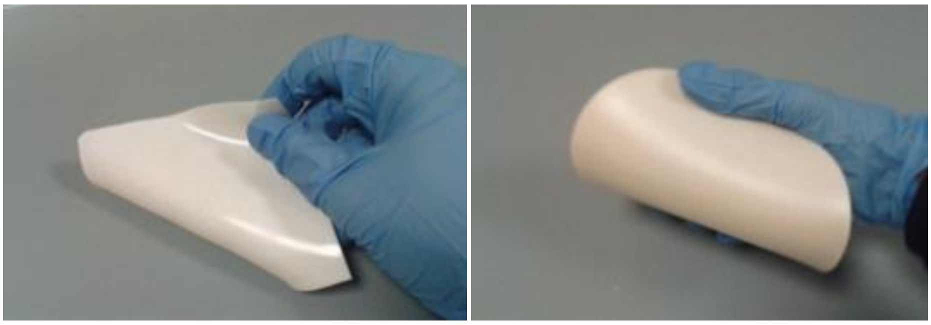


Figure 4. Photographs of bio-elastomers containing (a) 50% and (b) 70% unmodified corn starch granules. Photographs in (c) and (d) show that the bio-elastomers are somewhat transparent when placed on a surface, macroscopically indicating good degree of starch particle dispersion

Starch from different resources such as potato, corn or rice is combined with biodegradable polymer precursors to form elastomers with engineered mechanical properties (Figure 5). The elastomers also show exceptional water proof properties. In this technology, starch is not destructed compared to thermoplastic starch (TPS). Therefore, starch-based bioelastomers display superior hydrophobicity compared to TPS. The fabrication process is also environmentally friendly and can be done under ambient conditions requiring minimum energy.



Composition	Toughness (MPa)	Elongation (%)	Ultimate Strength	Contact Angle (°)
Pure Precursor	0.8	885	4.7	117
30% Starch	1.1	500	4.7	118
50% Starch	8.0	132	2.5	120
70% Starch	9.0	53	1.8	126
80% Starch	7.0	90	1.2	133

Figure 5. Bioelastomers from starch with engineered mechanical properties

Not only starch but also various vegetable, herb and cereal wastes created by industrial food processors can also be used in making bioelastomers similar to starch (Figure 6). The elastomerization was found to be highly sensitive to the type of plant waste used. In the case of starch, for instance, the polymerization is quite fast whereas in the case of oregano waste the polymerization is slower. For the process to be effective, all the plant waste should be ground to fine powder in order to increase their surface area for re-action. The elastomerization can be controlled in order to obtain highly or partially stretchable bioelastomers depending on the precursor chemistry as well as the amount of pulverized vegetable waste used. In general, up to 85% of vegetable waste can be used while maintaining a good degree of stretching.

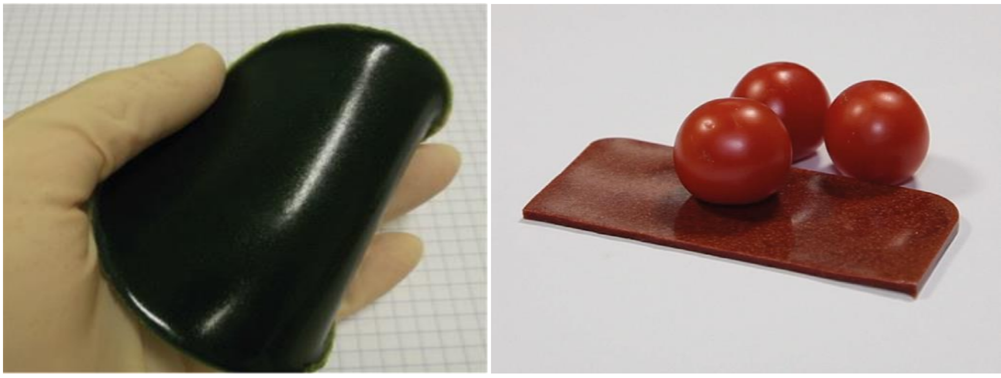


Figure 6. Bioelastomers obtained from spinach and from tomato skin residue originating from tomato pulp making

MARKET ANALYSIS

Based on IIT inventions described in the PCT applications PCT/IB2014/062919 and PCT/IB2014/065688, internal documentation on the technology and related literature publications by the inventors and competitors, the **Bioplastics Market** has been identified as the major reference marketplace. The Bioelastomers market has been understood as a subsegment of the bioplastic market with no possibilities to be studied separately. Accordingly, the Bioplastic market has been analyzed for its current dimension and future trends through a web search-based retrieval of specific information. Key players have been identified and their websites have been reported.

The Biopolastics Market

According to a report published in 2014 by Grand View Research and titled *"Market Analysis, Market Size, Application Analysis, Regional Outlook, Competitive Strategies And Forecasts, 2014 To 2020"* (http://www.grandviewresearch.com/industry-analysis/bioplastics-industryBioplastics, Report Code: GVR66), bioplastics refer to a family of plastics which are derived from bio-based material such as plant and animals rather than petroleum. These materials could be biodegradable or non biodegradable in nature. The development of these materials is expected to significantly save the consumption of petroleum for manufacturing of plastics. Furthermore, the improvement in technology and increased application scope of bioplastics make them an ideal choice over conventional plastics. The increased environmental awareness among consumers coupled with the increased importance of sustainability is expected to drive the demand for bioplastics over the next few years.

There are a variety of factors which have contributed in the shift towards bioplastics. Consumers have increased interest towards the consumption of green products and restoration of the environment. In addition, the stringent regulatory policy with regards to conventional petroleum products has led to an increased demand for bioplastics. However, the lack of infrastructure at raw material level coupled with the lack of support could hamper the development of the market. Bioplastics have been replacing convention plastics in applications such as packaging, automotive and electronics. Food packaging is expected to be a key opportunity for the bioplastics market due to the non toxic nature of its raw material which are ideally suited for food items.

The commonly produced polymer types of bioplastics includes bio-polyethylene (bio-PE), polylactic acid (PLA), polyhydroxyalkanoate (PHA), bio-polyethylene terephthalate (bio-PET), and bio degradable polyester among others. In the non degradable bioplastics segment, growth is expected to be led by bio-PE and bio-PET on account of the wide application scope of these plastics. In the biodegradable segment, polyhydroxyalkanoate (PHA) and polylactic acid (PLA) are expected to witness fastest growth over the next seven years. In addition, the market would also witness the development of bio-based building blocks which are a substitute to conventional platform chemicals.

Even though they still account for only a small share of the plastics market as a whole, bioplastics have become a real alternative to standard plastics manufactured from petrochemical feedstocks. The term "bioplastics" is utilized for a whole range of various products with different properties and applications. In a study published in February 2014, the market research institute Ceresana analyzes the developments on the global market for bioplastics (http://www.ceresana.com/en/market-studies/plastics/bioplastics/).

Bioplastics possess a tremendous market potential, even in times of economic difficulties: market analysts at Ceresana expect **global demand to increase at least by 18.9% p.a. in the future**. More and more often, the improved technical properties of bioplastics allow for a substitution of conventional plastics. Progress in production and the significant expansion of capacities enable manufacturers to lower prices and therefore to further increase the competitiveness of bioplastics in the face of conventional plastics. Additionally, processors of plastics and innovative companies are aiming for increased environmental protection and sustainability, not least to improve their image among consumers.

Propitious economic conditions, e.g. an increasing middle class in China, India, and parts of South America, will have additional positive effects on future sales volumes. Even though the market for bioplastics is developing at highly dynamic growth rates, considerable room for improvement remains. The major factor impeding a notably more dynamic development is the persistent skepticism of consumers regarding performance, processability, and the higher costs of bioplastics.

Europe Largest Consumer - Europe accounted for more than one third of total global bioplastics consumption in 2013. Thus, this region is the most important sales market, followed by North America, Asia-Pacific, and the rest of the world. Ceresana forecasts Europe to remain leading in research and development and the largest market for bioplastics for several years to come. Asia-Pacific and a number of South American countries, however, are likely to catch up significantly: given a sound economic surrounding and an as yet small market share of bioplastics in end applications, both regions offer an enormous potential for growth.

Focus on "Drop-In" Bioplastics - A global trend on the market for bioplastics is the increased use of non-biodegradable bioplastics, which are also known as "Drop In" bioplastics and include products such as bio-PE or bio-PET that possess properties similar to their equivalents made from fossil resources. International enterprises in segments such as foodstuffs, consumer goods, and the automotive industry are backing this development. Their aim is the reduction of their ecological footprint by using easily recyclable bioplastics. In order to meet future demand for bioplastics, Asia-Pacific and South America in particular are investing in a massive expansion and creation of production capacities. These regions can capitalize on the availability of a range of biological raw materials as well as propitious political and economic conditions.

Packaging Industry Most Important Sales Market - A sector to use a remarkably large amount of bioplastics is the packaging industry, especially in the food packaging subsegment. The major advantage of cups, bottles, plates, bags, and sacks made from biodegradable bioplastics is the fact that they can be disposed of along with leftover food. Bioplastics are also the material of choice in agricultural films that are plowed in when no longer needed, flower pots, and trays for seedlings. Bottles made from bioplastics are becoming more and more popular among manufacturers of beverages and detergents. Hence, we forecast the highest growth rates for this application area. In order for bioplastics to become established in this segment, however, it has to be made sure that the planned facilities are constructed and that producers of bottles actually do shift to utilizing biobased plastics.

The worldwide climate debate has been a constant theme in politics, business and the media for the last few years. Given the growing demand for more environmental protection and resource conservation by the general population, many companies are also thinking on how to base the development and manufacture of their products on greater sustainability. Above all, ever-rising crude prices lead the plastic industry to invest increasingly in research and development of bioplastics. Increased demand for bioplastics provides for an expansion of production capacities.

Exact worldwide bioplastics production figures and capacities are difficult to determine. They are mostly only based on estimates, and these are constantly changing due to the rapid growth of the bioplastics industry. The most reliable estimates are probably published by European Bioplastics. The results of European Bioplastics' annual market data update, presented on December 3rd 2014 at the 9th European Bioplastics Conference in Brussels, confirm the positive growth trend of the global bioplastics production capacities. "*The market is predicted to grow by more than 400 percent in the mid-term*" stated François de Bie, Chairman of European Bioplastics (http://en.european-bioplastics.org/blog/2014/12/03/pr-20141203/). The data compiled in cooperation with its respected scientific partners - the IfBB (Institute for Bioplastics and Biocomposites, University of Applied Sciences and Arts Hannover, Germany) and the Nova Institute (Hürth, Germany) - shows that **bioplastics production capacity is set to increase from around 1.6 million tonnes in 2013 to approximately 6.7 million tonnes by 2018** (Figure 7). Bio-based, non-biodegradable plastics, such as bio-based PE and bio-based PET, are gaining the most. PLA is a major growth driver in the field of bio-based and biodegradable plastics. Furthermore, renewable and compostable plastics produced locally are likely to benefit from the new EU directive on the reduction of shopping bags. Flexible and rigid packaging remains by far the leading application field for bioplastics (Figure 8). "*Besides this, a decisive growth can be observed in textiles and automotive applications; from functional sports garments with enhanced breathability to fuel line, bioplastics are constantly spreading into new markets*" explained de Bie.

The production of bio-polyethylene by Braskem as well as Dow, Crystalsev and the BASF products are mainly responsible for this development. However, the production capacity for bio-degradable plastics is expected to rise, too (Figure 9). For example the world market leader for PLA, Natureworks, has recently announced the construction of a new plant in SE Asia with a yearly capacity of 140kt, which will be completed by 2015.

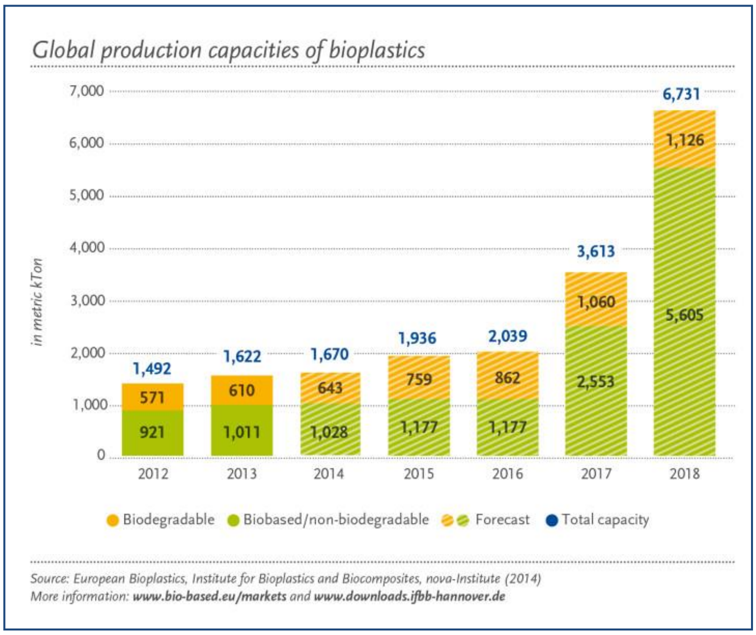


Figure 7. Global production capacity of bioplastics

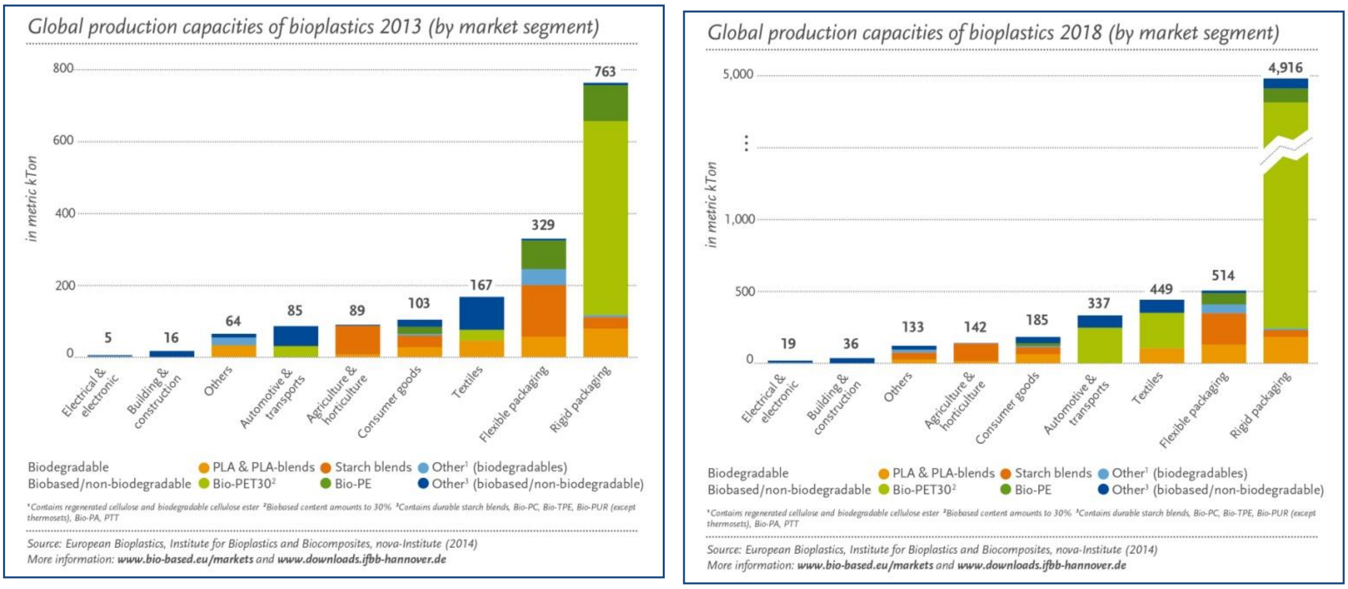


Figure 8. Global production capacities of bioplastics **by market segment** in 2013 compared to 2018

With a view to regional capacity development, Asia will expand its role as major production hub. Most of the currently planned projects are being implemented in Thailand, India and China. About 75 percent of bioplastics will be produced in Asia by 2018 (Figure 10). In comparison: Europe at the forefront of research and development will be left with only roughly 8 percent of the production capacities. Additionally, other regions of the world, such as the USA and Asia, invest into measures 'closer to market introduction', which results in a faster market development than in Europe.

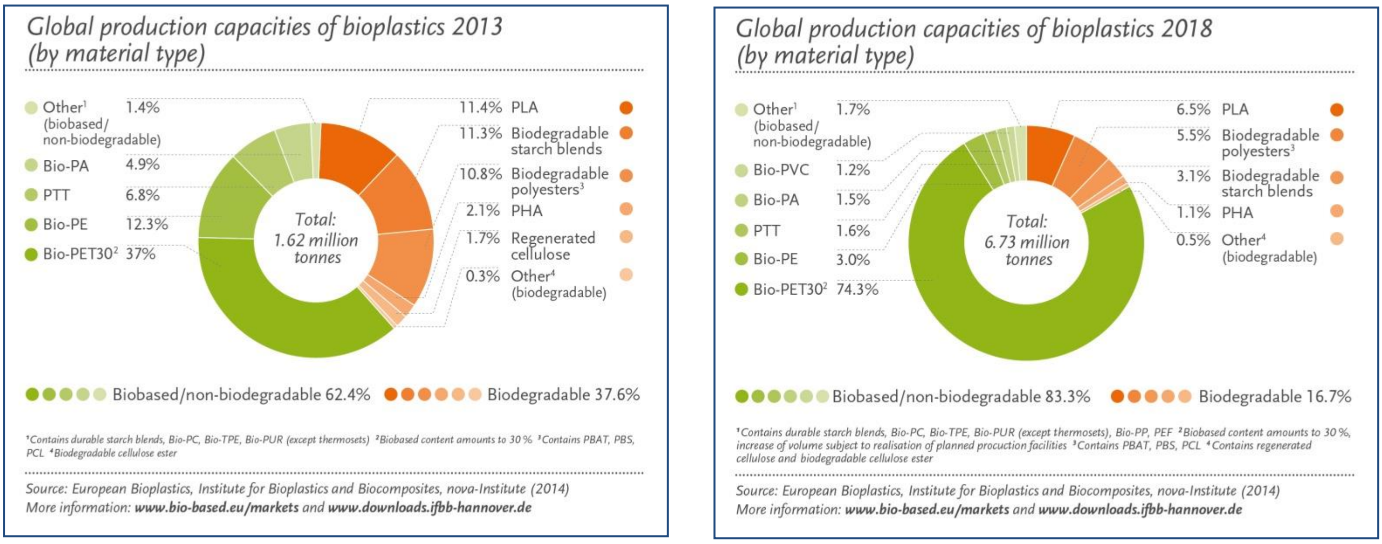
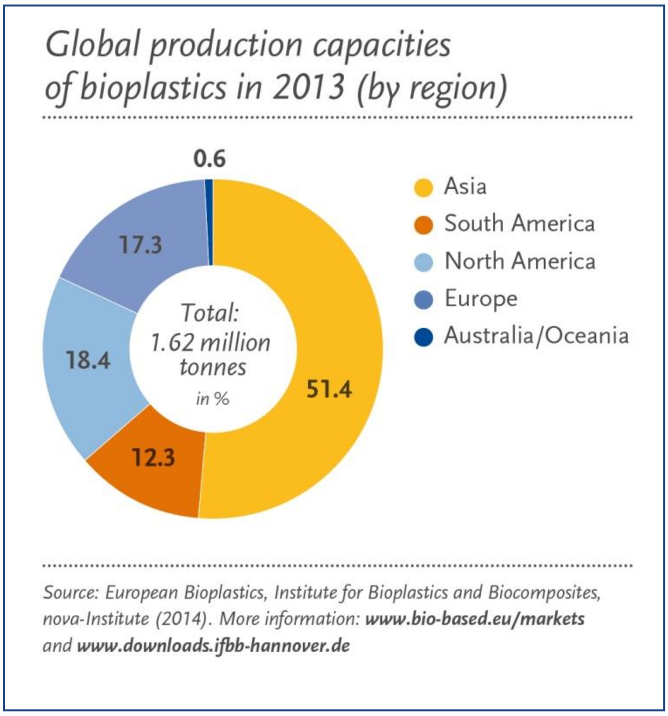


Figure 9. Global production capacities of bioplastics **by material type** in 2013 compared to 2018



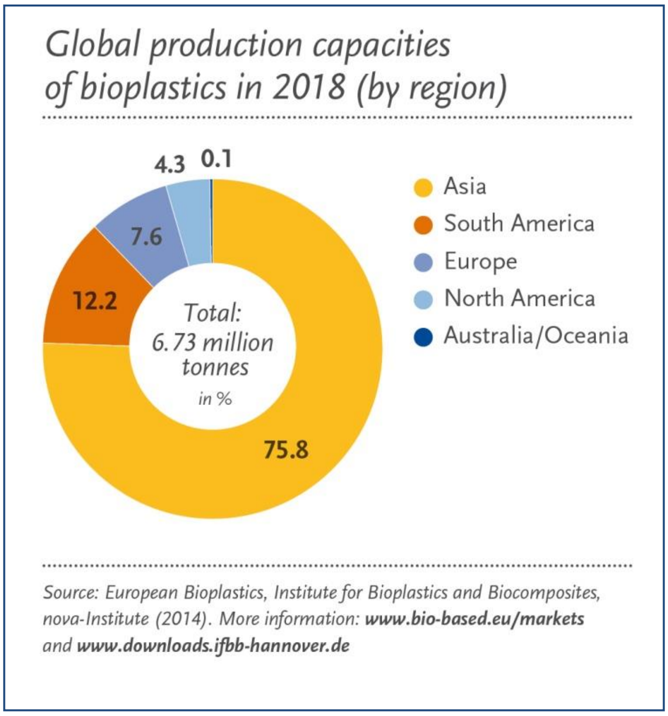


Figure 10. Global production capacities of bioplastics **by region** in 2013 compared to 2018

Lucintel, a leading global management consulting and market research firm, has conducted in January 2014 a detailed analysis on the bioplastic industry and presents its findings in *"Global Bioplastic Industry 2013-2018: Trend, Forecast, and Opportunity Analysis"* (http://www.lucintel.com/reports/chemical_composites/global_bioplastic_industry_2013-2018_trend_forecast_and_opportunity_analysis_january_2014.aspx). According to Lucintel, **the global bioplastic industry is expected to witness significant growth and reach an estimated $7.02 billion by 2018**. The major forces that are driving bioplastic market are high consumer acceptance, danger posed by climate change, increasing price of fossil materials, and dependence on fossil resources.

The wide variety of bioplastic applications under development is a positive factor for growth of bioplastic which also helps to capture market share from competing materials; huge potential lies within the fields of consumer electronics and automotive. On account of new technological developments, bioplastics are moving out of the niche and entering the mass market. Although full market penetration is just beginning, bioplastic materials and products are multiplying continuously. Multinational brand owners such as PepsiCo and Tetra Pak in the packaging market or Ford, Mercedes, Volkswagen, and Toyota in the automotive market have launched or integrated bioplastic products. Lucintel highlights some of the major challenges likely to be faced by the industry. Bioplastics are generally two to three times more expensive than the conventional plastics. Currently, bioplastic resins cost at least twice as much as petro plastic resins. Price considerations will be the primary determinant for the success of bioplastic market. It is expected that rising petroleum costs will allow some bioplastic resins to be able to achieve price parity with conventional plastics.

Life cycle analysis demonstrates that bioplastics can reduce CO2 emissions by 30%-70% as compared to conventional plastics. This shows a significant reduction in hazardous waste that is caused by oil-derived plastics. Global business is now turning to bio-plastics as governments demand cleaner alternatives to petroleum-based technologies and their reckless emission of greenhouse gas CO2. One metric ton of bioplastics generates between 0.8 and 3.2 fewer metric tonnes of carbon dioxide as compared to one metric ton of petroleum-based plastics. The product's bio based raw material helps reduce oil dependency, in addition to its biodegradable property alleviates waste disposal and toxic residues in the environment. The aforementioned characteristics draw global attention to the bioplastic usage, such as in the case in European countries. Various European countries were faced with plastic disposable issues that were increasing in severity. Therefore, the public, business, and household sectors cooperated to increase the use of bioplastic products. Examples of bioplastic support policies are the European Union mandating automotive producers to increase bioplastic component parts in its assembly, Italy's support for biodegradable single use plastic bags, and Japan's electronics appliance corporate such as Sony, Panasonic, and Toshiba changing to use bioplastic packaging and increasing bioplastic computer component parts. Furthermore, a research study by Samsung Fine Chemicals indicates that the population at large is willing to change their behavior to consume more of the environmental friendly bioplastic products if the quality were similar and even if they have to pay a higher price.

According to another report entitled: *"The Future of Bioplastics: Market forecasts to 2017"* published by the Smithers Rapra Market Reports firm (UK) in 2013, **the global demand for bioplastics is set to grow from 0.89 million tonnes per year in 2012 up to 2.9 million tonnes by 2017**
(http://info.smithersrapra.com/downloads/toc/Future%20of%20Bioplastics.pdf).
While the majority of bioplastic end use has been in packaging and food service non-durable applications, the disposal of such materials has impacted manufacturing. With one-time-use packaging often ending up in landfill, for example, biodegradability was considered to be the important application driver. Biodegrabability can be designed into many bioplastics, especially polylactic acid (PLA), polyhydroxyalkanoate (PHA), polybutylene succinate (PBS) and a few other aliphatic polyesters and starch compounds. However, the report remarked that biodegradability has become less of a focus in recent years, because it too represents a wasteful end-of-life option. Rather, the focus now is on bio-based products which are considered sustainable and renewable through feedstocks that are grown and end products which are recycled. Non-durable applications will continue to be an important part of bioplastic usage, however durable applications will increasingly become more important. The report said that having recyclable or compostable thermoplastics provider greater value if they are collected and separate from other waste plastics. High-density polyethylene (HDPE) milk containers and polyethylene terephthalate (PET) clear bottles were quoted as easily identified and recycled by most communities worldwide. However, plastic films used in packaging are less often recycled or composted, due to the difficulty of identification and separation in the consumer waste pool.
It's anticipated that the main difference between bioplastics today compared to the future will be production. Most bioplastics today are produced in "stand-alone single-technology facilities", based on a single feedstock such as corn. The report predicts that instead there will be multi-crop bio-refineries capable of using various types of bio-feedstock and producing many types of end products.

Findings predicted that 2nd/3rd generation cellulose conversion technology for non-food crops such as corn husks, grass, and wood will become economic. If so, the new technology would bypass the issue of 'food for fuels', using biomass waste, converted to ethanol and bio-monomers. To conclude, the report said: "*Bioplastic acceptance is advancing and improving, yet bioplastics are still in the early stages of market development and will only be considered as an alternative if cost, performance, or legislated* *regulations allow it. Today, bioplastics represent less than 1% of all polymer production worldwide. However, as fossil fuel costs increase relative to bio-based materials, and as biorenewable materials become a more important aspect of improving environmental sustainability, there will be an ever-increasing need for bioplastics*."

Though bioplastic price in the present is more expensive due to higher production costs, **future technological advancement should help lower bioplastic price.** Currently, the production costs of bioplastic are approximately 1.6-3.0 times higher than conventional plastic, depending on the type of plastic. In the early stages of bioplastic development, bioplastic was made from starch or sugar producing crops. However, in the future, producers should start producing bioplastic from other commodities especially from agricultural residues such as rice straw, rice husk, and tree bark, in addition to developing new technologies to reduce production costs so that bioplastic products is able to compete with conventional plastic products.

As said, bioplastic products could replace some of the conventional plastic products, especially packaging. At present, around **80% of the global bioplastic production is used to serve the packaging industry**, in which 40% of the packaging market share goes to producing plastic shopping bags, 33% to plastic bottles, and 7% to food packaging. An important factor that allows the packaging industry to utilize bioplastic products are its biodegradable nature such as plastic bags which has a short life span and does not need special qualifications. On the other hand, the use of bioplastic products in other industries such as automotive parts, construction, and medical treatment is still low. Nova Institute, a biotechnology expert, predicts that bio-PET plastic bottles will tremendously grow by ten-folds to 5 million tonnes in 2020. Bio-PET plastic bottles has the potential to replace all of the petrochemical base PET bottles in the future, including PLA packaging which is increasing its market share in the food packaging industry. Bioplastics packaging covers an array of industries, including organic foods, fruits and vegetables, beverages, bread and bakery products, and catering, which require disposable utensils (cups, mugs, trays, plates, and cutlery).

According to a new market report published in October 2014 by Persistence Market Research and *titled "Global Market Study on Bioplastics Packaging for Food and Beverages: Beverages Packaging to Witness Highest Growth by 2020"* the situation for **the global bioplastics packaging market for food and beverages is even significantly more optimistic than previously reported reports.** This specific market was valued at $3,191.3 million in 2013 and is expected to grow at a CAGR of 36.8% from 2014 to 2020, to reach an estimated value of $28,503.6 million in 2020 (http://www.persistencemarketresearch.com/mediarelease/bioplastic-packaging-market.asp).

Over the past few decades, a surge in the use of plastics due to increase in consumer demand for safety and convenience in packaged food and beverages has been observed. When it comes to food and beverages packaging, terms such as 'green', 'organic', 'fair trade', and 'locally sourced' have been drawing the attention of consumers in the recent years. With climatic changes taking place, health awareness and environmental issues are growing. Furthermore, media coverage has made consumers more aware about the factors that are guiding their purchasing decisions.

Bioplastics have been gaining attention of policymakers in the packaging domain in recent years as it is being sourced from renewable resources and carry implications for sustainable development. Governments in several countries are against the compost of non-biodegradable conventional plastics for land filling and have been formulating several laws and policies that limit their use. The increasing demand for bioplastics packaging for food and beverages is the result of certain advantages that bioplastics have over conventional plastics such as glossy and attractive appearance, antistatic behavior, printability, barrier effect, and enhanced shelf life of fresh products. Ongoing technology advancements for improvement of physical properties of bioplastics is another major driver of the bioplastics packaging market for food and beverages industry.

The introduction of nanotechnology-based bioplastics for food and beverages packaging has opened many new application in food and beverages packaging for bioplastics over the years. Nano-enabled packaging ensures food product safety, environmental safety, and improved performance characteristics such as barrier properties particularly in PLA and starch based bioplastics which makes them suitable for many moisture content foods packaging application.

Complex separation of bioplastics from the disposal site based on their resin type makes the recycling process tough, which is one of the restraints for the growth of this market. The market of bioplastics packaging in food and beverages industry is consolidated with fewer companies accounting for larger portion of the market. Some favorable legislative reforms and new product development holds large opportunities for the bioplastics packaging market.

COMPETITIVE SCENARIO

The following list is mostly extracted from the Business Directory of the portal Bio-Plastic.org, taking into consideration the subdirectories *raw materials* and *semi-finished products* (http://bio-plastics.org/en/business-directory--bioplastic-supplier). In addition, a few companies emerged from the above mentioned market reports have been included. Overall 87 companies have been identified as key major players. Their distribution witnesses the majority of them located in Europe (54), Germany being by far the most populated country: Germany 25, The Netherlands 5, France 4, Switzerland 4, Italy 4, United Kingdom 4, Austria 3, rest of EU 5, USA 14, Japan 6, China 5, Brasil 3, Australia 2, Korea 1, Thailand 1, Canada 1.

- Albis Plastic GmbH (D, www.albis.com)
- Agrana (A, www.agrana.at)
- Amynova Polymers GmbH (D, www.amynova.com)
- Arichemie GmbH (D, www.arichemie.com)
- Arkema SA (F, www.arkema.com/en/)
- BASF SE (D, www.basf.com/en.html)
- Bayer MaterialScience AG (D, www.bayermaterialscience.de)
- BioAmber (CA, www.bio-amber.com/)
- Bio-On srl (I, www.bio-on.itwww.minerv.it)
- Biomater Ltda.(BR, www.biomater.com.br)
- Biomer (D, www.biomer.de)
- BIOP Biopolymer Technologies AG (D, www.biop.eu)
- Biopearls B.V. (NL, www.biopearls.nl)
- Biotec Biologische Naturverpackungen GmbH & Co. KG (D, www.biotec.de)
- BioTec Environmental (USA, www.bio-tec.com)
- Borregaard (N, www.borregaard.com)
- Braskem (BR, www.braskem.com.br/)
- Cardia Bioplastics (AU, www.cardiabioplastics.com)
- Cereplast (USA, www.cereplast.com)
- Cargill Inc. (USA, www.cargill.com/)
- Clarifoil (UK, www.clarifoil.com)
- DaniMer Scientific, LLC (USA, www.danimer.com)
- Dow Chemical (D, www.plastics.dow.com)
- Dow Wolff Cellulosics (D, www.dowwolff.com)
- DuPont (USA, www.dupont.com/Plastics)
- Eastman Chemical GmbH (D, www.eastman.com)
- Fkur Kunststoff GmbH (D, www.fkur.com)
- Futerro (B, www.futerro.com/)
- Gehr GmbH (D, www.gehr.de)
- Genomatica (USA, www.genomatica.com/)
- Goodfellow Cambridge Ltd. (UK, www.goodfellow.com)
- HallStar (USA, www.hallstar.com)

- Horn & Bauer GmbH & Co. KG (D, www.horn-bauer.de)
- Huhtamaki Deutschland GmbH & Co. KG (D, www.huhtamaki.com)
- Innovia Films Ltd. (UK, www.innoviafilms.com/)
- Ire Chemical Ltd. (K, www.irechem.co.kr)
- JC Hagen GmbH (Bio-Plast Division, A, www.bio-plast.com)
- JC Hagen GmbH (Ecopond Division, A, www.ecopond.de)
- Jinhui Zhaolong High Tech (CN, www.ecoworld.jinhuigroup.com)
- Kaneka Corp. (JP, www.kaneka.co.jp/kaneka-e/)
- Kareline Oy Ltd (FIN, www.kareline.fi)
- Kingfa (CN, www.kingfa.net/)
- Koninklijke DSM N.V. (NL, www.dsm.com/corporate/home.html)
- Lanxess AG (D, lanxess.com/en/corporate/home/)
- Limagrain Cereales Ingredients (F, www.lci.limagrain.com/)
- Masterbatch Winter Herstellungs und Vertriebs GmbH (D, www.masterbatch-winter.de/)
- Mazzucchelli 1849 SPA (I, www.mazzucchelli1849.it)
- Meredian Inc. (USA, www.meredianinc.com/)
- Metabolix Inc. (USA, www.metabolix.com/)
- Mitsubishi Chemical USA Inc (USA, www.mitsubishichemical.com)
- Mitsui Chemical Europe GmbH (D, www.mitsuichem.com)
- NAPAC Schweiz AG (CH, www.napac.ch)
- Natureplast (F, www.natureplast.eu)
- NatureWorks LLC (USA, www.natureworksllc.com/)
- Novamont SpA (I, www.novamont.com)
- Novomer (USA, www.novomer.com/)
- Ofotec Folien GmbH (D, www.ofotec-folien.de)
- Perstorp AB (S, www.perstorpcaprolactones.com)
- Peter Holland BV (NL, www.peterholland.nl)
- Plantic Technologies Ltd (AU, www.plantic.com.au)
- Polymer Chemie GmbH (D, www.polymer-chemie.de)
- Polyone Corp. (USA, www.polyone.com/en-us/Pages/default.aspx)
- Procter & Gamble (D, www.pg.com)
- Purac (NL, www.purac.com)
- Radici Plastic GmbH & Co. KG (D, www.radiciplastics.de)
- Rhein Chemie Rheinau GmbH (Lanxess Group, D, www.rheinchemie.com/)
- Rodenburg Biopolymers B.V. (NL, www.biopolymers.nl)
- Shanghai Disoxidation Macromolecule Materials Co., Ltd (CN, www.dmmsh.com)
- Showa Denko (JP, www.shp.co.jp)
- So.F.teR. Spa (I, www.softergroup.com/)
- Solvay SA (B, www.solvay.com/)
- Sukano AG (CH, www.sukano.com)
- SwissGel AG (CH, www.swissgel.ch)
- Tate & Lyle PLC (UK, www.tateandlyle.com/Pages/default.aspx)
- Telles (USA, www.mirelplastics.com)

- Tecnaro GmbH (D, www.tecnaro.de)
- Tianan Enmat (CN, www.tianan-enmat.com)
- Thantawan Industry PLC (BioFoammat Division, T, www.biofoammat.com)
- Toray Industries Inc. (JP, www.toray.com/)
- Toyobo (JP, www.toyobo-global.com/),
- Toyota Motor Corporation (JP, www.toyota-global.com/)
- Unitika Ltd. (JP, www.unitika.co.jp/terramac)
- Vegeplast S.A.S. (F, www.vegeplast.com/uk)
- Ventura AG Kunststofftechnik (CH, www.ventura-ag.ch)
- Wentus Kunststoff GmbH (D, www.wentus.de)
- W.W. Textile Co. Ltd. (CN, www.2wtextile.com)

FOR FURTHER READING

- S. Bayer, S. Guzman-Puyol, J. Heredia-Guerrero, L. Ceseracciu, F. Pignatelli, R. Ruffilli, R. Cingolani and A. Athanassiou, "Direct transformation of edible vegetable waste into bio-plastics", ***Macromolecules***, 2014, *47 (15)*, 5135-5143;
  DOI: 10.1021/ma5008557 (http://pubs.acs.org/doi/abs/10.1021/ma5008557);
  http://ec.europa.eu/environment/integration/research/newsalert/pdf/producing_green_bioplastics_from_vegetable_waste_396na2_en.pdf (advertised by the EU Environmental Policy Office).

- Milionis, R. Ruffilli and I. S. Bayer, "Superhydrophobic Nanocomposites from Biodegradable Thermoplastic Starch Composites (Mater-Bi®), Hydrophobic Nano-Silica and Lycopodium Spores" ***RSC Advances***, 2014, *4*, 34395-34404;
  DOI: 10.1039/C4RA04117H
  (http://pubs.rsc.org/en/content/articlelanding/2014/ra/c4ra04117h#!divAbstract).

- L. Ceseracciu , J.A. Heredia-Guerrero, S. Dante, A. Athanassiou and I. S. Bayer. "Robust and biodegradable elastomers from unmodified corn starch". ***ACS Applied Materials and Interfaces***, 2014, under review.

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