FONDAZIONE ISTITUTO ITALIANO DI TECNOLOGIA

A TECHNOLOGY TEASER

# SMART PACKAGING AND BIOPLASTIC PRODUCTION

*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.*

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*- 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.*

# CONTENTS

# EXECUTIVE SUMMARY

According to a report by U.S.-based market intelligence company Transparency Market Research, the green sustainable packaging market (recycled, reusable & (bio) degradable) is expected to surpass US$178 billion by 2018. As more and more consumers become aware of green issue and environmental impact and choose to buy sustainability-conscious products, green packaging can be a big game-changer in the coming years.

There will be three main sustainable packaging trends in the future:

**#1 Trend: Bio or Plant-based Plastics despite of falling crude oil price**
We'll realize that our lives will not come to a standstill if petroleum-based plastics were to disappear from the market. Plant-based plastics or bioplastics are poised to play a greater role in packaging and will play an even greater role in shaping consumer attitudes towards brands. An example is given by big brand companies such as Coca-Cola, which, as of June 2014, sold over 25 billion of its PlantBottle™ packages in about 40 countries. The company claims this has translated into 525,000 barrels of oil being saved.

**#2 Trend 2: Smaller, Lighter and Less Packaging**
The biggest brands have already set goals to reduce packaging from sourcing. Mid-size and small brands will feel the pressure to follow suit. According to the Grocery Manufacturers Association (GMA), its members cut packaging weight by 1.5 billion pounds in the past three years and expected to reduce packaging weight by another 2.5 billion pounds through 2020.

**#3 Trend: Recyclability**
Millions of tons of waste are generated in the process of producing and transporting packaging materials. Most consumers are likely already aware of these environmental issues. They want to know where a brand's packaging material has been sourced from, what materials have been used for packaging, or whether the packaging can be recycled.
Given the trends depicted above, the technologies developed by IIT represent a first step towards a more sustainable approach to packaging. In particular, we describe two technologies which address these issues: the first one concerns a new coating for fibrous materials with hydrophobic and oleo-phobic properties which does not affect the recyclability of the final product while insuring insulation of the content; the second technology describes instead a process for producing fully biodegradable plastic from vegetable waste material.

These technologies represent a unique chance for companies active in textile 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/IB2011/055904 - 22 December 2011 |
| **Priority Application #** | TO2010A001040 - 22 December 2010 |
| **Regional Patent Applications filed** | **EP** 11813425.3, **US** 13/995204, **CA** 2822781, **JP** 2013-545617, **CN** 201180062593.9, **KR** 2013-7019241, **RU** 2013134001, **BR** 1120130159219 |
| **Applicant** | Fondazione Istituto Italiano di Tecnologia |
| **Inventors** | Roberto CINGOLANI, Athanassia ATHANASSIOU, Ilker S. BAYER |
| **Title** | A process for providing hydrorepellent properties to a fibrous material and thereby obtained hydrophobic materials and articles. |

**Short Description**

The present invention relates to a process for conferring properties of water resistance, hydrophobicity and water repellence on fibrous materials and then to a process for production of fibrous materials and finished articles, having the aforementioned properties together with other properties, such as in particular better fireproof properties.

| | |
|---|---|
| **PCT International Application #** | PCT/IB2014/061457 - 15 May 2014 |
| **Priority Application #** | TO2013A000396 - 16 May 2013 |
| **Regional Patent Applications filed** | **EP** 14731050.2, **US** 14/890913, **JP** 2016-513486, **CN** 201480026929.X |
| **Applicant** | Fondazione Istituto Italiano di Tecnologia |
| **Inventors** | Ilker S. BAYER, Elisa MELE, Roberto CINGOLANI, Athanassia ATHANASSIOU |
| **Title** | Process for the production of poly(cyanoacrylate) fibres |

**Short Description**

The present invention relates to a process for the production of micro- and nanofibers of poly (cyanoacrylate), to continuous, uniform coating layers obtained from said fibers and to substrates or articles provided with said coatings. The production of polymer nanofibers, which are characterized by their high surface area/volume ratio and by their mechanical properties, is of considerable interest in various applications such as the production of reinforced composites, of materials used as tissue scaffolds, as filter media and for controlled drug delivery.

| | |
|---|---|
| **PCT International Application #** | PCT/IB2014/066964 - 16 December 2014 |
| **Priority Application #** | TO2013A001037 - 18 December 2013 |
| **Applicant** | Fondazione Istituto Italiano di Tecnologia |
| **Inventors** | Elisa MELE, Ilker S. BAYER, Athanassia ATHANASSIOU, Roberto CINGOLANI |
| **Title** | Method for the encapsulation of liquid |

**Short Description**

The present invention relates to a process for the production of globular structures comprising a liquid nucleus within a solid envelop which wrap said nucleus, and to globular structures having micro- and nano-metric dimension so obtained.

| | |
|---|---|
| **PCT International Application #** | PCT/IB2014/067030 - 17 December 2014 |
| **Priority Application #** | TO2013A001036 - 18 December 2013 |
| **Applicant** | Fondazione Istituto Italiano di Tecnologia |
| **Inventors** | Athanassia ATHANASSIOU, Paul UTTAM, Elisa MELE, Despina FRAGOULI, Ilker BAYER, Roberto CINGOLANI |
| **Title** | Packaging material with barrier properties against migration of mineral oils and process or its preparation |

**Short Description**
The present invention relates to a process for the production of cellulose-based substrates that have barrier properties against the migration of mineral oils and/or of their volatile components.

| | |
|---|---|
| **PCT International Application #** | PCT/IB2014/062919 - 07 July 2014 |
| **Priority Application #** | TO2013A000570 - 08 July 2013 |
| **Applicant** | Fondazione Istituto Italiano di Tecnologia |
| **Inventors** | Ilker S. BAYER, Elisa MELE, Despina FRAGOULI, Roberto CINGOLANI, Athanassia ATHANASSIOU |
| **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 applications in **US**, **BR**, **CN** and **JP**. |
| **Applicant** | Fondazione Istituto Italiano di Tecnologia |
| **Inventors** | Ilker S. BAYER, Elisa MELE, Despina FRAGOULI, Roberto CINGOLANI, Athanassia ATHANASSIOU |
| **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

## *Hydrophobic and Oleophobic Treatments for Food Packaging*

“Intelligent” fibers to fabricate various types of materials have attracted much interests in the last decade. Such interest derives from several problematics that smart fibers can solve, from hampering water absorption, fungal growth, loss of mechanical properties, water soaking, etc. (based on water resistance, water repellence and hydrophobicity characteristics), as well as protecting against mineral and vegetable oily fluids.  Materials that are best positioned to benefit from this process are paper, cardboards, textiles, shoes, crockery, etc.

IIT has developed a new technology able to protect by coating several types of fibers with no apparent formation of polymeric coating on the fibrous material. The paper sheets and the textiles for example feel unaltered upon contact, but every single fiber is protected by an ultrathin polymeric layer (polymeric nanocomposite, Figure 1 and Figure 2). For each type of fibrous substrate, a different kind of polymer treatment is used.

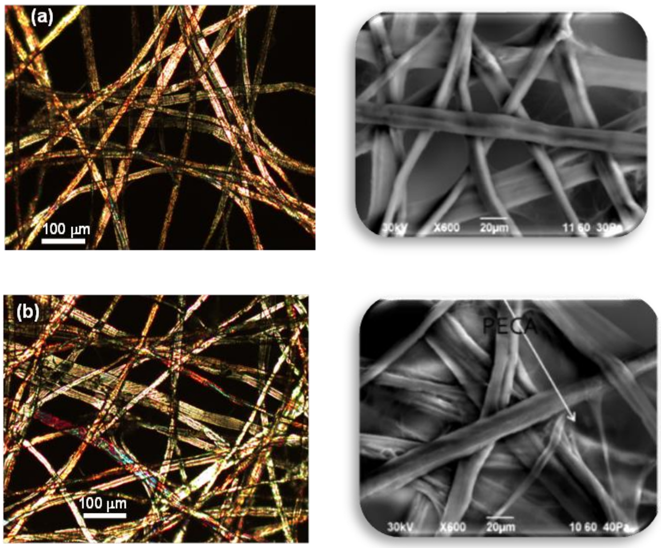



**Figure 1.** Optical (on the left) and electronic (on the right) microscope images of (a) untreated and (b) treated cellulose fiber networks with acrylate-based polymer (fibers are clearly visible in both cases and the breathability is conserved after the treatment)

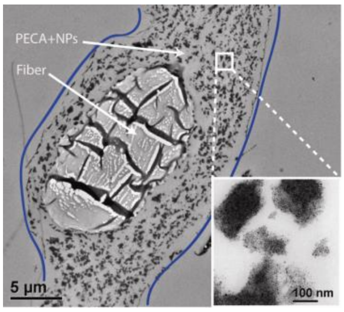



**Figure 2.** Cross section of a single cellulose fiber with the polymeric composite material cladding around it (electronic microscope)

Figure 3 shows the capability of IIT technology to produce water proof cellulose sheets: dyed water cannot enter the central area of the paper treated with the nanocomposite material, whereas Figure 4 shows that newspaper prints and printing capability of copy paper are not affected by the treatment.

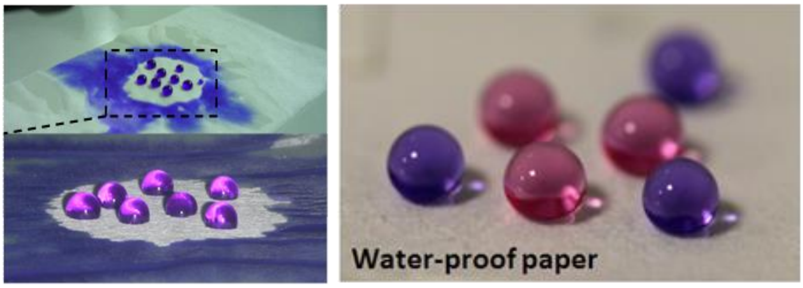



**Figure 3.** Hydrophobic properties: dyed water cannot enter the treated central area of the paper

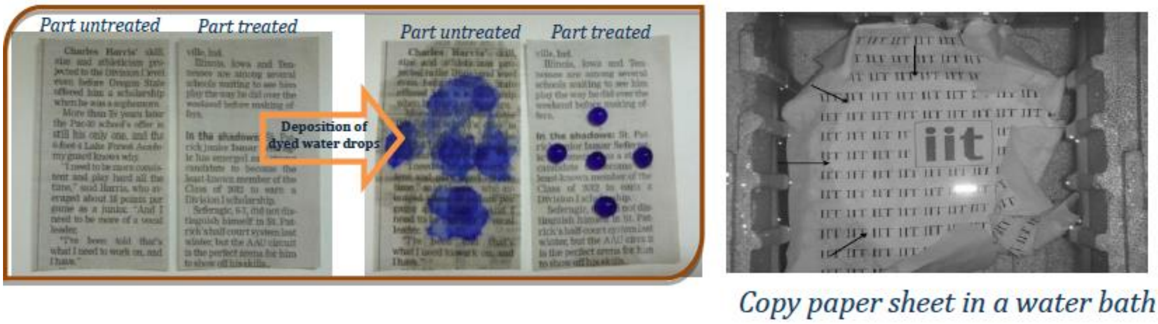



**Figure 4.** The treatment doesn't modify the external aspect of printed paper (left). Printing capability of copy paper is not affected by the treatment (right).

IIT technology consists of a treatment with polymeric nanocomposite materials which can provide different functionalities to the treated fibrous sheets, related to the properties of the nanoparticles used in the nanocomposites: hydrophobic, magnetic, antibacterial, luminescent.

## Advantages

In the Packaging Industry, IIT technology can be used on different kinds of cellulosic containers that are used in food packaging in order to act as barrier for:

- Water and oils from the food to the food containers;
- Oxygen and aromas from the content to the outside, thus maintaining nutrition properties, freshness and shelf life unaltered;
- External gases, thus avoiding any kind of contamination;
- Mineral oils from recycled paper to the food, which is especially problematic when high temperature and greased foods are involved.

All the polymers used for this scope are FDA approved. Cellulose is a natural polymer that is extensively used for the production of paper and paperboard. Although cellulose is an environmentally friendly material, its water/humidity absorbency limits the applicability in the food packaging area, particularly when paper containers come in contact with food of high content of water. To solve this drawback, the side of the paper container in contact with food is often coated with films of synthetic materials to achieve water barrier properties. Unfortunately, in this way, the final product loses its natural and biodegradable properties, as well as its recyclability. Moreover, the fabrication of this type of containers requires different steps that complicate the production process and increase the cost and the weight of the final product. IIT developed a technology that is able to add new functionalities to cellulose-based fibrous materials, reaching a high degree of water and oil resistance. Composite polymeric materials are used to effectively treat each single fiber of the network without altering their appearance. The treatments are applied on the fibrous materials in the post-production phase and the recyclability of the final products is not affected. Moreover, the polymeric shell can be functionalized with nanoparticles having specific properties, like fluorescent, magnetic and antibacterial.

Paper obtained by recycling urban wastes contains mineral oils and contaminants derived from newspapers, magazines and catalogs. When recycled, paper is used for food packaging; these substances can migrate to dry food (such as pasta, cereals and biscuits) and adulterate it, with consequent negative effects on human health. In the developed procedure, the fibers constituting the paper network are encapsulated in a thin shell of polymeric composites that act as barrier against the migration of mineral oils (Figure 5). Moreover, the resulting paper possesses characteristics of water and oil resistance.

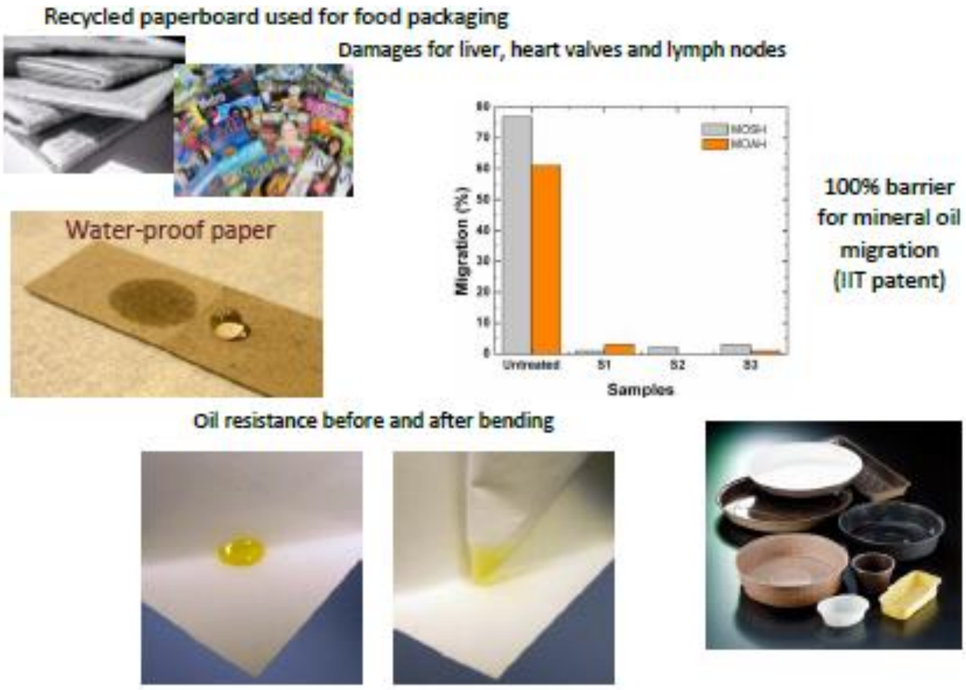



**Figure 5.** Polymeric composite nanomaterial as a barrier to mineral oil migration

As sorting and setting aside packaging for recycling remains the number one environmental activity among consumers, it is important to stress how IIT technology allows full recyclability of the treated material, while adding insulating properties and insuring lightness to the final product as no film is needed and the process takes place at the nanoscale level.

## *Bioplastics and Bioelastomers*

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 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.

Parsley Stem Powder Oat Hulls Orange Peel Powder

**Figure 7.** Examples of agro-waste raw materials that can be used to produce bioplastics

### 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 8.


**Figure 8.** 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 9). It is possible to 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.

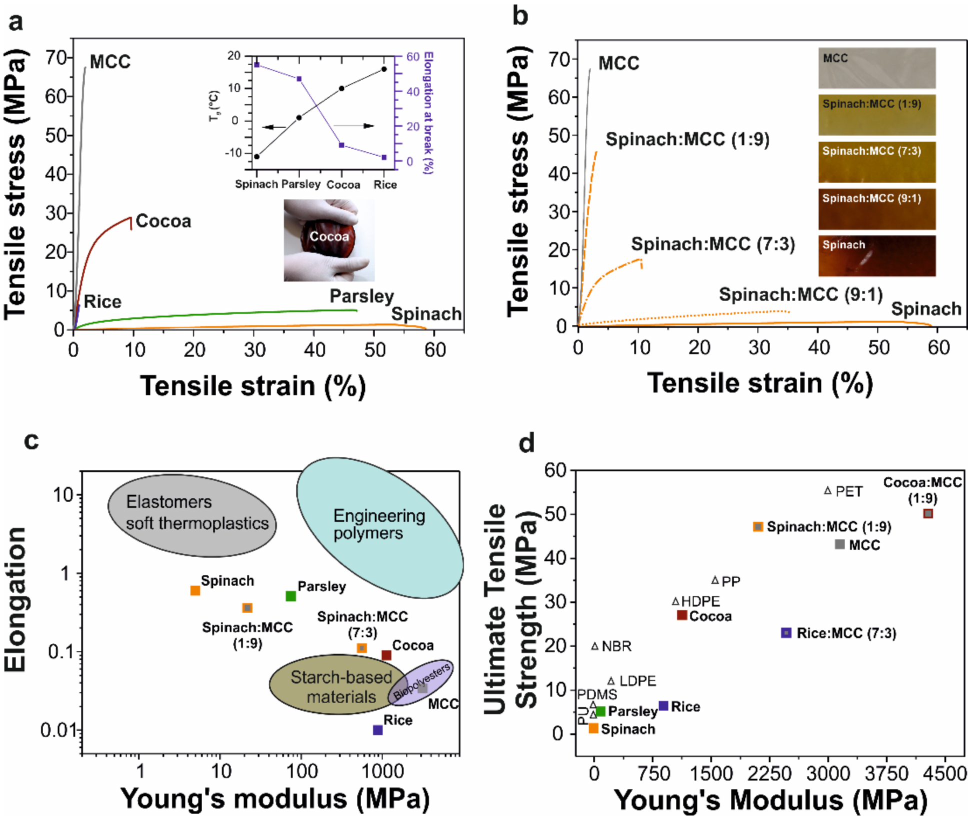



**Figure 9.** Mechanical properties of pure cellulose and inedible plant bio-plastics: **a**, Typical stress-strain curves for pure cellulose, cocoa, rice, parsley and spinach films. An important set of different mechanical properties is observed. In the upper inset the relationship between the glass 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 10.

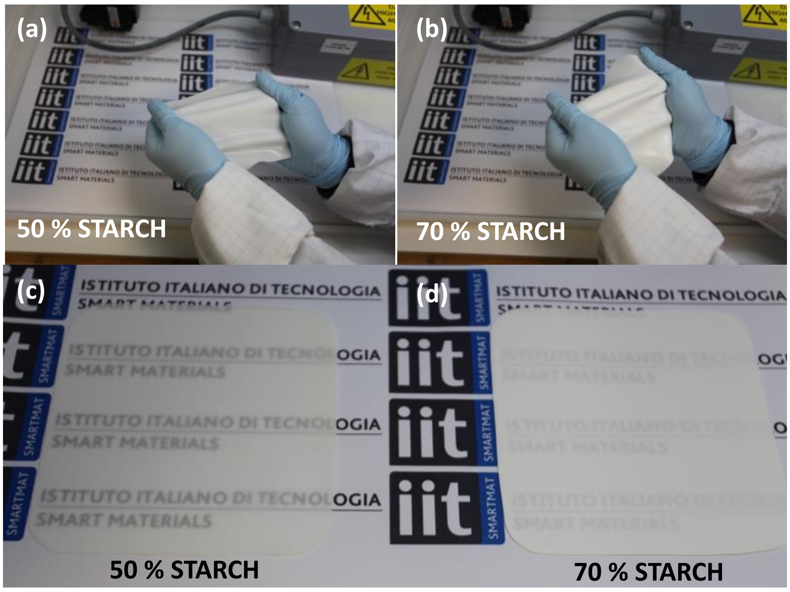
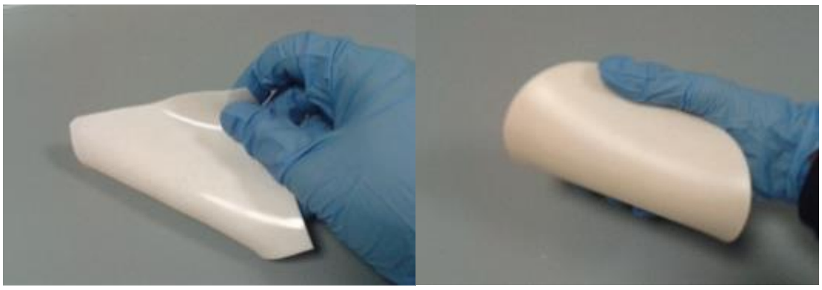



**Figure 10**. Photographs of bio-elastomers containing (a) 50% and (b) 70% unmodified corn starch granules. Photographs in (c) and (d) show that the bio-elastomers are somewhat transparent when placed on a surface, macroscopically indicating good degree of starch particle dispersion

Starch from different resources such as potato, corn or rice is combined with biodegradable polymer precursors to form elastomers with engineered mechanical properties (Figure 11). 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 11**. 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 12). 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 reaction. 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.

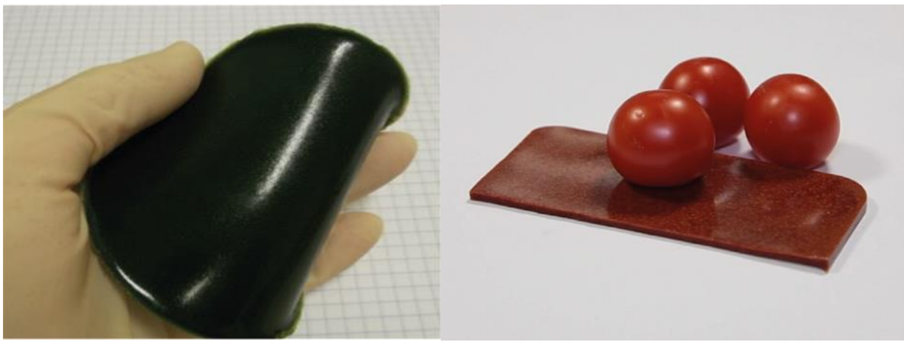


**Figure 12.** Bioelastomers obtained from spinach and from tomato skin residue originating from tomato pulp makin

# MARKET ANALYSIS

Two main markets have been identified and will be analyzed in the following paragraphs.

### *Nano-enabled Food & Beverage Packaging Market*

The *"Global Nano-enabled Food and Beverage Packaging Market 2014-2018"* research report published by ReportsnReports (RnR) in October 2014 forecasts this market to grow at a CAGR of 10.48% over the period 2013-2018 (http://globenewswire.com/news-release/2014/10/30/678195/10105423/en/Beverage-Packaging-Market-Review-Nano-Enabled-F-B-Packaging-Industry-Forecasts.html). Nano-enabled food and beverage packaging products use nano-engineered materials to enhance food safety and quality; such nano-engineered materials include solutions such as nanocoatings and nanocomposite-based packaging films. Active, intelligent, and controlled release technologies are the major types of nano-enabled food and beverage packaging technologies.

In another report by RnR, the beverage packaging market is projected to grow at a CAGR of 4.4% from 2014 to 2019. In 2013, the Asia-Pacific region was the largest beverage packaging market, wherein China dominated this market. New technologies have initiated the emergence of innovative packaging designs, but stringent regulations challenged the beverage packaging manufactures to prioritize environment health. Developing countries present a viable market for this industry as the regions of the western world have become a saturated market for beverage manufacturing and beverage packaging companies as well. To calculate the market size, the report considers the revenue generated through the sales of nano-enabled food and beverage packaging solutions by vendors in the market. The research has been prepared based on an in-depth market analysis with inputs from industry experts. The report covers the Americas, and the APAC and EMEA regions; it also covers the Global Nano-enabled Food and Beverage Packaging market landscape and its growth prospects in the coming years.

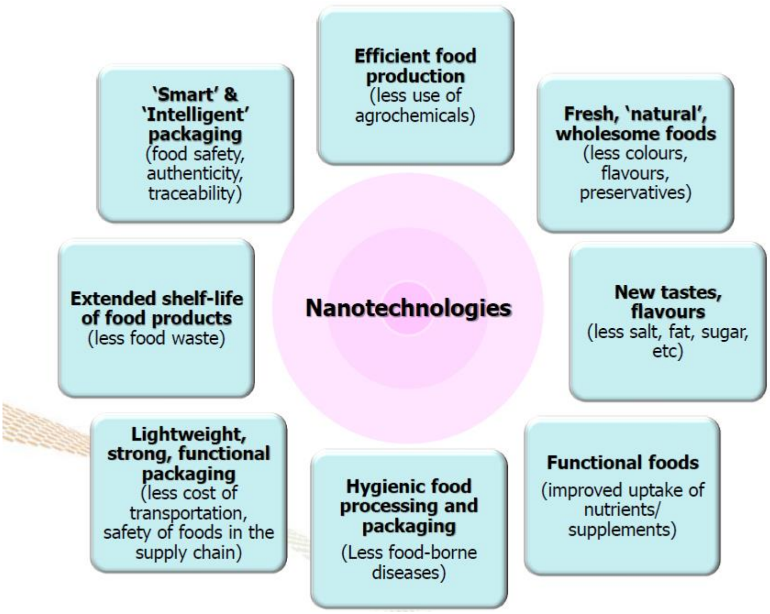



**Figure 6.** Potential benefits of nanotechnologies in Food & Beverage Packaging applications (taken from Dr. Qasim Chaudhry presentation titled *"Nanotechnology Applications for Food Packaging"* by The Food and Environment Research Agency)

In the report titled: *"Safety, convenience and quality drive barrier packaging trends*" published on the web (http://www.multibriefs.com/briefs/exclusive/barrier_packaging_1.html), by Don Rosato (President of PlastiSource Inc., a prototype manufacturing, technology development and marketing advisory firm located in Concord, Massachusetts), a deep analysis of the drivers for effective barrier coatings in the food & beverage packaging market is presented.

With an increasingly global food retailing customer base, food packaging must meet longer shelf-life requirements and adherence to international food safety/quality standards. Growing demand for convenience foods and "ready meals" created by busier lifestyles and increased disposable income are reflected in high growth in food packaging. Changing global demographics, lifestyles and consumer preferences means global demand for food packaging - estimated to be USD 120 billion for 2013 - is expected to experience an average growth rate of 3.8% over the next five years. Of this global food packaging market, the global active, intelligent and smart food-and-drink-packaging market was supposed to reach USD 12.1 billion last year.

In addition to product protection from packaging, consumers want to see the food they buy; they want it to stay fresh for a longer period; they want it to be safe to eat; and, above all, they want it to be tasty. Food-purchasing decisions are based on taste and appearance as well as convenience, making excellent barrier quality to maintain product freshness vital in food packaging - not only to extend shelf life, but also to protect brand image. Number one with the public is food safety, and active or barrier packaging that can help prevent spoilage or contamination is in strong demand.

Recalls can be particularly damaging to brand image and the company's bottom line. Most companies understand the added expense of improving packaging to help prevent recalls or a liability case is often far less than the cost of losing many customers because of an unhealthy or unsafe product. Consumers want easy-to-open, see-through economic packaging that also protects against oxygen, water vapor and aromas

Nanotechnology is enabling new food and beverage packaging technologies to address the needs for longer shelf life and the ability to monitor food safety and quality based upon international standards. Government policy and regulations are also impacting barrier plastic packaging design. The use of nano-based packaging for food products has raised various safety, environmental and regulatory issues with the European Food Safety Authority (EFSA) and the Food and Drug Administration (FDA) in the USA. Packaging waste is a growing environmental concern, and consumers are seeking more sustainable packaging choices, driving food packagers to look for bioplastic materials with good barrier properties. The presence of $O_2$-sensitive unsaturated fats is also fueling development of active and barrier packaging in flexible and rigid formats.

## *The Bioplastics Market*

According to a report published in 2014 by Grand View Research 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.

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. 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. "*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.

# COMPETITIVE SCENARIO

## *Key players in nano-enabled Food & Beverage Packaging Market*

The companies in this list are mentioned in the report "*Global Nano-enabled Food and Beverage Packaging Market 2014-2018*" as key or prominent vendors of the sector.

- Amcor (AU, https://www.amcor.com/home)
- Bayer (D, http://www.bayer.com/)
- Danaflex-Nano (RU, http://danaflexnano.ru/en/)
- Honeywell (USA, https://honeywell.com)
- Tetra Pak International (S, http://www.tetrapak.com/)
- 3M (USA, http://www.3m.com/)
- Agion Technologies (USA, http://www.sciessent.com/)
- BASF (G, https://www.basf.com/)
- Bemis Company (USA, http://www.bemis.com/)
- Braskem (BR, https://www.braskem.com.br/)
- Chevron-Phillips Chemical (USA, http://www.cpchem.com/)
- Sealed Air (USA, https://sealedair.com/)
- InMat (USA, http://www.inmat.com/)
- Innovia Films (UK, http://www.innoviafilms.com/)
- Kraft Foods (USA, http://www.kraftheinzcompany.com/)
- Mitsubishi Gas Chemical (JP, http://www.mgc.co.jp/eng/)
- Multisorb Technologies (USA, http://www.multisorb.com/)
- Pactiv (USA, http://www.pactiv.com/)
- PPG Industries (USA, http://corporate.ppg.com/Home.aspx)
- Ripesense (NZ, http://www.ripesense.co.nz/)
- Sidel (CH, http://www.sidel.com/)
- Sonoco (USA, http://www.sonoco.com/)
- Timestrip (UK, http://timestrip.com/)
- Toppan Printing (JP, http://www.toppan.co.jp/english/)
- Toyo Seikan Kaisha (JP, http://www.toyo-seikan.co.jp/e/)
- Triton Systems (USA, http://www.tritonsys.com/)
- W. R. Grace (USA, https://grace.com/en-us)

## *Key players in Bioplastics Market*

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 that the majority of them located in Europe (54), Germany being by far the most populated country.

- 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)
- 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)
- 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/),
- 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)

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