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RESULTS PACK

Bioplastics: Sustainable materials for building a strong and circular European bio-economy

BIOPLASTICS: SUSTAINABLE MATERIALS FOR BUILDING A STRONG AND CIRCULAR EUROPEAN BIO-ECONOMY

EDITORIAL

Bioplastics are becoming a crucial component in the drive to create a fully sustainable and circular bio-economy. The EU has been actively supporting the development of these materials through ambitious and collaborative research that aims for a greater uptake that will help transform Europe's plastics' industry over the coming years.

Plastics are increasingly problematic from an environmental and sustainability perspective. It is estimated that by 2050, the world's oceans could contain more plastic than fish (by weight) and that plastics production will account for a greatly increased share of global oil use and GHG emissions. The current system of plastics production is mainly linear, with heavy reliance on non-renewable, fossil feedstock, has low levels of re-use and recycling, and suffers from high levels of leakage into the surrounding environment.

The EU, through its Circular Economy (CE) Action Plan, is dedicated to stimulating Europe's transition to a circular economy that will boost competitiveness, foster sustainable economic growth and result in the creation of new jobs. As a major source of growth and jobs, the European plastics industry must also be included in this transition – for this purpose, the European Commission is due to adopt a new strategy on plastics as part of the CE Action Plan by the end of 2017.

A new but growing industry

Bioplastics can play an important role in this transition. Encompassing a whole family of materials with different properties and applications, bioplastics can be made from renewable resources such as crops and wood, or from waste streams such as the residues of food processing.

With the emergence of more sophisticated materials, applications, and products, the global market is already growing by about 20 to 100% per year. By 2021, it is expected that Europe will possess around a quarter of the world's bioplastics production capacity.

Supporting European research initiatives

This CORDIS Results Pack is highlighting the results of eight innovative projects that have benefited from funding from the EU's Seventh Framework Programme (FP7) and that are making important scientific and innovative contributions to such an exciting and potentially game-changing industry.

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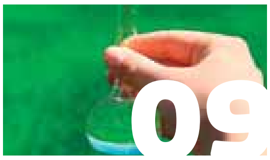

feedstock that is currently considered agro-food waste, has no market value, doesn't compete with food and is not affected by price volatility. 'This alone transforms what was once an expense into a revenue,' says Sanchez.

Furthermore, the 100 % compostable bioplastics developed by the project will form the basis for the development of high quality food-grade bioplastics. 'These bioplastics can be disposed of together with food and managed as organic waste by industrial composting and anaerobic digestion that meets EU standards,' adds Sanchez.

Together, these results demonstrate the potential of PHA-based compounds derived from PHA-generated waste for sustainable, cost-effective food packaging materials.

Novel technology to boost the European Bioeconomy: reducing the production costs of PHA biopolymer and expanding its applications as 100 % compostable food packaging bioplastic

FEDERACION DE COOPERATIVAS AGRARIAS DE MURCIA S COOP, Spain

FP7-SME

http://europha.eu/

Creating a market for crude glycerol

Researchers with the EU-funded GRAIL project are developing new technologies and uses for crude glycerol, a by-product of biodiesel production.

The overall concept of the GRAIL project is the use, exploitation and further development of state-of-the-art technology in the field of bio-based products from glycerol.

In response to a legislative push towards green initiatives, the global production and consumption of biodiesel is on the rise. Due to its co-production in the transesterification process, this increase in the biofuel production also creates an increase in the generation of crude glycerol. The problem is that, to date, the existing uses for the glycerol derived from the manufacturing of biodiesel are not able to fully utilise the large volume generated worldwide. As a consequence, a vast amount of unused raw glycerol is generated each year, reducing its market value to the point of becoming a 'waste-stream' rather than a valuable 'coproduct'. As glycerol prices fall, more and more companies who chemically produce glycerol are going bankrupt.

The EU-funded GRAIL project aimed to integrate and develop existing and new bio-technologies that use glycerol as a competitive biological feedstock. By doing so, the project will also contribute to improving the economics and environmental viability of biodiesel production.

'The overall concept of the GRAIL project is the use, exploitation and further development of state-of-the-art technology in the field of bio-based products from glycerol, along with the development of new uses for crude glycerol for both high-value platforms and end products,' says Project Coordinator Carles Estévez. 'As a result, the project has a strong business focus, with the ultimate goal being the setup of biorefineries in close relationship with the production of biodiesel.'

New uses for glycerol

GRAIL builds from knowledge acquired in previous projects. These previous projects and studies, which focused on marketable uses for waste-glycerol, have proposed several isolated approaches. However, their results have failed to


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integrate a process for resolving the main barriers for the valorisation of this co-product. 'GRAIL was born from this need to produce a replicable methodology for using economic and scientific arguments to overcome the main scientific, technological and economic barriers to seeing crude glycerol as a suitable feedstock for producing a range of economically valued products,' says Estévez.

The GRAIL project is focused on developing both known and new types of applications and products that go beyond the state of the art using glycerol as the starting material. Reactions that already have been extensively applied to convert glycerol into new molecules, such as oxidations, reductions, dehydrations, etherifications, esterifications, etc., are being replaced by bio-transformations. The end goal is to develop a set of scalable and cost-effective technologies for converting waste glycerol from biodiesel production into, for example, propanediol, fatty acid glycerol formal ester, polyhydroxyalkanoates (PHA), hydrogen, ethanol, synthetic coatings, powder coating, resins, biobutanol, and trehalose, among others.

To accomplish this, the project has designed an overall strategy based on three main pillars covering the entire value chain. This includes the evaluation of crude glycerol and purification, along with researching how to transform crude glycerol into other high added value products, such as biofuels, green chemicals and food supplements.

The project is also looking at industrial feasibility aspects of glycerol-based products, including economic and environmental evaluation. 'Now as the project comes to a close, we are shifting our focus to taking the results of GRAIL from product development to the industrial site,' explains Estévez.

Project	Glycerol Biorefinery Approach for the Production of High Quality Products of Industrial Value
Coordinated by	INSTITUT UNIV. DE CIENCIA I TECNOLOGIA SA, Spain
Funded under	FP7-KBBE
Project website	http://www.grail-project.eu/

Speeding-up the production of green plastic

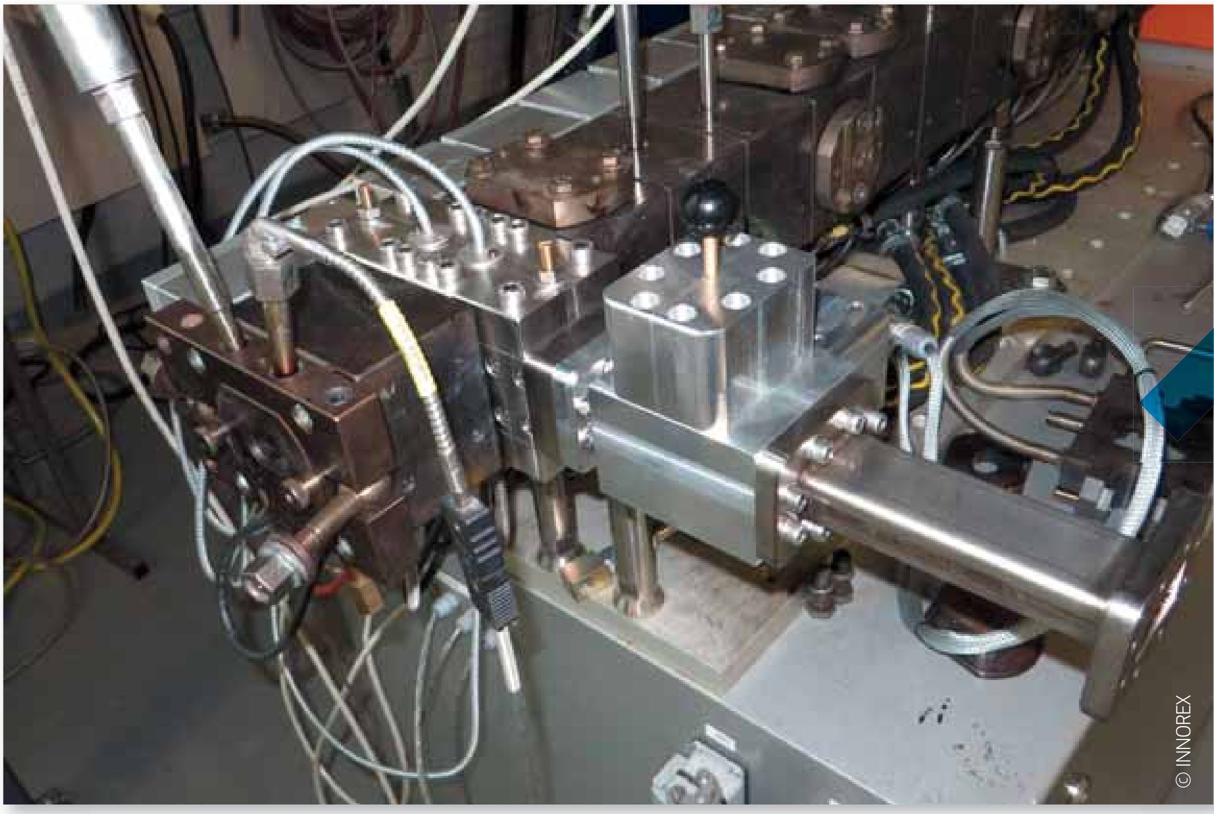
EU scientists are working on ways to speed-up the environmentally-friendly and energy efficient production of bio-based polymers so they can become commercially viable.

Demand for biobased polymers is growing fast, but current production technology uses catalysts containing metal which can be an environmental and health hazard. One EU-funded project is has developed a new reactor to make the process metal-free.

The INNOREX project is replacing metal-containing catalysts with organic catalysts. It has also developed an innovative reactor using alternative energies that allow for a continuous and precise metal-free polymerisation process.

Our project demonstrates methods that enhance the production of polymers allowing for a large scale production at a reasonable price.

'Our project demonstrates methods that enhance the production of polymers allowing for a large scale production at a reasonable price,' explains Björn Bergmann, INNOREX project coordinator.



© INNOREX

The particular polymer used by INNOREX is polylactic acid (PLA) which is mainly used in food packaging and single use cutlery, among other things. 'PLA is a polymer built up from long chains of lactic acid molecules. The lactic acid itself is produced by bacteria which are fed by corn, for example, so the feedstock of the polymer is renewable,' Bergmann says.

'Another big advantage of PLA is not only that it is bio-based but that it is also biodegradable. This means that when it is disposed at industrial composting plants, the polymer is digested by bacteria ultimately resulting in water and CO_2,' he adds.

INNOREX works by demonstrating ways to enhance reaction kinetics, speeding up the process of polymerisation using twin screw extruders.

Currently twin screw extruders are not used for polymerisations on a large scale because they are not efficient and precise enough as well as not offering sufficient residence times. But INNOREX is working on overcoming this by using alternative energies – microwaves, ultrasound and laser light. These techniques can achieve an enhanced, controlled and efficient polymerisation of PLA in a twin screw extruder.

'We managed to introduce microwaves and ultrasound into the extruder which provide additional highly targeted energy and enhance the reaction. We also adapted an online viscometer which can continuously analyse the material and tell us how complete the polymerisation process is. We then used a second type of extruder to purify the product, improving its quality,' Bergmann explains.

He continues: 'We hope to see more processes switch to using twin screw extruders, leaving out solvents, to make the process more environmentally friendly. We also hope that our technology will help other processes that use the same intensified production processes to be brought onto the market. Producing PLA in twin screw extruders has been done before. But without intensification it has not been economically beneficial to do so – yet.'

The project is hoping to help the EU achieve its ambitious environmental goals. 'The intensification process reduces the use of energy. Moreover, by removing the need for solvents, we have also demonstrated the potential to cut energy use and minimise our CO_2 footprint,' Bergmann explains.

By using a biobased polymer, INNOREX is moving away from fossil fuel resources to renewable feedstocks. Finally, the project can help reduce the amount of waste in landfill sites since the polymer is biodegradable. INNOREX now hopes that its partners will now develop the technology further, leading to eventual full-scale commercialisation.

Project	**Continuous, highly precise, metal-free polymerisation of PLA using alternative energies for reactive extrusion**
Coordinated by	FRAUNHOFER GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V., Germany
Funded under	FP7-NMP
Project website	http://www.innorex.eu/

Perfecting the biotechnological production of chitosans

Researchers with the EU-funded NANO3BIO project are using specially optimised fungi, bacteria and algae to produce the environmentally-friendly chitosans that serve as raw materials for many important applications.

Oil production is slowing and, as a result, renewable resources are becoming increasingly important. In the near future, the biological production of raw materials will have to play an even greater role if we are to meet customer and industry needs in an environmentally friendly manner.

To help facilitate this transition to the biological production of raw materials, the EU-funded NANO3BIO project has developed a process for the biotechnological production of chitosans.

The huge potential of chitosans

Chitosans can be used as raw materials by the medical, agriculture, water treatment, cosmetics, paper and textile industries, as well as many other applications. For example, one specific chitosan is suitable for finishing seeds to protect them from pests and diseases and to yield richer harvests. Another acts as an anti-bacterial, film-forming agent in the spray plaster that accelerates scar-free wound healing. In medical applications, specific chitosans can ensure the transport of drugs to their target sites (e.g., in the brain or in cancer cells).

'Chitosans are typically obtained by chemical means from such limited resources as the shells of crabs and shrimps or, rarely, from fungi or squid pens,' explains project researcher Achim Hennecke. 'In the biotechnological processes targeted by the NANO3BIO project, specially optimised fungi, bacteria and algae will take over the production of chitosans.'

According to Hennecke, these so-called third generation chitosans benefit from more defined – or even novel – structural characteristics, clearly defined biological activities and known cellular modes of actions. As a result, they not only create new market opportunities, they are also more efficient,

In the biotechnological processes targeted by the NANO3BIO project, specially optimised fungi, bacteria and algae will take over the production of chitosans.

© NANO3BIO

more environmentally friendly and less expensive than using currently available methods.

A menu of important breakthroughs

The NANO3BIO project has already achieved breakthroughs in several important fields. For example, researchers developed protocols for producing chitosans with better defined structures and a low-cost protein engineering technology to support their biotechnological optimisation. They also successfully isolated and identified the first natural chitosans produced by microalgae.

'The project has identified genes from different organisms that can be used to drive the biotechnological production of chitin and chitosan modifying enzymes,' explains Hennecke. 'These were then characterised and used for the biotechnological conversion of chitin into new, high-quality chitosans.'

For example, NANO3BIO researchers successfully developed electro-spun chitosan nanofibres and electro-sprayed chitosan nanoparticles as technological platforms for the encapsulation and efficient release of bio-actives, vaccines and drugs. They also invented thermos-sensitive chitosan hydrogels, which are promising materials for regenerating damaged tissues.

Another important outcome of project is its significant insight into the internalisation of chitosan nano-capsules into human cells, a breakthrough that promises targeted delivery of chemotherapeutics to cancer metastases at a very early stage. 'This lays the groundwork for the development of more effective therapies with reduced adverse effects and better quality of life for patients,' says Hennecke.

According to Hennecke, many of these achievements have huge economic potential. 'The NANO3BIO project has achieved encouraging results,' he says. 'As chitosans are non-toxic, the project has contributed to building an environmentally sustainable European economy and strengthening the competitiveness of European industry and SMEs.'

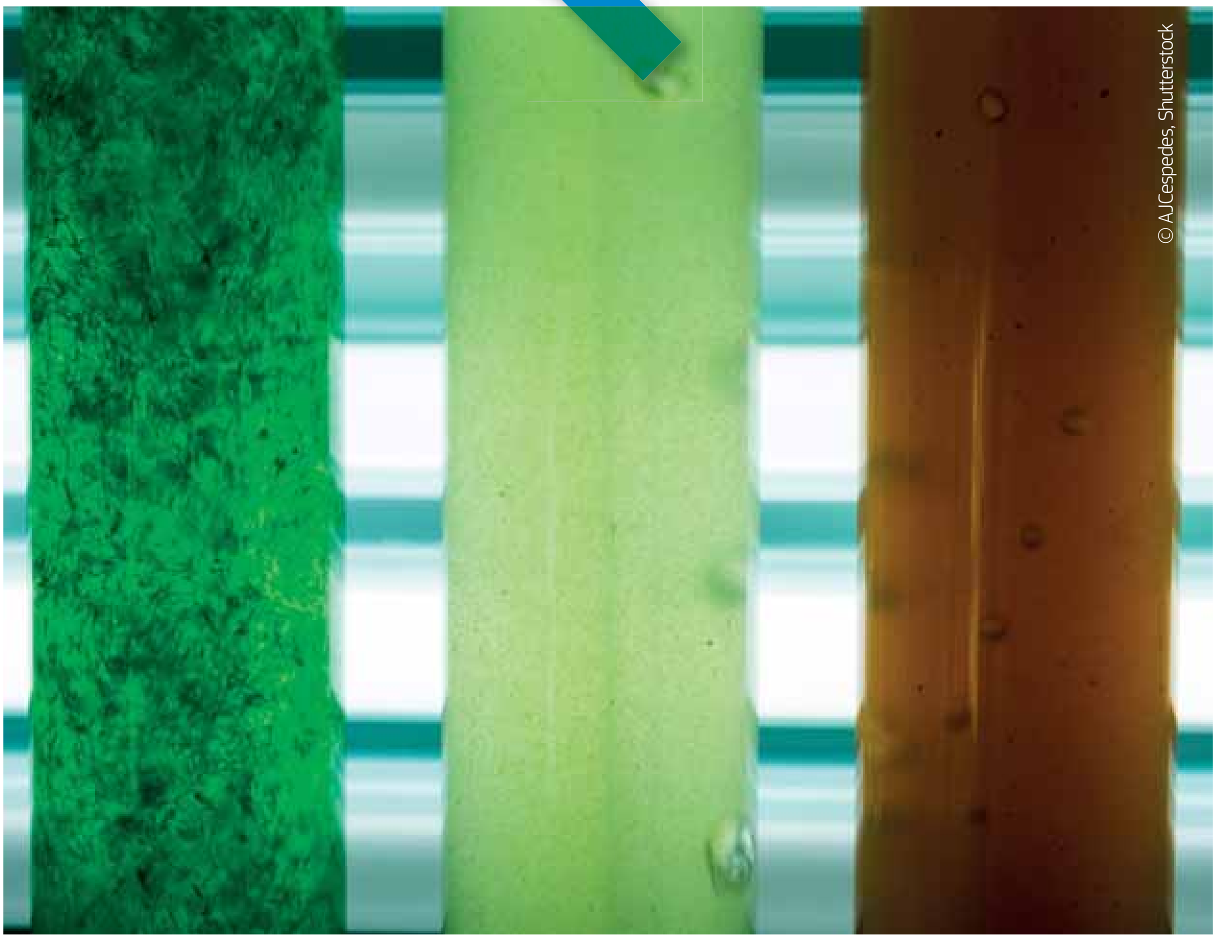
Project	**NanoBioEngineering of BioInspired BioPolymers**
Coordinated by	WESTFAELISCHE WILHELMS-UNIVERSITAET MUENSTER, Germany
Funded under	FP7-KBBE
Project website	http://www.nano3bio.eu/start/

Are microalgae the feedstock of the future?

The EU-funded SPLASH project has shown that microalgae are a viable raw material for the sustainable production of feedstock for chemicals and plastics. This innovation has the potential, at least in the long term, to reduce significantly Europe's over-reliance on fossil-based production.

Europe is transitioning from a wasteful fossil-fuel based economy towards a more sustainable, circular economy. In order to complete this transition, viable cost-effective replacements to fossil-based products must be found. One possible avenue of opportunity is microalgae, which are being investigated as a promising new renewable feedstock for chemicals and plastics.

'A key advantage of microalgae is that they can be cultivated on non-arable land and yield valuable compounds for chemical industries,' explains SPLASH project coordinator Dr Lolke Sijtsma from Wageningen Food & Biobased Research in the Netherlands. 'If microalgae could be sustainably cultivated at an industrial scale, then this would help us to decrease our dependency on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fossil feedstocks, and potentially contribute towards climate mitigation and reduced pressure on land resources.'

Understanding algae

The EU-funded SPLASH project has taken a significant step forward in this quest by demonstrating that hydrocarbons and polysaccharides can be extracted from the microalgae species *Botryococcus braunii* and converted into renewable polymers. By focusing on producing high value molecules, the project represents an important step forward in kick-starting an economically and environmentally sustainable market for microalgae-based products.

A key advantage of microalgae is that they can be cultivated on non-arable land and yield valuable compounds for chemical industries.

'We wanted to first understand at a fundamental level how these algae produce hydrocarbons and sugars,' explains Sijtsma. 'From this, we were able to make a kind of metabolic map. If you go to a big city like Amsterdam and want to get from A to B, then there are a number of possibilities open to you. In the same way, we developed a map that shows scientists how they might go about developing molecules by mapping the various genetic pathways.'

Algal cultivation and product formation was optimised at small scale and this process was then demonstrated at pilot scale. Hydrocarbons and carbohydrates were successfully extracted from selected strains and converted into viable products. Sustainability assessments and market analyses were also carried out in order to identify a path towards eventual commercialisation.

Benefits along the supply chain

The entire supply chain – from cultivators through to industrial manufacturers and end users – was involved in this project, and all ultimately stand to benefit. 'Our findings provide industrial partners with an excellent opportunity to conduct further pilot tests of their technologies in order to achieve more reliable industrial solutions and to scale up production,' says Sijtsma.

'At the same time, end users like chemical companies now have a better understanding of how they can use biological raw materials in products, and also a clearer picture of the challenges ahead. Existing chemicals are relatively cheap, so the production and cultivation of microalgae-based products must become more price-competitive.'

Sijtsma notes that there might be better opportunities in the specialised products sector in the short term, since these have higher development value and require smaller amounts of raw material. 'One interesting area of discovery was the extraction of lipid components, which could be used in cosmetics and other high value products. We are not in a position to say however that we'll be ready for market in a year's time with this; there is still a fair amount of research that must first be implemented.'

Nonetheless the SPLASH project is a step in the right direction and a necessary investment in Europe's future circular economy. 'Thanks to the work of this project, we now have a group of highly skilled professionals with expertise in microalgae cultivation, processing and chemical conversion systems coming through,' notes Sijtsma. 'This will help to ensure that bioplastics from microalgae can become a reality.'

Project	**Sustainable PoLymers from Algae Sugars and Hydrocarbons**
Coordinated by	STICHTING WAGENINGEN RESEARCH, the Netherlands
Funded under	FP7-KBBE
Project website	http://www.eu-splash.eu/

Building bioplastics from waste streams

EU-funded researchers have used biowaste, agricultural residues and other carbon-rich waste streams to produce price competitive bioplastics. The strategy could open up new sustainable business opportunities and contribute towards Europe's transition towards a post-carbon economy.

This process will help to reduce landfill waste as well as the harmful impact of petrochemical plastics by offering a viable alternative.

Whilst the market potential for environmentally friendly alternatives to fossil fuel-based plastics remains huge, cost remains a critical factor. 'In order to become commercially viable, bioplastics need to compete in the same price range as petroleum-based plastics,' explains SYNPOL project coordinator Prof. Jose Luis Garcia Lopez from the Spanish National Research Council.

'One way of achieving this is to make use of already existing waste streams such as household waste that ends up in landfills, or sewage sludge from water treatment plants.'

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Another important benefit here is that European countries spend a lot of money in transporting municipal waste many miles out of cities or states to be landfilled, leading to long-term environmental problems. Valorising this waste would save local authorities money, in addition to benefitting the environment and providing a boost to the waste conversion industry.

Tapping benefits of biowaste

The key success of the EU-funded SYNPOL project has been to capitalise on this opportunity by developing a viable process to efficiently turn waste into biopolymers. The system works by converting complex biowaste into syngas, which is then fed into a bioreactor for bacterial fermentation.

This creates polyhydroxyalkanoates (PHAs) and building blocks for novel biopolymers.

Researchers found that straw was the most promising raw material for producing syngas. Impressive progress was also made during the project in optimising the fermentation product yield by microorganisms. 'This process will help to reduce landfill waste as well as the harmful impact of petrochemical plastics by offering a viable alternative,' says Garcia.

In addition, the syngas fermentation technology opens up new possibilities for converting a range of industrial biowastes. This will strengthen links along the supply chain (between producers and waste converters for example) and create new opportunities in food production, pharmaceuticals, packaging industries and recycling. Indeed, some biopolymer products developed by SYNPOL partners are already on their way to the market.

'For example, an Irish SME project partner is producing a biodegradable biopolymer that can be used as film for packaging applications,' says Garcia. 'Another polymer prototype can be used to create scaffolds for biomedical applications.'

In addition, new technologies to polymerise PHAs by chemical and enzymatic procedures have been developed by various SYNPOL consortium partners with a view to securing patents.

'The technology transfer office of the Spanish National Research Council is currently trying to extend and licence two patents that have been derived from the SYNPOL project so far,' says Garcia. 'One of the two patent applications is about a novel microwave-induced pyrolysis technique for organic waste conversion to syngas and the other concerns aerobic CO metabolism in microorganisms.'

A long-term investment

Completed in September 2016, the SYNPOL project underlines how investment in sustainable production processes can bring both economic and environmental benefits. The project has shown how waste streams can be exploited to produce biopolymer building blocks, reducing Europe's need for both landfill space and plastics based on fossil fuels. There is potential for this pioneering fermentation technology to be applied to other complex waste streams in order to produce new biopolymers and other high added value compounds.

'The project findings will be continued through the EU-funded CELBICON and upcoming ENGICOIN projects,' says Garcia. 'In both projects, collaboration with chemical engineers will bring the bacterial gas fermentation process closer to the industrial scale. Many project partners are also keen to further develop SYNPOL's bacterial syngas fermentation process through future projects and networks.'

Project	**Biopolymers from syngas fermentation**
Coordinated by	SPANISH NATIONAL RESEARCH COUNCIL, Spain
Funded under	FP7-KBBE
Project website	http://www.synpol.org/

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