TOWARDS A CIRCULAR BIOECONOMY FOR THE LOMBARDY REGION

Industrial Case Studies for Biopolymer Production

CONSORZIO ITALBIOTEC

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VANGUARD INITIATIVE

New growth through smart specialisation

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ABBREVIATIONS AND ACRONYMS

VFAs	*Volatile fatty acids*
bio-PE	*Bio-polyethylene*
bio-PET	*Bio-polyethylene terephthalate*
CIB	*Consorzio Italiano Biogas*
CNR	*Consiglio Nazionale delle Ricerche*
COD	*Chemical Oxygen Demand*
DISAA	*Department of Agricultural and Environmental Sciences*
EFB	*European Federation of Biotechnology*
EPD	*Environmental Product Declaration*
EAFRD	*European Agricultural Fund for Rural Development*
ERDF	*European Regional Develpment Fund*
ESF	*European Social Fund*
OFMSW	*Organic Fraction of Municipal Solid Wastes*
ICSC PAS	*Institute of Catalysis and Surface Chemistry of Polish Academy of Sciences*
LCA	*Life Cycle Assessment*
LGCA	*Lombardy Green Chemistry Association*
LSK	*Life Science Klaster Krakow*
PBS	*Polybutylene succinate*
PE	*Polyethylene*
PHA	*Polyhydroxyalkanoates*
PHB	*Polyhydroxybutyrate*
P(HB-co-HV)	*Poly(hydroxybutyrate-co-hydroxyvalerate)*
PLA	*Polylactic acid*
PP	*Polypropylene*
PTT	*Polytrimethylene terephthalate*
PVC	*Polyvinyl chloride*
SME	*Small and Medium Enterprise*
S3	*Smart Specialisation Strategy*
TRL	*Technology Readiness Level*

GLOSSARY

Biomass	The biodegradable fraction of products, waste and residues of biological origin from agriculture (including vegetal and animal substances), forestry and related industries, including fisheries and aquaculture, mowing and pruning from public and private green space, as well as the biodegradable fraction of industrial and municipal waste (Directive 2001/77/EC and Legislative Decree 387/2003, as amended by Directive 2009/28/EC and Legislative Decree 28/2011).
Bio-refinery	A facility where biomass operations are carried out to obtain energy, fuels, chemical products and materials.
Bioeconomy	Economy that uses biological resources from land and sea as an input for energy, industrial, food and feedingstuff production.
Technology Cluster	Networks comprising public and private subjects operating on the national territory in sectors such as industrial research, training and technology transfer. They act as catalysts of the resources needed to meet the needs of the territory and the market, and to coordinate and strengthen the connection between research and business. Each aggregation refers to a specific technological and application area which is held as strategic for the country.
Circular economy	An economic system designed as being able to regenerate itself, thus ensuring its sustainability. Once the product has finished its function, the materials of which it is composed are reintroduced, wherever possible, in the economic cycle. This way it is possible to continuously reuse them within the production cycle, generating added value, extending products life cycle of and helping to reduce waste to a minimum.
Eco-design	A concept that characterizes the design of a product or a social or economic system in the respect of the environment in which we live.
Bio-based material	A bio-based material wholly or partially derived from biomass, which does not include components of fossil origin (coal or petroleum).
Smart Specialisation Strategy (S3)	A tool used throughout the European Union to improve the effectiveness of public policies for research and innovation.
Vanguard Initiative	A European network that aims to contribute to the revitalization of the European industry based on the S3 strategy.

ABSTRACT

In Lombardy the companies that invest in the green economy are 61,650, almost 20% of the national total, confirming the growing regional drive for the adoption of eco-efficient solutions for raw materials use, energy consumption, waste production and the reduction of atmospheric emissions[1].

The Lombardy Region's commitment to sustainable development has led to the definition of regulatory instruments, including the regional law "Lombardia è Ricerca"[2] (Lombardy is Research) and guidance documents, such as the Three-Year Strategic Program for Research, Innovation and Technology Transfer[3] supporting the innovation capacity of the entire territory in the three-year period 2018-2020.

The sustainable growth paradigm is here defined in its ecological, social and economic dimensions, with direct impacts on the future of our planet and on the behaviour of its inhabitants, who are called to be increasingly responsible for environmental problems and watchful of the limited natural resources.

Scientific research plays a central role in the creation of sustainable production models. In this respect, regional technology clusters have the important task of encouraging responsible innovation and the development of new business opportunities for local businesses.

In the Bioeconomy sector, the Lombard Cluster of Green Chemistry (LGCA) is a point of reference for the development of new supply chains based on the valorisation of renewable biological resources and their transformation into biomaterials and bioenergy with low environmental impact through industrial biotechnology technologies. The LGCA Cluster coordinates the Bioeconomy Pilot of the Vanguard Initiative, which brings together over 25 European regions interested in developing an interregional Bioeconomy Strategy and identifying demonstration cases of the latest generation of biorefineries for the creation of goods and processes alternative to the use of fossil sources. The continuous search for sustainable production models is a prerogative of all industrial realities, and some issues play a strategic role not only for the development of a single business idea, but for the entire productive ecosystem of a region.

Among the most important environmental and social challenges, the replacement of plastic and the problem of its non-biodegradability has pushed many companies to invest in the study of new bioplastics able to secure the same standards as traditional plastic, with the advantage of being completely biocompatible.Carried out by Consorzio Italbiotec, the first Italian not for profit organization in the biotechnology sector, in collaboration with LGCA, this study aims to demonstrate the sustainability and industrial potential for the development of the bioplastics market in the Lombardy Region. A number of regional and European success stories have been analysed, and in particular, that of the PHA-STAR industrial research project has been elected as an integrated and innovative supply chain model.

Against this background, the PHA-STAR project, funded by the Lombardy Region under the Smart Fashion and Design call for proposals, aims to develop a protocol for the production of polyhydroxyalkanoates (PHA), microbial biopolymers obtained through fermentation processes, starting from unused by-products of the Lombard dairy supply chain[4].

The feasibility of the project was demonstrated through the production of Eco-design artefacts for the floriculture world. Coordinated by Agromatrici Srl, an industrial company engaged in the recovery of biomass and in the development of solutions for the enhancement and recovery of waste and refuse, the project used the expertiseof the Ricicla research group of the Department of Agricultural and Environmental Sciences (DISAA) of the Università degli Studi di Milano and of Consorzio Italbiotec.

The entire supply chain was then analysed, defining the role of each actor in the value chain in order to bring the world of biomass producers closer to that of converters, thus demonstrating the sustainability and potential socio-economic impact of the PHA-STAR model.

1 Green in Italy 2018 Report. Regional ranking according to the number of companies that have carried out eco-investments in the 2014-2017 period and / or will invest in 2018 in green products and technologies (Source Unioncamere). In first place Lombardy (61,650 companies), followed by Veneto (34,979) and third place, Lazio (32,545).

2 LR n. 29 of 23 November 2016 "Lombardia è ricerca e innovazione": https://www.openinnovation.regione.lombardia.it/it/lombardia-ricerca/la-legge

3 Three-year Strategic Program for Research, Innovation and Technology Transfer: https://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioAvviso/servizi-e-informazioni/cittadini/scuola-universita-e-ricerca/programma-strategico-triennale-ricerca

4 PHA-STAR acronym for "Development of new products for the sustainable bioplastics design sector" ID187066

GENERAL CONTEXT

1. General Context

1.1 TOWARDS A CIRCULAR BIOECONOMY FOR THE LOMBARDY REGION

In 2015, the definition of the 17 Sustainable Development Goals (SDGs) by the 193 UN member countries contributed to the affirmation of an integrated vision of the different dimensions of sustainable development, which include, in addition to the environmental one, also the social and economic dimensions. The creation of new production chains that aim to be sustainable allows the achievement of some of the Sustainability Objectives. In terms of bioeconomy and the affirmation of the industrial sector based on the exploitation of biological resources, the objectives of sustainable growth, innovation and responsible consumption are the essential aspects for the conversion of traditional production chains into sustainable and integrated ecosystems.

OBJECTIVE 8 is essential for achieving a circular bioeconomy promoting inclusive economic growth and full employment for all.

OBJECTIVE 9 supports industrialization and sustainable innovation, referring not only to the development of innovative technologies, but also to the improvement of existing practices, policies, business models and means of communication.

OBJECTIVE 12 highlights how sustainable consumption and production are important for the production of new bio-products, underlining how consumer acceptability is fundamental for the development of the bioeconomy.

OBJECTIVE 15 can only be achievedwhen business models based on the exploitation of biomass are able to promote and restore a sustainable use of terrestrial ecosystems, taking the limited resources into account.

The bioeconomy represents one of the largest and most important policy areas of the European Union, covering all sectors and systems based on the use of biological resources, such as agriculture, forestry, fisheries, food production, bio-energy and bio-products.

With an annual production value of around 2,000 billion euros and the employment of 18 million employees, it is considered as one of the drivers of sustainable development in Europe. Since 2012 the EU has launched strategies to encourage the development of knowledge, research and innovation in the sector of the conversion of renewable biological resources into products and energy[5]. The main objective is the development of a circular logic that does not take away resources from primary uses, such as food, but maximizes opportunities for reuse through continuous and constant technological innovation.

Since the beginning the concepts of Bioeconomy and Circular Economy have proved to be closely related. Two main policies represent these efforts: on the one hand, the **Circular Economy Package** (2015)[6], based on the three R's: "Reduce, Reuse, Recycle", with the primary aim of "closing the circle" of materials by stimulating the market of secondary raw materials; on the other hand, the **Bioeconomy Strategy** (2018)[7] which represents a research and innovation programme for the sustainable enhancement of biomaterials.

Both converge towards the creation of a model of economic growth in full respect of the environmental concerns related to the limited natural resources.

The implementation of a strategy for the development of a circular and sustainable bio-economy requires a joint effort on the part of public authorities and the industry, called to support the new measures implemented by the European Commission since 2019, including:

5 The Bioeconomy Strategy – European Commission: https://ec.europa.eu/research/bioeconomy/index.cfm?pg=policy&lib=strategy

6 Closing the loop - An EU action plan for the Circular Economy: https://eur-lex.europa.eu/legal-content/IT/TXT/?uri=CELEX%3A52015DC0614

7 A sustainable Bioeconomy for Europe: strengthening the connection between economy, society and the environment: https://ec.europa.eu/research/bioeconomy/pdf/ec_bioeconomy_strategy_2018.pdf#view=fit&pagemode=none

- **EXPAND AND STRENGTHEN BIOSECTORS:** the bioeconomy has the potential to innovate and modernize European economy and industries. The development of an investment platform dedicated to the circular bioeconomy with an endowment of €100 million will make it possible to bring bio-innovations closer to the market and to facilitate the development of biorefineries throughout Europe.

- **INTRODUCE BIOECONOMIES ACROSS EUROPE:** Member States and regions have great potential in terms of biomass and underused waste. The introduction of an EU support mechanism for bioeconomy policies will allow Member States to equip themselves with national and regional programmes and start pilot actions for its development in rural, coastal and urban areas.

- **PROTECT THE ECOSYSTEM AND UNDERSTAND THE ECOLOGICAL LIMITS OF THE BIOECONOMY:** our ecosystem is facing serious threats and challenges, including population growth, climate change and soil degradation. The implementation of a system to monitor progress towards a circular and sustainable bioeconomy will help to expand knowledge about specific biosectors and promote good practices which will be used to provide guidance for operating the bioeconomy within safe ecological limits.

Italy was one of the first those Member States to adopt a Strategy for the development of the Bioeconomy and is committed to increasing the value of production by 20% and employment in the sector by 15% by 2030. According to the 5th Report of the Centro Studi Intesa San Paolo, in collaboration with Federchimica and Assobiotec, in 2017[8] the set of activities related to the bioeconomy in Italy generated a turnover of around €328 billion, employing over two million people.

According to these estimates, the bioeconomy accounts for 10.1% in terms of production and 7.7% in terms of employment of the Italian economy in the year 2017.

Taking a close look at the local Italian bioeconomy, Lombardy has an important role among Italian regions in driving the bio-based sector. 26,000 Lombard companies operate in the biochemical sector according to the Milan Chamber of Commerce, accounting for over a fifth of the Italian total (21.65%), with research and innovation as a decisive development factor. These invest €3 out of the €11 billion euro spent annually in Italy in this sector and employ 33,000 people out of 50,000[9].

The strategic value of the bioeconomy in creating a sustainable development model is demonstrated by the commitment made by the Lombardy Region in identifying governance tools based on the aggregation of subjects involved in the processes of innovation and future competitiveness of the regional economy. Among the identified themes is the green chemistry, or sustainable use of renewable raw materials, which is at the heart of the development of the bioeconomy.

With this in mind, the **Lombardy Green Chemistry Association** (LGCA), a reference point for all innovators operating in the bioeconomy sector, was founded in 2013 by Consorzio Italbiotec, the first Italian not for profit organization for the development of industrial biotechnologies, InnovHub-SSI, Politecnico di Milano and Università degli Studi di Milano. Today the Cluster is the Lombardy Region's interlocutor concerning the initiatives in support of the local bioeconomy and brings together over **50 public and private entities**, including 11 universities and research institutions, 34 small, medium and large enterprises and 7 associations and consortia.

8 La Bioeconomia in Europa 5° Rapporto: https://assobiotec.federchimica.it/attivit%C3%A0/dati-e-analisi/bioeconomia

9 http://opendata.milomb.camcom.it/openDataFront/#/

The Cluster helps to create favourable conditions for bioeconomy development in the region and encourages the creation of an ecosystem of innovation and collaboration between research centres, universities and companies. The industrial realities involved in the Cluster are mainly divided into 3 macro-areas, based on the market in which they operate: the fine chemicals sector, with the production of cosmetics, food supplements and drugs; the biogas production sector; and that of biotechnology research and development services. These employ over **1,800 people**, with a total turnover of over **€650 million**.

In order to promote the development of the bioeconomy in Lombardy, it is necessary to define regional policies to support innovation in the sector, promoting a greater use of renewable resources to support sustainable growth. Against this background, the LGCA Cluster collaborates in the implementation of the **Smart Specialization Strategy of the Lombardy Region**[10], encouraging the development of sustainable business models consistent with territorial programming.

A key element of the EU's reformed 2014-2020 Cohesion Policy, the Smart Specialization Strategy (S3) is a self-assessment tool used throughout the European Union to improve the effectiveness of public policies for research and innovation. It represents an innovative approach that aims to increase growth and employment in Europe, allowing each region to identify and develop its competitive advantages.

The S3 Strategy of the Lombardy Region for research and innovation constitutes the ex-ante conditionality for the use of European structural funds (ERDF/ESF/EAFRD). It aims to identify the resources and the innovative potential of the territory and to select the priorities, in terms of productive sectors and technological areas on which to concentrate investments.

Considered among the main pillars of the regional development strategy, Eco-industry and Agribusiness are the two main areas of specialization of the bioeconomy in the Lombardy Region. Over 40,000 companies are involved in the Eco-industry specialization area, with around 190,000 employees operating in the sectors of clean energy generation, water management and purification, sustainable construction – In Lombardy the energy production system involves over 28,000 employees and generates a turnover of €9 billion – and green chemistry, production of chemicals and energy from renewable sources (biomass and/or organic waste). Green chemistry is an interesting opportunity for the manufacturing sector, as it is at the crossroads of almost all the macro-trends identified by the European Union: resource efficiency, increased use of renewable raw materials, fight against climate change, development of a knowledge-based economy, reduction of the environmental impact of the economy.

The Agri-food specialization area is the most important in Italy and one of the most relevant in the European context. The priority research topics that have a direct inclusion in the bioeconomy sector are closely related to agricultural production, to the implementation of integrated and sustainable transformation systems that include enabling technologies related to biotechnologies, advanced materials and advanced production systems.

1.2 THE INTERREGIONAL DIMENSION: DEMONSTRATION MODELS FOR BIOPOLYMER PRODUCTION

Through its Clusters the Lombardy Region encourages the development of new market opportunities within the areas of specialization through the evolution of traditional industries into emerging industries and promotes a market-driven approach in research activities able to respond to the challenges of society.

In Europe, the LGCA Cluster contributes to the definition and implementation of policies to support innovation in the bioeconomy sector through participation in interregional cooperation networks, such as the **Vanguard Initiative**, where it is Technical Coordinator of the Pilot on Bioeconomy. Vanguard is a European network of over 35 regions committed to the revitalization of the European industry based on the smart specialization strategy, with the aim to strengthen and accelerate the development of markets with high innovative potential.

10 Smart Specialisation Strategy S3 – Lombardy Region: http://www.s3.regione.lombardia.it

The LGCA Cluster and the Lombardy Region coordinate the **Bioeconomy Pilot - Interregional cooperation on innovative use of non-food Biomass**, a project involving over 25 European regions interested in developing a strategy for the development of the Bioeconomy and supporting innovation projects with a high innovative and competitive impact[11].

The Pilot encourages the development of new value chains based on the valorisation of bio-based resources by encouraging cutting-edge demonstration projects and their placing on the market.

Currently the Pilot involves three partnerships set up around corresponding sustainable business models based on the recovery and transformation of biomass for the production of high value-added products and systems:

- **PRODUCTION OF BIOAROMATIC MOLECULES:** a business model based on the development of aromatic compounds from biomass. The partnership is led by the Flemish region and involves further fifteen European regions participating in the Vanguard Initiative[12].

- **LIGNOCELLULOSIC BIOREFINERY:** a business model focused on the conversion of the lignocellulosic biomass fraction into intermediates and building blocks for biofuels and chemicals production. The partnership is led by South Holland and involves five other European regions[13].

- **LIQUEFIED BIOMETHANE:** a business model for the production and use of liquefied biomethane in public transport. The partnership is led by Emilia-Romagna in collaboration with Lombardy and involves four other European regions[14].

The Bioeconomy Pilot encourages the creation of partnerships around sustainable business models able to develop technologies with a high innovative potential, ready to market biobased products and production models. In 2019 the Pilot carried out a mapping of the most promising demonstration cases, among which the production of biopolymers is among the most interesting and with highest industrial potential, involving the Małopolska region (Poland) in this activity.

The Małopolska Region has brought together all innovators in the life sciences sector in a single strategic interlocutor, the **LifeScience Klaster (LSK)** of Krakow, established in 2006 with the aim of developing and marketing innovations in the field of biotechnologies.

11 Vanguard Initiative – Bioeconomy Pilot https://www.s3vanguardinitiative.eu/cooperations/bio-economy-interregional-cooperation-innovative-use-non-food-biomass

12 Randstad, North Rhein Westfalia, Slovenia, Piemonte, Upper Austria, Lower Austria, Galles, Paesi Baschi, Vallonia, Värmland, Navarra, Lombardia, Emilia-Romagna, Scozia.

13 Randstad, Fiandre, Scozia, Galles, Slovenia

14 Randstad, Upper Austria, North Rhine Westphalia, Northern Netherland

LSK is a collaborative research-oriented network committed to allow an effective global connection. The aim is the optimization of the potential of individuals and organizations and encourage the development of research and the marketing of its results. An important aspect of the Cluster is to associate technologies and products by improving the quality of individual life. This includes drug discovery and research services, medical diagnostics, telemedicine, complementary foods, cosmetics and environmental technologies. The Cluster boasts the collaboration of more than 70 entities, including SMEs (47%), other public institutions (31%), and large companies (18%).

Founded in 1968, the **Institute of Catalysis and Surface Chemistry of the Polish Academy of Sciences (ICSC PAS)** is a member of the Cluster. Its research activities cover various fields and include design, synthesis, practical verification of materials and advanced processes. Many of the Institute's efforts are focused on the development of new "intelligent" nanomaterials and bioactive systems.

With respect to the bioeconomy the Institute is working on two projects based on the development of new biopolymers. Two demonstration cases currently being developed under the coordination of the research group of Dr. Maciej Guzik are contributing to the definition of a model for the production of sustainable and environmentally friendly biopolymers.

PHATechMat - *Vegetable oil biorefining technology for production of advanced composite materials.* The main goal is to put forward a biorefinery model for the production of polyhydroxyalkanoates (PHA). The secondary purpose is to demonstrate the potential of these polymers in the development of the Polish economy, preparing composite materials for different uses in the medicine sector (bone or cartilage implants), and in the textile, food, packaging and plastic products sectors.

The research activity involves the construction of a prototype, its validation and the production of two types of PHA polymers from rapeseed oil hydrolysis products. The technology thus developed will be patented and so made available on the market. A series of PHA and polymeric-ceramic compounds will be created and then used to create bone implants that will be characterized by physical-chemical and biological analyzes (*in vitro* and *in vivo*).

FunBioMed - *Novel functionalised biopolymers for medical applications.*

The purpose of FunBioMed is to produce new biopolymers for medical applications. PHAs will be modified through a biocatalytic esterification process with antibiotics, steroid and non-steroidal anti-inflammatory drugs.

The materials will be created in the form of foams and their physical-chemical and antimicrobial characteristics will be determined. *In vitro* studies on the formation of tissue on the foam by chondroblasts and osteoclasts will allow the evaluation of their applications in the tissue engineering sector. Migration assay of skin cells on functionalized foams and *in vivo* studies on laboratory mice will be conducted to evaluatetheir effectiveness in wound healing.

Bioplastics production in the Lombardy Region represents one of the fastest growing sectors. The need to use eco-sustainable raw materials and principles of circular bioeconomy has given impetus to numerous research and development projects. Among the most mature industrial cases are those represented by the Rainbow project and the e-Koala company.

Rainbow - *Renewable RAw materials valorisation for INnovative BiOplastic production from urban Waste.*

Funded by the Lombardy Region in the context of the "R&S Linea per aggregazioni" R&D call for tenders (2016), the project is led by Agromatrici Srl, in partnership with industrial and academic partners Alan Srl, Cat-Ronzoni, Università degli Studi di Milano and CNR-ICRM. With an investment of €1,300,000 and a full two years of testing, the project validated a biorefinery model by developing an ecologically and economically sustainable protocol for the production of bioplastics, polyhydroxyalkanoates (PHA), starting from the organic fraction of municipal solid waste (OFMSW).

15 The BioMonitor project (2018-2022) involves 18 academic and industrial partners from 11 European countries. The contributions reported in the paragraph report some key concepts defined and transcribed in the project proposal and in the deliverable "D1.1: Framework for measuring size and development of bioeconomy with a list and detailed description of bioeconomy indicators, measures, and data requirements".

This protocol can be easily integrated into the waste processing chain and the production of bio-based products alternative to those of fossil origin. The RAINBOW project is based on the development of a "percolator" type pilot plant for the production of VFAs, which represent the basis for the subsequent transformation of waste into PHAs. OFMSW, being ubiquitous and continuously generated, becomes an innovative resource that lends itself to be used as a substrate for the production of PHAs, useful for drastically reducing raw material costs. Currently the OFMSWin the region is used for compost or energy production: RAINBOW proposes the OFMSWas feedstock for the creation of a new value chain with the primary objective of producing new biomaterials to be used in other manufacturing sectors, thus allowing production diversification.

eKoala - *From agriculture to bioplastics: a model of Lombard circular economy.*

A start-up founded in Lombardy by two siblings, Beatrice and Daniele Radaelli, eKoala Srl (www.ekoala.eu), is one of the first Italian companies that has chosen to replace traditional plastics with new and innovative bioplastics for the creation of completely biodegradable and non-toxic childcare products.

For the production of its products eKoala uses Mater-Bi, the patented bioplastic marketed by Novamont Spa, whose essential components are corn starch and vegetable oils. The material, that can be processed in a way similar to other plastic materials even as regards colouring and sterilization, has the advantage of being completely biodegradable.

The whole eKoala product range must pass the most stringent laboratory tests that guarantee the absence of toxic substances and certify that they are 100% safe for children.

An example of sustainability and circular economy in the Lombardy Region, eKoala can be considered as a case of excellence.

1.3 THE BIOECONOMY AND THE MONITORING OF THE INDUSTRIAL, SOCIAL AND ENVIRONMENTAL POTENTIAL

In the context of the inter-regional cooperation network Vanguard Initiative the LGCA Cluster has signed a collaboration agreement with the European BioMonitor project (www.biomonitor.eu), with the aim of sharing knowledge and tools for determining the impacts generated by the Bioeconomy.

Monitoring the regional industrial potential and its sustainable development to bring producers closer to transformers is among the objectives of the European BioMonitor project, which is involved in the development of a statistical model to measure the bioeconomy in Europe, quantifying its economic, social and environmental impacts[15].

BioMonitor contributes to bridging a knowledge gap connected to the production of emerging markets, such as bioplastics, aiming to find a solution to the lack of a comprehensive database of statistics on the industrial uses of biomass, of a transparent methodology for data collection, and, finally, of integrated indicators of value chains that can illustrate the flows between the activities that transform the organic raw material into a finished product. The improvement of such databases contributes to the creation of new governance models (*BioMonitor Model Toolbox*) to support companies and government bodies in their long-term strategies, and to develop a platform (*BioMonitor Data Platform*) to test and disseminate the results derived from innovation initiatives.

The definition of indicators for the quantification of the economic, environmental and social impact of the bioeconomy of emerging sectors, such as that of polyhydroxyalkanoates (PHAs), makes it possible to measure the compliance of these products to the targets set by the European Commission, for example that of "*40% reduction of greenhouse gases by 2030 compared to 1990", assessed by measuring "carbon and energy emissions and energy absorption*"[16].

To capture all the aspects of sustainability and circularity that characterize the bioeconomy, BioMonitor integrates data and indicators of the entire value chain through the development of input-output matrices for the sectors and sub-sectors of interest. Value chains are directly linked to input-output tables, allowing the identification of participation shares and their interconnections along the supply chain, their degree of circularity, and finally their changes over time and space.

The collection of data from Member States regions is an essential factor to validate the sustainability of the business model, showing the quantity of reused and reusable material in the regions, starting from the use of the by-products in combination with the local production and processing capacity.

The ultimate goal of the BioMonitor project is to obtain a clearer picture of how the bioeconomy affects our lives, defining a new and consolidated statistical framework and modelling of the bioeconomy, compatible with the systems of statistical and customs offices, laboratories and industries. Stakeholder engagement with the developed platform ensures the knowledge generated by the project does not remain within the academy, but is disseminated to all the actors involved.

16 This is one of the indicators selected by BioMonitor through a review of those already used (eg by EUROSTAT, Forest Europe, European Environment Agency), bioeconomy monitoring initiatives (eg SAT-BBE, BERST) and finally based on feedback received from a wide range of stakeholders involved through workshops.

NEW SUSTAINABLE SUPPLY CHAINS FOR THE DEVELOPMENT OF A LOMBARD BIOPOLYMERS MARKET

2. New Sustainable Supply Chains for the Development of a Lombard Biopolymers Market

The industry of compostable bioplastics is among the supply chains with the greatest social and environmental impact for the development of a sustainable economic model. The reutilization of raw materials obtained from agricultural biomasses and renewable resources, such as the by-products of the agri-food transformation and the organic wastes, involves all the actors of the supply chain, from the producers to the processors and the final end users.

In 2018, in Italy, the biodegradable and compostable plastic industry was represented by 252 companies – divided into chemicals and intermediates producers (5), granules producers and distributors (20), first transformation operators (162), second transformation operators (65), accounting for 2,550 dedicated employees, with a production of 88,500 tonnes of compostable artefacts, and a turnover of €685 million. The number of enterprises operating in the sector grew from 143 operators in 2012 to 252 in 2018 (Plastic Consult, 2018)[17].

The sector of biodegradable and compostable plastic production in the Lombardy Region accounts for about a quarter of the national industry in terms of contribution to the production value, and it comprises first and second transformation operators for disposable shoppers production, bags for organic fraction collection, artefacts for agricultural purposes, food services, food packaging and personal hygiene. In 2018 the value of production reached €264 million, employing 700 workers (data elaborated by LGCA, 2019)[18].

The innovation potential of compostable plastic production can thus count on a complex economic system, able to face the challenge of a conversion of productive activities based on fossil sources into bio-based processes.

This study aims to consider the whole supply chain of compostable bioplastics from raw material producers and transformers to the post-consumer management, verifying the considered demo-cases and the potential economic, social and environmental impact generated on the Lombard territory.

2.1 THE AGRO-INDUSTRIAL SYSTEM IN LOMBARDY: A SUSTAINABLE USE OF RAW MATERIALS

The production of bioplastic through the use of agricultural by-products represents a market with a strong potential impact for the Lombardy Region. Obtained from renewable vegetal sources, bioplastic is not a competitor for the food supply chain. It presents various advantages: it is biodegradable, it does not use petrochemical processes and it guarantees the same thermo-mechanical properties of conventional plastics.

The local availability of raw materials is an essential pre-condition for the development of this market, that can become really sustainable through an accessible logistic system. In this context, the agro-industrial sector of the Lombardy Region is the most significative at the Italian level and one of the most relevant in the European context. In 2016, the regional agro-industrial production value has reached €12.8 billion, accounting for to 3.5% of the gross domestic product of the Lombardy Region. The agricultural production, its related activities and those of food transformation involve 60,000 productive units and 225,000 workers, 140,000 of which are permanently employed, accounting for 3.2% of the total Lombard work units (The Lombard agri-food system 2017)[19].

17 V Rapporto Annuale Assobioplastiche 2018 http://www.assobioplastiche.org/ricerca.html

18 Data processed by the Lombardy Green Chemistry Association, 2019

19 The Lombard agro-food system. Report 2017: https://www.regione.lombardia.it/wps/portal/istituzionale/HP/DettaglioRedazionale/servizi-e-informazioni/Imprese/Imprese-agricole/ricerca-e-statistiche-in-agricoltura/rapporto-agroalimentare-2017/rapporto-agroalimentare-2017

The bioplastic production through the recovery of agro-industrial by-products offers us dual benefits: using of all secondary products, which industrial potential is under-exploited and eliminating waste creation along the whole supply chain, though the production of biodegradable material. Among the agro-industrial sectors considered for the bioplastic production, the dairy compartment is the one with the greatest potential impact on the Lombardy territory.

According to milk market data (CLAL) updated to 2019[20], the Lombardy Region produces 44% of the Italian milk. Therefore, a significative amount of by-products like milk and ricotta whey is generated here, accounting for 36% of whey produced in Italy and 2.75% of whey produced in the world. The whey valorisation and its transformation into high added-value goods can generate an indirect benefit for the producers, which would be able to convert the disposal cost into a source of income, creating synergies with companies involved in plastic granules production.

The production costs of fossil-based PE plastic granules are about 600-800 €/ton. The extraction and processing costs in the case of bioplastic production (PHAs), about 300/350 €/ton, show that there is scope for the rise of a competitive supply-chain bringing bioplastic to the usability of the plastic granules that are currently marketed, although the technological properties of this material still require further refinement passages (LCA data from CoWBoy Project – Cariplo Foundation 2015)[21].

2.2 BIOTRANSFORMATIONS: A BIOREFINERY MODEL FOR THE LOMBARDY REGION

Obtaining bioplastic from urban waste is a further biorefinery model, aside those linked to the valorisation of raw materials of agricultural and agro-industrial origin (corn silage, sugarcane, milk whey). The use of microbial consortia able to improve the conversion efficiency of urban solid wastes into reusable organic polymers represents a new frontier of circular economy, which exploits the bacterial ability to metabolize big amounts of carbon to produce high added-value molecules.

An integrated biorefinery model is based on the valorisation of unused by-products, and on conversion technologies like anaerobic digestion, a biological process that, operating in the absence of oxygen, is able to transform the organic matter contained in materials of vegetal and animal origin into biogas, which mainly composed of methane (CH_4) and carbon dioxide (CO_2).

In recent years, anaerobic digestion processes have registered a considerable increase, by combining co-digestion approaches using different biomasses (manure, dedicated crops, by-products and waste).

The applied methodology includes the reutilisation of manure from farms, crop by-products, agro-food transformation products and urban waste for the production of renewable energy and other high added-value products obtained with reduced atmospheric emissions. The digestate, which remains after the anaerobic digestion of matrices, is a transformation intermediate and a raw ma-

20 CLAL Lombardy Region 2019: https://www.clal.it/?section=quadro_lombardia

21 CoWBoy Project – Cariplo Foundation 2015: https://www.italbiotec.it/index.php/it/progetti/374-cowboy

terial for the creation of further products usable as an alternative to fossil-based products.

The total production of urban waste in the Lombardy Region in 2017 was 4,685,489 tonnes, accounting for 15% of the Italian total production. Of these, 1,206,000 tonnes were the organic fraction (organic fraction of the municipal solid waste – OFMSW)(Ispra data, 2018)[22].

OFMSW is characterized by a high content of carbohydrates and proteins and represents an optimal substrate for anaerobic digestion. In 2018 on the Lombard territory over 300 agricultural biogas plants were active, with €1.6 billion in investments, to which €300 million/year for the plant's maintenance must be added (Consorzio Italiano Biogas data, 2018)[23].

Therefore, the agricultural biogas supply chain of Lombardy is the leader in Italy in this field,combining primary sector industries with a high technology level with internationally relevant biogas plants that are strongly committed to research and development.

2.3 POST-CONSUMER: COLLECTION, RECYCLING AND REUSE IN LOMBARDY

Through the adoption of the circular economy principles, all EU Member States are called to meet the challenge of the European Commission to ensure the recycling of 55% of urban waste by 2025 and the progressive reduction of waste destined to landfill to 10% of total waste by 2035. In order to reach this ambitious aim, it is necessary to find solutions to overcome technological and regulatory limits, encourage the creation of new integrated supply chains and sustain policy instruments in support of waste collection, recycling and reuse.

In Lombardy the separate collection for urban solid waste amounts to 61%, with some virtuous cases like Mantova, Varese and Cremona. The objective is to reach the challenging target of 67% of separate collection in the region in the next years. Meanwhile, the municipalities with more than 65% of separated collection are constantly increasing (they were 686 out of 1527 in 2016).

59.3% of urban wastes is currently destined to the recovery of materials and this rate is increasing by 1.5/2% every year. For the year 2016 the rate of material and energy recovery was 89.6%. Therefore, the model of landfill disposal has been overcome and currently only 2.6% of urban wastes is placed in landfill. Direct landfill disposal decreased to 0.6%, while it accounted for over 80% only 20 years ago (Legambiente data, 2018)[24].

22 Rapporto Rifiuti Urbani - Edizione 2018: http://www.isprambiente.gov.it/it/pubblicazioni/rapporti/rapporto-rifiuti-urbani-edizione-2018

23 VI Permanent Environment and Civil Protection Commission of the Lombardy Region: https://www.consorziobiogas.it/biogas-agricoltura-lombardia-primo-come-investimenti/

24 Legambiente, Comuni ricicloni Lombardia 2018 https://www.legambiente.it/sites/default/files/docs/comuniriciclonilombardia-2018.pdf

BIOPLASTICS

3. Bioplastics

3.1 BIO-BASED PRODUCTS AND REFERENCE MARKET

Bioplastics are partially or entirely made up of by polymers derived from biological sources, like sugarcane, starch, cellulose, straw and cotton and comprise a wide family of materials with different properties and applications.

They offer the double benefit of the preservation of fossil resources and the reduction of carbon dioxide emissions, proving to be key resources for sustainable development.

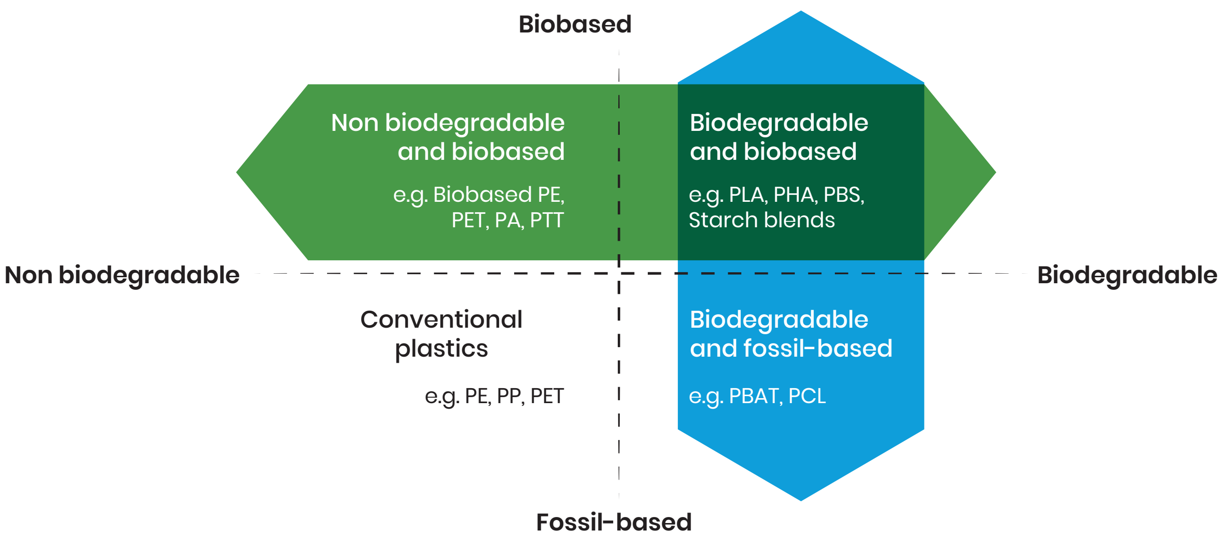
According to the European Bioplastics Association, bioplastics can be biodegradable, bio-based or have both characteristics[25].

A bio-based material is entirely or partially obtained from vegetal biomasses, therefore it is of biological origin and does not include any fossil source (coal or petroleum).

The term "biodegradable" refers to a material able to be degraded by microorganisms (bacteria or fungi) in water, natural gases like methane or carbon dioxide, or in biomass.

Bio-based materials can be biodegradable, like polylactic acid (PLA), polyhydroxyalkanoates (PHAs), polybutylene succinate (PBS) or non-biodegradable, like bio-polyethylene terephthalate (bio-PET), bio-polytrimethylenterephthalate (bio-PTT) and bio-polyethylene (bio-PE).

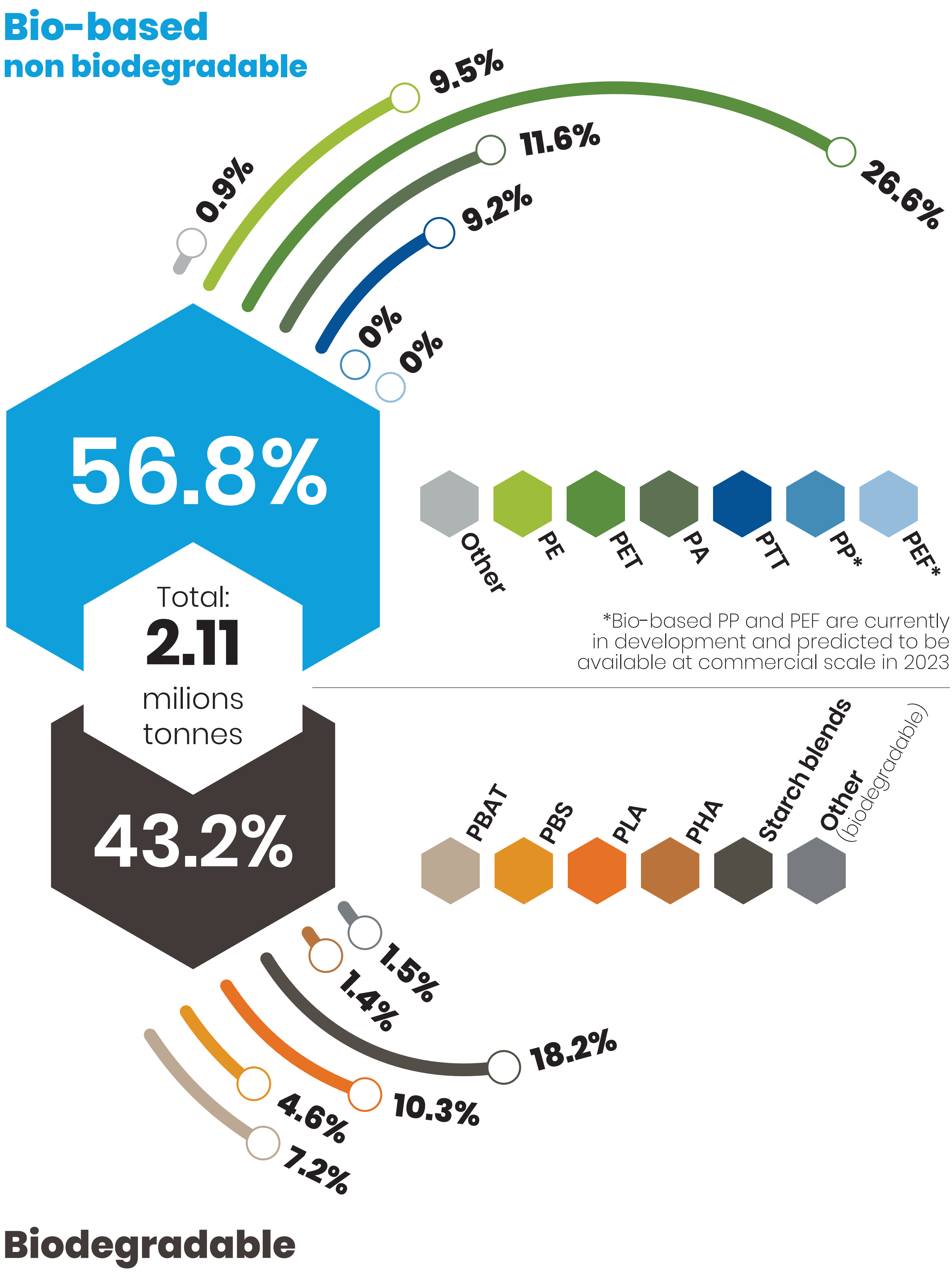
On the other side, some fossil-based polymers, like PBS, a semi-crystalline polymer produced through bacterial fermentation, show biodegradable characteristics. However, most of the conventional polymers for food packaging currently marketed are not biodegradable, like polypropylene (PP), polyethylene (PE) and polyvinyl chloride (PVC). According to data from the Plastics Eu-



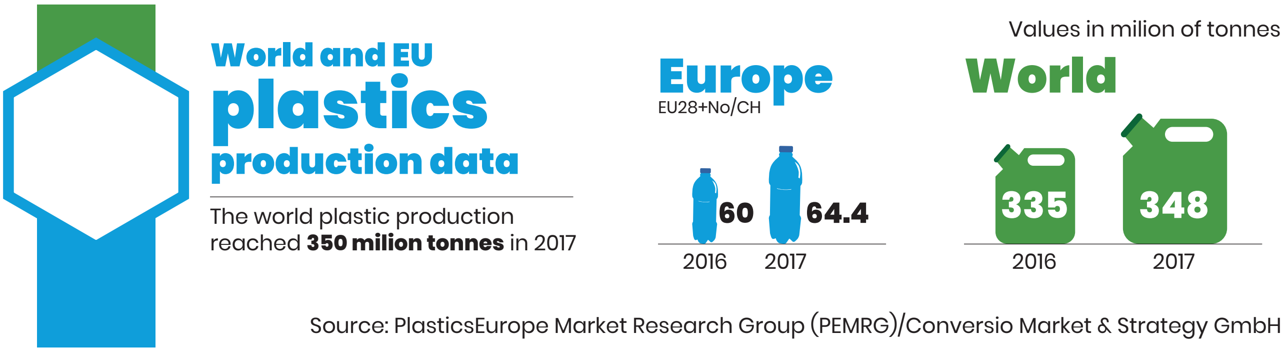
25 https://www.european-bioplastics.org/bioplastics/

Global production capacities of bioplastics 2018

by material type



Source: European Bioplastics, Nova-Institute 2018

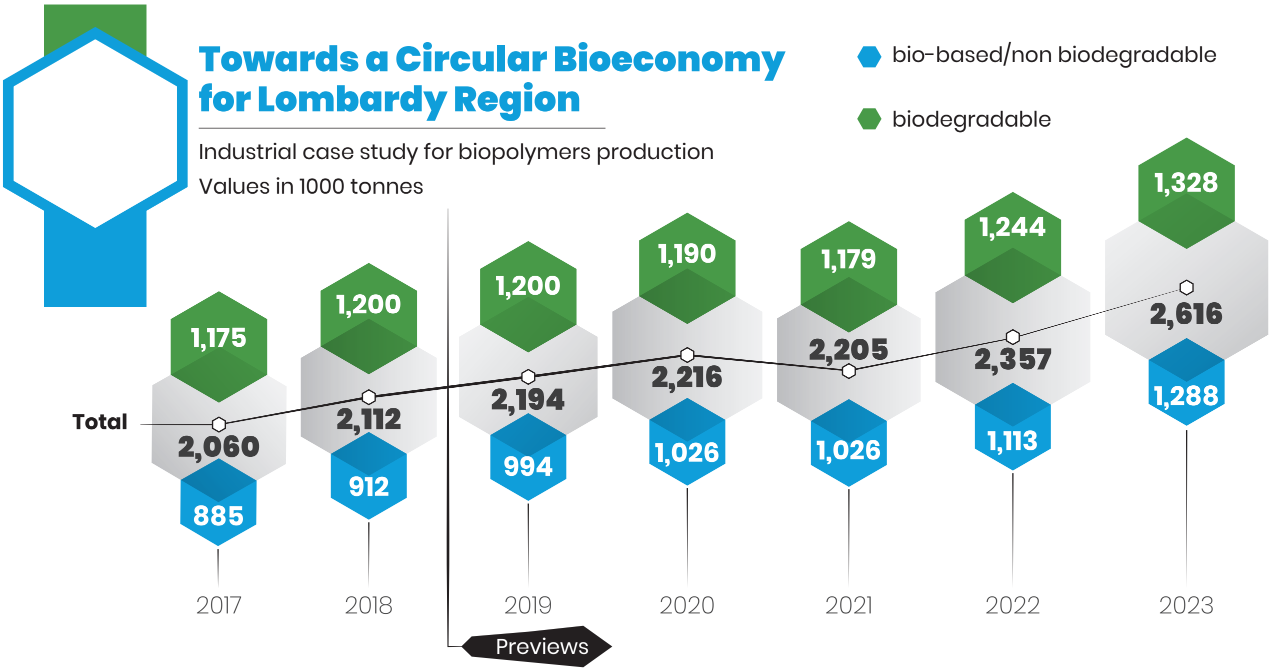


rope Market Research Group[26], the 2017 global plastic production was 348 million tonnes, of which 64.4 were produced in Europe. Unfortunately, the way plastic is produced, used and disposed of does not support a circular economy and is detrimental to the environment. An alarming example is represented by the tonnes of plastic present in the oceans, which have important consequences on marine wildlife, human health, economy and climate.

The context of environmental emergency has stimulated the demand for products with a low environmental impact such as bioplastics, which offer the same features of traditional plastics with a potentially lower environmental impact.

Of extreme interest are trials to produce biopolymers from waste materials, like those deriving from agri-food (canning, dairy and tomatoes processing) industries, but also from algae, maize stalks o from the separate collection of the organic fraction of the municipal solid waste (OFMSW). Currently, bioplastics account for 1.7% of the 335 million tonnes of plastic produced annually (Plastics Europe Facts and Figures 2017)[27].

European Bioplastics, in collaboration with Nova-Institute, has declared that the global production of bioplastics will increase from 2.11 million tonnes in 2018 to 2.62 million tonnes in 2023[28].



26 Plastics - the Fact 2018: https://www.plasticseurope.org/it/resources/market-data

27 https://www.plasticseurope.org/it/resources/publications

28 Bioplastic market data: https://www.european-bioplastics.org/market/

3.2 BIOPLASTIC PRODUCTION BARRIERS

The several advantages of bioplastics notwithstanding, such as the lower environmental impact, the possibility to be recycled and the production from renewable resources, their market introduction has a number of obstacles.

COMPETITIVENESS OF BIOPLASTICS AGAINST CONVENTIONAL PLASTICS

The production cost of PHAs exceeds five times that of traditional plastics, due to the high costs of the fermentation process and of recovery and purification technologies, which are slowing down their market introduction.

RAW MATERIAL AVAILABILITY

Since bioplastic production requires the use of vegetal biomass it is necessary to avoid a conflict between food resources and raw materials for bioplastic production and identify sufficiently abundant resources to supply manufacturing companies.

PERFORMANCES AND QUALITY COMPARED TO TRADITIONAL PLASTICS

During conventional plastic production additives are used to confer unique characteristics to the materials; this technique could also be used in bioplastic production. However, the additives market for biopolymers is still very small. Furthermore, while it is necessary to generate a product with constant characteristics, the wide variety of raw materials does not yield sufficient chemical uniformity.

For all the above reasons, “eco” materials have so far reached a successful positioning only in market niches such as organic foods or luxury goods, often in the form of packaging.

ECO-DESIGN PRODUCTS FROMSUSTAINABLE BIOPLASTICS: THE PHA-STAR CASE STUDY

4. Eco-Design Products from Sustainable Bioplastics: the Pha-Star Case Study

4.1 CHALLENGES AND OPPORTUNITIES FOR BIOPOLYMER PRODUCTION IN THE LOMBARDY REGION

The PHA-STAR project, funded by the Lombardy Region under the "Smart Fashion and Design" call for proposals, is aimed at the validation of a sustainable production protocol for polyhydroxyalkanoates (PHAs), biopolymers of microbial origin, using by-products from the Lombard dairy industries (milk and ricotta whey).

The experimental plan included the development of a method for a sustainable process for PHA production, aimed at the development of completely biodegradable eco-design artefacts for gardening purposes.

The concept of sustainability is declined in all the phases of production, including the development of sustainable methods for PHA separation and extraction from microbial cultures through the use of non-toxic solvents as well as the use of mixed microbial cultures to guarantee a greater competitivity compared to other biopolymers on the market. The model proposed by PHA-STAR allows the opening of agro-food industries to a new dynamic market, offering an alternative to bearing the costs of milk whey disposal and creating an opportunity for the transformation of waste into high added-value products. The recovery and reuse of dairy by-products promotes the development of new circular supply chains.

With a total investment of about €1,500,000, the PHA-STAR project is coordinated by Agromatrici Srl (www.agromatrici.com). An innovative start-up company operating in the sector of biomass recovery, it develops solutions to promote the sustainable use of resources, waste, by-products and biowaste for green energy generation and high added-value products for agricultural purposes.

The Ricicla Group of the Università degli Studi di Milano and Consorzio Italbiotec are the project partners.

Gruppo Ricicla (http://users.unimi.it/ricicla/gruppo.html) can count on a consolidated international experience in the field of anaerobic fermentation, working on research projects aimed at developing high added-value products and contributing to significative industrial innovations[29].

Consorzio Italbiotec (www.italbiotec.it), the leading not for profit organisation in the field of industrial biotechnologies in Italy, works on the creation of a cooperative ecosystem between universities and companies operating in the sectors of Life Science, Bioeconomy and Agrofood. In collaboration with the Lombardy Green Chemistry Cluster, Italbiotec has worked to elaborate a market and socio-economic impact analysis, evaluating the industrial potential for the development of new supply chains in the Lombardy Region and analysing all the actors in the bioplastic production value chain.

29 Cowboy (Cariplo Foundation) for the laboratory-scale validation of pre-treatment methods of dairy product sub-products; AgrIdEn - Production of bio-hydrogen and renewable energy residues from agrolivestock (Regione Lombardia); Biobi - Biomass to biogas (Regione Lombardia); Eco-Biogas - Economic and environmental impacts analysis of biogas production: implications for the agri-food chains and regional policies (Regione Lombardia).

4.2 POLYHYDROXYALKANOATES: PROPERTIES, COMPETITIVE ADVANTAGES AND TECHNOLOGICAL CHALLENGES

Polyhydroxyalkanoates or PHAs are natural thermoplastic polyester polymers. They are one of the most studied biopolymer categories because of their full biodegradability and biocompatibility, which make them potential substitutes for petroleum-based plastics (Bordes et al., 2009; Chanprateep, 2010).

PHAs are intracellular bio-products of different bacterial species mainly belonging to *Bacillus*, *Rhodococcus*, *Ralstonia* and *Pseudomonas* and are obtained through fermentation using sugar or lipids as substrate.

In specific cultural conditions, like nutrient depletion of nitrogen, phosphorus and sulphur or in presence of excess carbon sources, PHAs are accumulated as reserve carbon sources in the form of granules (Anderson and Dawes, 1990; Lee, 1996).

Granules can reach high concentrations, reaching 90% of bacterial dry mass (Khanna et al., 2005).These granules vary in dimension and quantity among the different bacterial species and compriseconstituted PHAs (97%), proteins (1-2%) and lipids (0.5%) (Koller et al., 2009). The great variability of lateral chains and monomers makes PHAs equally variable in terms ofphysical characteristics, with melting points ranging from 40° to 180° C. As a consequence, many PHAs are thermoplastic polymers, like polyhydroxybutyrate, while others are elastomers, like polyhydroxyottanoate. Therefore, PHAs composition is very varied and also depends upon the type of bacteria from which they are synthesized as well as from the culture matrix (Koller et al., 2011).

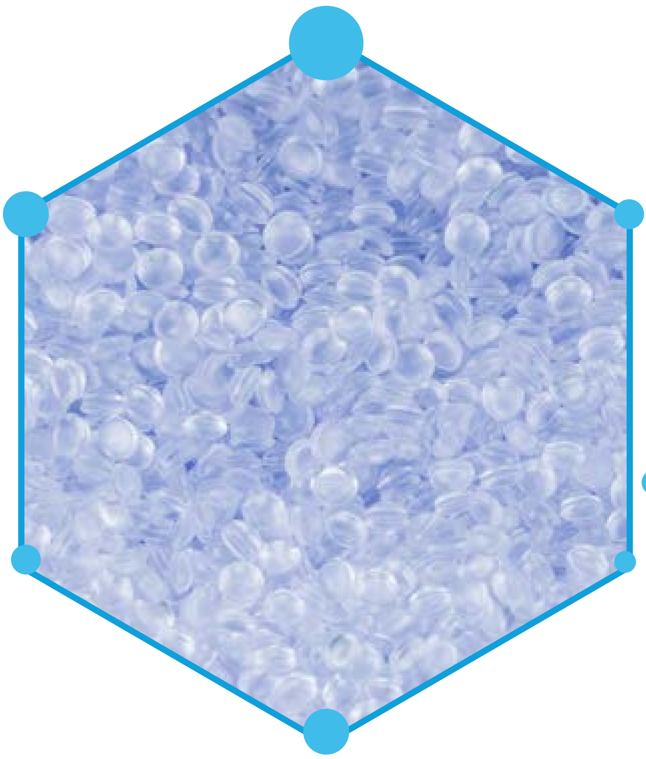
PHAs are characterised by various competitive advantages:

THERMOPLASTICITY:
the property of plastic polymer materials to become soft and pliable at elevated temperatures and to solidify upon cooling without any change of the inherent properties.

BIODEGRADABILITY:
the ability of organic substances and materials to be degraded into simpler substances through the action of enzymes from microorganisms. This characteristic can be used to decrease the storage volume in landfills (Koller et al., 2009).

BIOCOMPATIBILITY:
the possibility to use biopolymers in the medical field for the preparation prosthetic and surgical devices.

CARBON BALANCE:
the petroleum combustion generates a high quantity of CO2, which is widespread in the atmosphere and cannot be reabsorbed in the carbon cycle. By exploiting PHA biodegradability by soil microflora, the cycle could be closed. Furthermore, biopolymers come from renewable resources and, for this reason, do not depend on the availability of fossil raw materials.



FRAGILITY AND ELASTICITY:
the tendency to break and deform under the action of an applied force and to reacquire the original form when the imposed action stops.

Polyhydroxybutyrate (PHB) is among the most studied PHAs as well as one of the few to be industrially produced for different uses (packaging, banknotes, car parts).

PHB is a transparent film and possesses physical properties similar to those of polypropylene (PP), including good oxygen permeability, good UV resistance, a high crystallinity which provides high resistance to solvents, but low resistance to acids and bases (Shen et al., 2009).

Despite all the above advantages, the production cost of PHAs, estimated to be more than €5/Kg, makes this material less competitive with respect to the market price of conventional polymers (<€1/Kg), and is the main obstacle to its large-scale take-up.

The PHA-STAR project proposes the adoption of alternative strategies through the use of mixed microbial cultures and the reuse of low-cost organic waste as carbon sources for microbial fermentation, as a replacement for synthetic substrates.

Furthermore, the use of non-toxic and sustainable solvents for the extraction and purification process results to be of great importance for the economy of the process, because it significantly influences the quality of the obtained polymer, its application possibilities and, therefore, its market value.

It is necessary to consider that the sustainable production of PHAs is based on the use of by-products that are not suitable for use as foodstuffs, but are very sought after by biogas plants. PHAs are only a fraction of the bacterial biomass produced during its manufacturing procedure, usually around 10%. With appropriate agreements and supply-chain regulations, the by-products of PHA production could be used in the biogas plants already existing on the Lombard territory, contributing to generate further high value-added products.

4.3 PHA PRODUCTION PROCESS OF FROM MILK WHEY

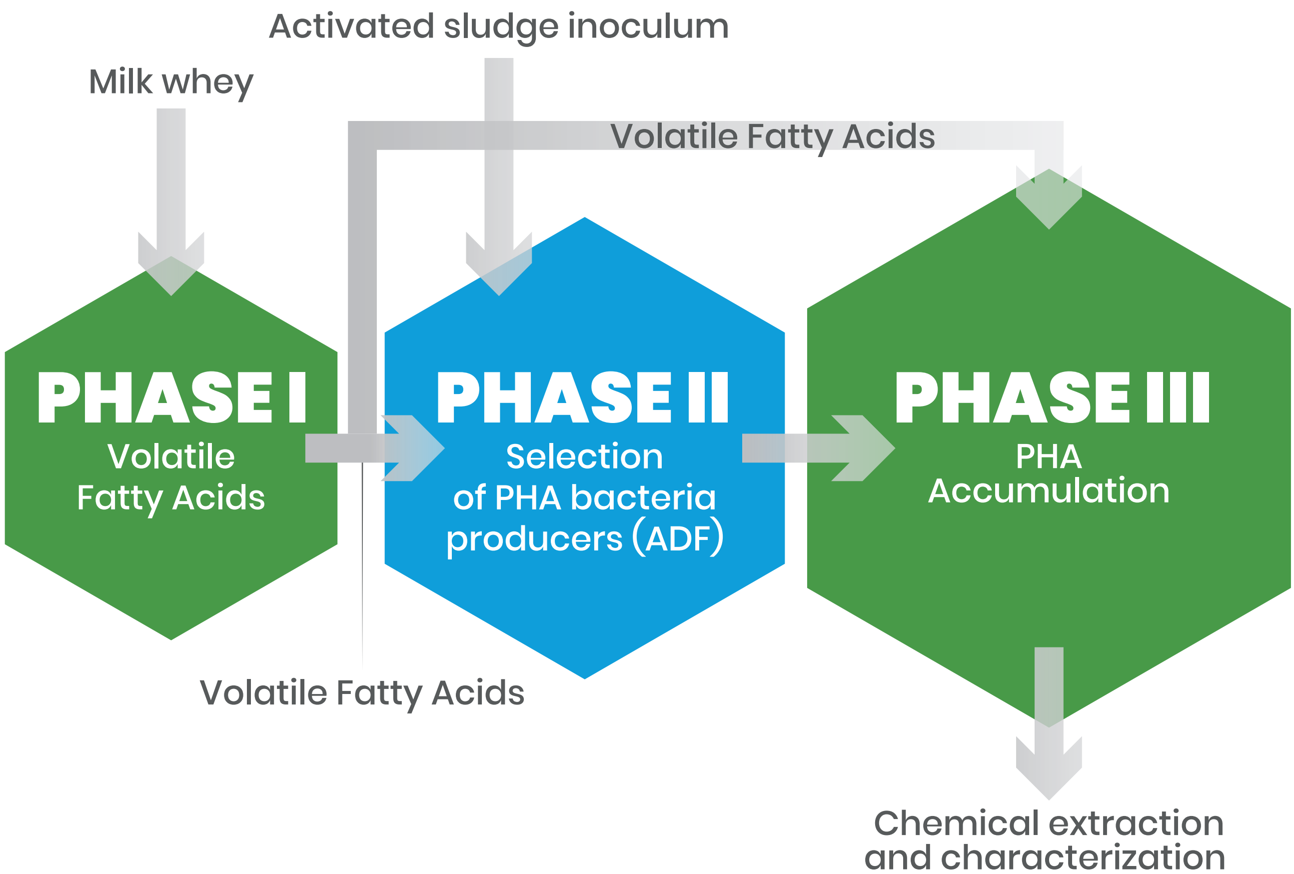
Milk whey is separated from the curds during the cheese-making process and is the main by-product of the dairy industry, accounting for 85-95% of the initial milk volume and containing 55% of its nutrients. Among the latter the most important are lactose (4.5-5%), soluble proteins (0.6-0.8%), lipids (0.4-0.5%) and mineral salts (8-10% of dry substance) (Gonzalez-Siso, 1996).

Milk whey is considered as the most important pollutant in thedairy sector, because of its high organic load (COD=50-102 g L-1) and the high amount generated (Carvalho et al., 2013). Approximately 50% of milk whey is disposed in wastewater treatment plants or used as animal feedingstuff (Pescuma er al., 2015). Sometimes it is applied as fertilizer in agriculture, but the high salinity restricts its use (Gonzalez-Siso, 1996). 80 million tonnes of milk whey are produced in the European Union every year, 8 of which in Italy (Nikodinovic-Runic et al., 2013).

One of the most cost-effective systems adopted by the dairy industry to use milk whey is as raw material for ricotta production. The ricotta production process has ricotta whey as further by-product, an important pollutant with adverse effects especially on aquatic ecosystems (Carvalho et al., 2013).

Currently a fraction of ricotta whey is used as food supplement in farming, but most of it remains unused and its disposal without any treatment could cause serious environmental damages. Whey disposal is thus a problem for the dairy industry sector and, for this reason, its reuse for PHA production could be an effective solution (Girotto et al., 2015).

The production process tested by the PHA-STAR project is divided in 3 main stages, from the collection and treatment of biomass to PHA granules production



1 MILK WHEY PRETREATMENT

Before its use as starting substrate for PHA production, milk whey undergoes heating for the thermocoagulation of serum proteins and is filtered for their removal. Pretreated milk whey is then introduced in a fermentation reactor (1m^3) and, through a process of dark fermentation, an AGV-rich fermented productis obtained to be used as carbon source for the mixed microbial culture contained in the second reactor of the pilot plant.

2 SELECTION PHASE OF PHA-PRODUCER BACTERIA

The PHA-producer bacteria selection inside the selection reactor (1m^3) is obtained starting from active biomass suspended in water and submitted to a process named Aerobic Dynamic Feeding (ADF). Selection iss guaranteed by feedingthe effluent with constant properties and using feeding cycles in controlled conditions, so as to select the bacteria able to resist these conditions. The scheme consists in the imposition of alternated conditions of feast (presence of excess of carbon source) and famine (absence of carbon sources), that is, the fermented milk whey in aerobic conditions. The prolonged absence of carbon source during the famine phase causes the depletion of intracellular components essential for bacterial growth (enzymes, RNA). When the carbon source is once again available at high concentrations in the feast phase, microorganisms do not have a sufficient amount of enzymes to reach the maximum growth rate. Instead, less enzymes are required for PHA accumulation and, consequently, this happens at a higher speed with respect to bacterial biomass growth; in this way, it is more convenient for microorganisms to accumulate PHA than to use the substrate for their growth. In the successive famine phase , accumulated PHAs are used for growth and cellular maintenance. These conditions create a competitive advantage for PHA-producer bacteria, allowing the selection of cultures with constant and high accumulation capacity.

3 PHA ACCUMULATION AND EXTRACTION PHASE

The accumulation of PHAs takes place inside a second reactor (0,2m^3), where the biomass of PHA-producer bacteria, produced during the selection phase, is subjected to the feeding of the carbon source (fermented milk whey) in fed-batch mode. The fed-batch culture (feeding close system) allows to extend the growth time of cells before reaching the stationary state. Soil is continuously added to the culture, until the achievement of the maximum content of PHAs inside the bacterial biomass.

Through a timely monitoring of process parameters like temperature, oxygen quantity and reaction times, it is possible to manage modes and quantities of bacteria PHA-accumulation. In particular, the growth time of biomass and polymer accumulation has been optimized, as well as the fermentation process of milk whey to transform lactose in simpler sugars like glucose and galactose. This activity allows production yields with maximum percentage of stored PHAs, accounting for 70% of bacterial cell weight in absence of nitrogen, phosphorus and oxygen. The usage efficiency of lactose from bacteria is monitored through the analysis of its disappearance in the culture.

Once the accumulation phase is concluded, PHAs are extracted from cells and purified using non-toxic and chemically characterised solvents. The cell wall is broken (cellular lysis) at room temperature, by dipping bacteria in distilled water thus producing a cell swelling and successive break.

Once outside the cell PHAs are separated through centrifugation, sedimentation and filtration. Granules are washed with non-toxic solvents and separated from cellular residues. The broth separated from granules can be used as potential fertilizer or sent to anaerobic digestion plants for energetic valorisation. The washed and dried polymer is transformed into white powder, which is melted, extruded and converted in pellet, workable as conventional plastics.

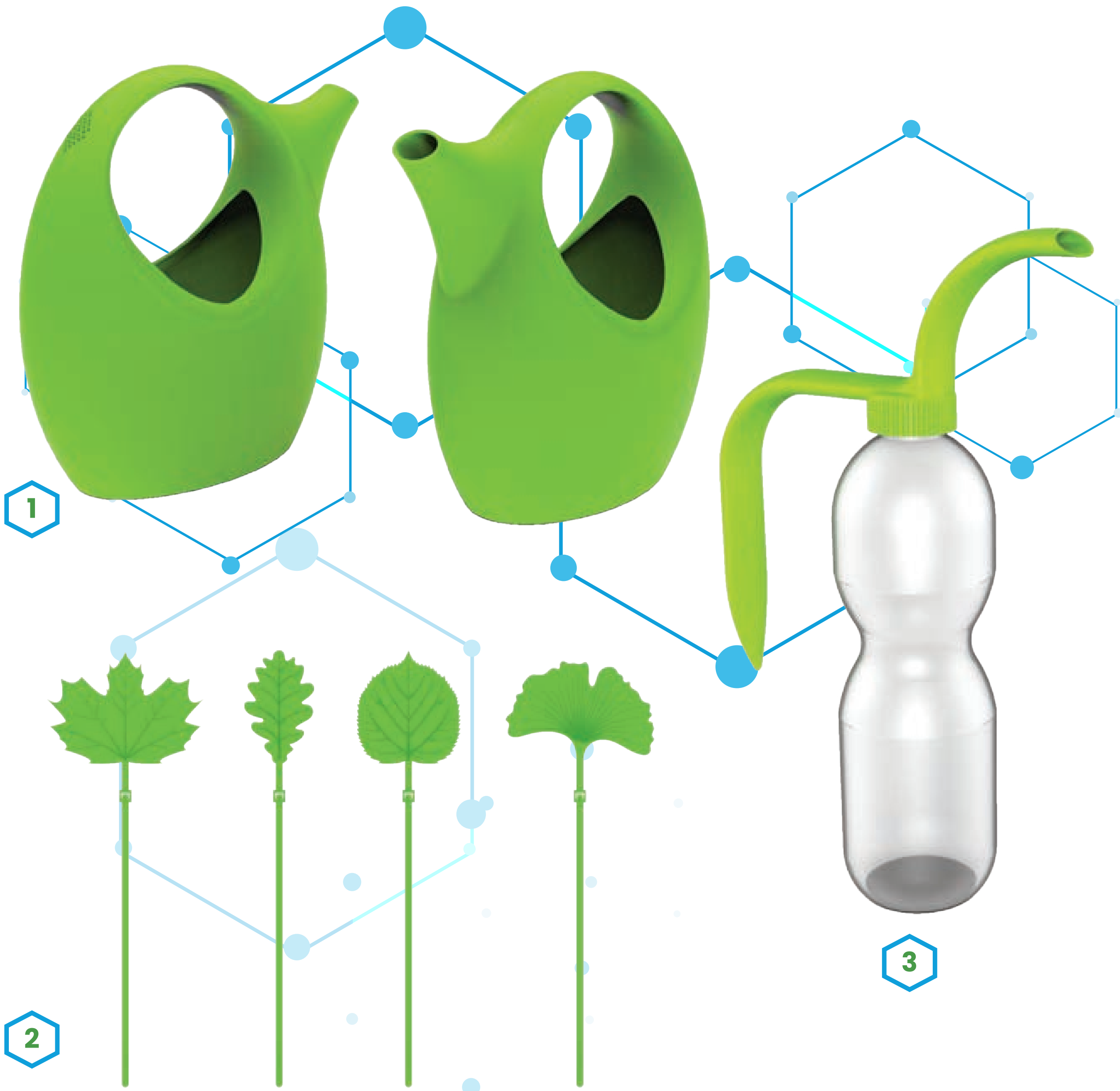
4.4 COMMERCIAL APPLICATIONS OF PHA

In the last decade PHA applications have increased exponentially and the main fields of application are the industrial, medical and agricultural sectors.

The potential applications include commercial packaging (Bhardwaj et al., 2014; Bugnicourt et al., 2014), agricultural purposes (Akaraonye et al., 2010) and medical uses (Dinjaski and Prieto, 2015; Moze-jko-Ciesielska and Kiewisz, 2016), tissue engineering and bony plates production as well as surgical sutures.

In agriculture, PHAs are widely used for mulching fabric production; an example is that of Nodax™, produced by Procter & Gamble and used for biodegradable film production.One of the most important applications of biopolymers in agriculture is the gradual release of fertilizers and insecticides. Fertilizers and insecticides are integrated into PHA pellet and sown together with cultures. Gradually, bacteria degrade the polymer and the substance is released (Philip et al., 2007).

Although the hope is that PHAs can eventually replace conventional plastics, the main limit to PHA application is their production cost, that is currently prohibitive for all applications, except for medical uses of high value (Keshavarz and Roy, 2010; Chen and Patel, 2012).



Ambrogio Rossari, Antonella Andriani. *From left to right: Watering can, cable ties, funnel, gardening kit*

Furthermore, the cost of carbon substrates is another main obstacle to the industrial production of PHAs and is estimated to be 28-50% of the total productive process (Choi and Lee, 1999; Obruca et al., 2015).

To overcome this problem, various kinds of waste have been analysed for their suitability to be used as carbon sources for microbial PHA production, such as those derived from biodiesel (Kenny et al., 2012; Escapa et al., 2013), municipal wastewater (Rahman et al., 2014) and agroindustrial waste (Linton et al., 2012).

To date, food waste is the best candidate as inexpensive carbon source, thanks to its wide availability. Its use could improve the circularity of economy, by ensuring the re-entering of waste materials in the production of other supply chains supporting the creation of high added-value products.

In the context of the PHA-STAR project, in collaboration with the Design Studio Rossari & Associati sas, 5 prototypes of eco-design artefacts have been developed and designed for gardening applications.

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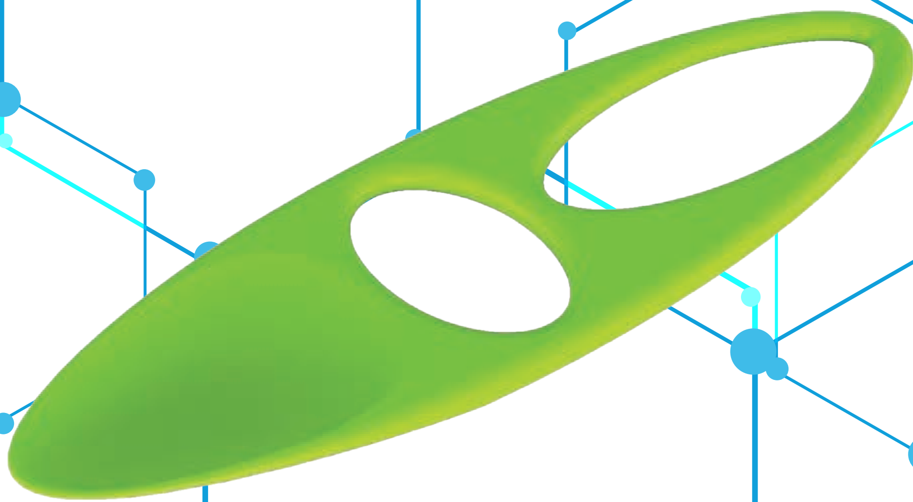

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CONCLUSIONS

The Lombardy Region has been the first Italian region to equip itself with a legislation in support of research and innovation and, through the drafting of a Three-year Strategic Programme, over €250 million have been deployed, using own funds, the European Regional Development Fund (ERDF) and the European Agricultural Fund for Rural Development (EAFRD). The vocation to innovation translates into a constant commitment towards a sustainable development able to consider the environmental, social, and economic dimensions of growth.

The creation of new sustainable production chains is part of this commitment and, in the matter of bioeconomy, the affirmation of an industrial sector based on the valorisation of biological resources is the first step towards a sustainable and integrated ecosystem.

The Lombardy Region holds a quarter of the national production value of biodegradable and compostable plastics, with a production value of €264 million and employing 700 workers. These data are a marker of an innovative entrepreneurial community open to the valorisation of locally available biomasses.

Indeed, the Lombardy Region occupies a leading position in the agro-food sector, from which reusable biomass is sourced, with over 60,000 companies present on the territory and 140,000 employees.

The use of secondary materials of agro-industrial origin ensures the reduction of waste production along the supply-chains and an underexploited industrial potential on the Lombard territory. Among the considered agrifood sectors for bioplastic production, the dairy sector is among those with a major potential impact on the Lombard territory, with the production of over 44% of Italian milk and the generation of large quantities of milk whey, which, to date, is an underused resource.

This study aims to demonstrate the potential of the Lombard supply chain for biodegradable plastics, starting from the industrial model proposed by the PHA-STAR project, which demonstrated the sustainability of a new supply chain, through the meeting between the agro-industrial and design fields.

The reported case studies are proposed as virtuous examples of circular bioeconomy, enhanced at interregional level thanks to the Lombardy Green Chemistry Association, coordinator of the Bioeconomy Pilot within the Vanguard Initiative.

This study is intended to contribute to the implementation of instruments for the industrial potential evaluation on the territory, to be integrated in the regional Smart Specialisation Strategy as well as in the Three-year Strategic Programme, in which circular economy occupies a strategic role for the competitivenss of our territory.

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