Preface

> '*The great problem of packaging, which every experienced chemist knows, was well known to God Almighty, who solved it brilliantly, as he is wont to, with cellular membranes, eggshells, the multiple peel of oranges, and our own skins, because after all we too are liquids. Now, at that time there did not exist polyethylene, which would have suited me perfectly since it is flexible, light and splendidly impermeable: but it is also a bit too incorruptible, and not by chance God Almighty himself, although he is a master of polymerisation, abstained from patenting it: He does not like incorruptible things*.'

I find this extract from Primo Levi's book '*The Periodic Table*', the best introduction to biodegradable polymers.

The durability of conventional plastics is a serious environmental drawback when these materials are used in applications with little probability of recycling, when recycling happens to be too expensive, or when plastics have a high probability of contaminating the natural environment or organic waste. In these, and only in these applications, biodegradable polymers really make the difference.

Biodegradable polymers must not be a simple replacement for traditional plastics. They must be used as an opportunity to redesign applications by focusing on the efficient use of resources and tending towards the elimination of waste, by transforming local issues into business opportunities and by developing a systemic vision to counterbalance the management culture that has contributed to the dissipative growth model we are now living in.

The fundamental criterion needed to avoid any aggravation of this situation, and indeed to reverse the trend, is the efficient use of resources, being aware that only a type of growth which could restore its central focus on local areas, a knowledge economy, the cascading model, and the absence of waste and rejects, will lead to continuous and harmonious growth.

A similar approach requires the selection of standards which have to go beyond products and towards systems. The objective should not be to maximise market volumes but to boost local regeneration from an environmental, social and economic viewpoint, promoting a cultural leap towards a system-based economy and shared trust among the different stakeholders.

For this purpose, the quality rules for biodegradable polymers have to be strict and guarantee, besides compostability and biodegradability in different environments, nontoxicity of products and additives, as well as a low environmental impact throughout the life cycle, with improving targets in terms of raw material quality and renewability level, feedstock sustainability, inuse efficiency and end of life options to close the loop.

Over the past 30 years, increasing effort has been dedicated to developing polymers designed to be biologically degraded in selected environmental conditions. In particular, industrial research has focused on discovering and developing biodegradable polymers that are, at the same time, easily processable, exhibit good per-

https://doi.org/10.1515/9781501511967-203

formance and are cost-competitive (considering both internal and external costs) with conventional polymers. When bioplastics are biodegradable according to European Norms 13432 – the European reference for the technical material manufacturers, public authorities, composters, certifiers and consumers – or its equivalents the American Society for Testing and Materials D6400, or International Organization for Standardization 14855, they can, besides other disposal options, be organically recycled through composting. Such characteristics, when composting infrastructures are available, may therefore represent a significant advantage in sectors like waste collection, catering or packaging which have a high probability of being contaminated by food, or ending up in organic waste or nature: in such cases, organic recycling must be preferred to mechanical recycling. The property of a plastic to biodegrade in household compost permits its disposal in widespread composting infrastructures, at the same time optimising the quality of organic waste and maximising its diversion from landfill. The ability of a plastic to biodegrade *via* composting is also proof that its chemical structure is intrinsically biodegradable.

Significant literature shows that the most widespread compostable bioplastics, currently available on the market, are also able to fully biodegrade in soil and even in the marine environment or through home composting. A range of standards are also available to certify the behaviour of these bioplastics in many different environments.

The present volume reviews the most important achievements, the programmes and approaches of institutions, the private sector and universities to develop biodegradable polymers, and it explores their potential in depth. The volume covers: the most relevant biodegradable polymers of renewable and nonrenewable origin, the present business situation, a review of the main studies on their environmental impact and a critical analysis of the methodologies involved, the potential of new areas such as biocatalysis in the development of new renewable building blocks for biodegradable polymers, the expansion of the biorefinery concept towards integrated biorefineries, and the main policy and funding initiatives recently undertaken at the European Union (EU) level to foster the innovation capacity in Europe and to favour the market entry of innovative biobased and biodegradable products. It also takes into consideration aspects related to the biodegradation of these polymers in different environments and the related standards and case studies (including the interactions of biodegradable items with different anaerobic digestion technologies), showing their use in helping to solve specific solid waste problems.

The demand for biodegradable polymers has steadily grown over the last 10 years, at an annual rate of between 20–30%, in regions where composting infrastructures are well developed and the separate collection of organic waste is well established. Wherever the separate collection of biowaste is in place (and this is an unwavering trend in the EU), all the traditional short life pollutants of organic waste (when it is with polyethylene, renewable or not) are critical, because they are not biodegradable. The *organic recycling of biowaste requires plastic-free streams* in order to assure high recycling rates.

The existing link between the increasing use of biodegradable polymers and the efficient infrastructures for organic recycling and the separate collection of organic waste can be perceived as a limitation to the fast growth of this class of material. Instead it represents a unique opportunity to reconnect the solution of long-lasting environmental problems to local growth and regional regeneration putting into practice the knowledge-based economy.

The Italian case study presented in the book curated by Walter Ganapini '*Bioplastics: A Case Study of Bioeconomy in Italy*' shows how biodegradable polymers can be a powerful catalyst for the activation of local area regeneration. The book is dedicated to the Italian approach for resolving the problem of disposable carrier bags. It is all about transforming a category of waste which presents extremely critical issues (high surface area-volume ratio, large number of articles produced, the fact that the bags, if dispersed, cannot be reabsorbed into the environment, and marine pollution) into an opportunity, in order to solve an even more pressing problem; that of organic waste being sent to landfill.

A small number of disposable carrier bags, if coupled with reusable bags, and made from biodegradable, compostable plastics, can be reused as valuable resources in organic waste collection. This makes them a powerful and important means of intercepting organic waste, with no expense required from local councils, helping to achieve the objective of improving the quantity and quality of organic waste: a feedstock that is important for the future development of the bioeconomy, and for the fertility and quality of soil. Being able to count on a niche market (which is already of significant size), facilitates achieving economies of scale for biodegradable polymers, resulting in increased possibilities to build integrated local biorefineries dedicated to medium-high value-added products, demonstrators and flagships required not only for biodegradable polymers but also for a range of related building blocks and agricultural chains as a whole. This will also generate new opportunities for traditional chemistry, by laying down the foundations for the redevelopment and environmental upgrading of deindustrialised chemical plants.

The change in the perception of biodegradable polymers is evident by simply considering the trends from 1989 to 2012 in the fields of 'biodegradable' (+2,800% for scientific literature and +1,100% for the sum of World Intellectual Property Organization (WIPO) patents, European patents (EP) and United States (US) patents) and 'biodegradable plastics' (+1,400% for scientific literature and +4,200% for the sum of WO, EP and US patents).

The opportunity to utilise renewable raw materials (RRM) in the production of some of these biodegradable polymers and to reduce the dependency on foreign petroleum resources, along with the exploitation of new functional properties in comparison with traditional plastics, has significant benefits. Besides biodegradability, the technical developments made during the research process could have significant advantages for the final consumers and could contribute to the solution of technical, economic and environmental issues in specific market areas.

RRM as industrial feedstocks for the manufacture of chemical substances and products, such as oils from oilseed crops, starch from cereals and potatoes, and cellulose from straw and wood, as well as organic waste, have therefore been given more and more attention over the last few years. By employing physical, chemical and biochemical processes, these materials can be converted into chemical intermediates, polymers and speciality chemicals able to replace fossil feedstocks, thus implying less energy involved during production and a wider range of disposal options resulting in a lower environmental impact.

Legislative attention able to properly address this issue could become a further incentive to the development of products from RRM and maximise the environmental, social and industrial benefits.

Biobased products were, in fact, one of the six sectors included in the 2007 'Lead Market Initiative' of the European Commission (EC), with the aim of fostering the emergence of such lead markets with high economic and societal value, focusing on areas where coordinated policymaking can speed up market development [1]. More recently, in February 2012, the EC launched a new 'Bioeconomy Strategy' [2], focusing resources and investments in the strategic sector of biobased products, in order to shift Europe towards a greater and more sustainable use of renewable resources.

In addition, in July 2013, the EC encouraged the creation of a public-private partnership of Biobased Industries. It includes approximately 70 full members (EU large and small companies, clusters and organisations) and more than 100 associated members (universities, research and technology organisations, associations, European trade organisations and European technology platforms) from the fields of technology, industry, agriculture and forestry, with the shared commitment to invest in collaborative research, development and demonstration of biobased technologies.

A supportive and coordinated European strategy for an increased market uptake would help many biobased products, among them biodegradable biopolymers, to accelerate reaching economies of scale, in order to attract investments and generate sustainable economic growth. The EU bioeconomy already has a turnover of nearly €2 trillion and employs more than 22 million people, 9% of the total employment in the EU. Each euro invested in EU-funded bioeconomy research and innovation, with a coherent and incentivising framework, is estimated to trigger €10 of added value in bioeconomy sectors by 2025 [2]. It is also estimated that this growth will be enhanced with the development of the model of integrated biorefineries for the production of high value-added products, such as biobased chemicals and materials. Biorefineries will process a variety of biomass-based feedstocks, and the necessary growth in biomass production is expected to increase the turnover and employment of the seed sector by 10%, resulting in 5,000 extra jobs [3].

The significant increase in the importance of innovative biopolymers is linked to the achievement of high-quality standards.

The quality of biodegradable products is assured not only by the control of the biodegradability parameters but also by the assessment of real functionality. A biodegradable product is useless if it does not perform as a traditional product or better in terms of mechanical resistance, duration and so on. For this reason, the commitment of producers of biodegradable biopolymers in the creation of a quality network able to guarantee the standards of the product, in all the steps of the life cycle, becomes very relevant.

The elaboration and diffusion of best practices in the field of organic waste collection, where the use of biodegradable compostable bags is a tool to improve the quality of the system, has for example, permitted thousands of municipalities all over Europe to implement the proposed model. In fact, it has been demonstrated that, despite the heterogeneity of anaerobic digestion technologies and processing conditions, an efficient and optimised treatment of municipal biowaste, collected with compostable bioplastic bags, allows preserving the advantages given by the bags in the collection phase and to secure the most efficient treatment of the collected feedstock enabling the highest input and minimum production of residues.

The cooperation with public bodies is also a key factor in the success of biodegradable biopolymers, because the topics under discussion are strictly related to public interest, such as safety, environment and health.

The implementation of appropriate environmental policies in key areas (like waste collection) can become a further incentive to the development of products from RRM and can maximise the environmental, social and industrial advantages. Together with the intensification of investment, as well as research and development actions in the biodegradable polymers sector, it would be possible to create a network of partnerships among stakeholders of the entire supply chain, from agriculture to waste management, and thereby promote new models of development towards higher levels of sustainability and cultural growth.

Today, biodegradable biopolymers are available on the market, at different levels of development, and are mainly carbohydrate-based materials. Starch can be physically modified and used alone or in combination with other polymers, or it can be used as a substrate for t h e fermentation and production of polyhydroxyalkanoates or lactic acid, is then transformed into polylactic acid through standard polymerisation processes. An alternative option is represented by vegetable oil-based polymers.

Despite the constant growth of the market, the land use for bioplastics currently represents just 0.006% of the global agricultural area (which means around 300,000 ha out of 5 billion ha) and it is expected to rise to 0.022% by 2016 (that is, 1.1 million ha). Meanwhile, the increase in the efficiency of feedstock and agricultural technology is continuously enhancing good agricultural practices [4]; moreover, recent trends have focused on the use of marginal lands or contaminated soils and residues.

The increasing use of bioplastics has opened entirely new generations of materials with new performances in comparison with traditional plastics. The possibility offered by physically modified starch to create functionalised nanoparticles able to modify the properties of natural and synthetic rubbers and other synthetic polymers, the naturally high oxygen barrier of starch and its derivatives, and their high permeability to water vapour already offer a range of completely new solutions to the plastic industry.

The use of RRM, however, is not by itself a guarantee of low environmental impact. Aspects such as the production processes, the technical performance and the weight of each final product, and its disposal options, have to be carefully considered along all the steps of the product's life. The engineering of biobased materials for specific applications using life cycle analysis in a cradle-to-grave approach is therefore a critical aspect.

The involvement of upstream players, that is farmers and their associations, is a very important prerequisite. In agriculture, new agronomical approaches and the development of new genotypes for nonfood applications should be taken into consideration. Agricultural crops and processes associated with lower environmental impact and lower costs are important factors in the development of new biobased products.

Effort must also be made at the industrial level in order to develop less expensive and higher performance products and low- impact technologies. Policies should therefore be focused more on supporting innovation and scale up of new technologies which can create solid added value and are capable of responding to the societal challenges faced by our planet.

The involvement of specific stakeholders can be achieved if a communication programme is launched and operated in parallel with industrial activities. The success of the project is very much linked to the diffusion of a new environmental awareness, at all levels: politicians, public administrators, investors, associations, customers, non-governmental organisations (NGO), citizens and society at large, all of them must be reached by specific communications, in order to initiate a comprehensive and coherent sustainable strategy, with positive effects in the local areas involved.

This, in turn, must give rise to specific legislative actions in order to quantify the social and environmental benefits linked to the nonfood use of agricultural and natural raw materials, and to the bioconversion of waste materials into industrial products.

References

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