Bioeconomics in solving environmental problems

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Abstract. Biotechnology is defined as any technological application that uses biological systems, living organisms or their derivatives to produce or modify products or processes for a specific use. The large-scale use of biotechnologies in industry, agriculture, as well as in many other types of economic activity is considered in many countries of the West (USA, Germany, France, Great Britain, Italy, etc.) and the East (China, India, Indonesia, Japan, etc.) as the most important condition for innovative and sustainable development. The progress achieved made it possible to consider the created biotechnologies as the basis of a new field of activity - bioeconomy.

1 Introduction

Since the beginning of the 21st century, and especially in the second decade, significant changes in the environment have been noted, which are obviously due to various anthropogenic causes [1-2]. First, the widely recorded and dangerously high pollution of the aquatic environment on Earth, which spreads from the effluents of industrial enterprises into rivers and to the oceans, is associated with human economic activity. Appropriate approaches and biotechnologies are being proposed and continue to be developed to address the problems of wastewater treatment and pollution of water sources, which contribute to the development of the bioeconomy. Secondly, agro-industrial and domestic wastes accumulating with increasing intensity have a significant impact on the environment. Work on the creation of effective biotechnologies for the disposal of such waste has led to the creation of specialized enterprises, which, in turn, has actually become an important direction in modern bioeconomy. Thirdly, in thousands of publications, including reviews, an increase in negative climate change has been noted. It is believed that anthropogenic greenhouse gas emissions may play a key role in such changes. Thus, according to the estimates given worldwide, greenhouse gas emissions (CO2, CH4 and N2O) in the agricultural sector increase by about 1% per year and, in addition, deforestation, in turn, gives an increase of 12-17% of the total amount. greenhouse gases. Materials of a number of studies indicating that the work in the field of bioeconomics can open the way to solving climate problems [3].

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It is widely known that since the beginning of the 21st century, pollution of the aquatic environment on Earth has been accelerating, which creates a number of global environmental problems. A somewhat complete consideration of these problems and the approaches being developed to solve them, of course, cannot be carried out within the framework of this monograph, but it seemed appropriate to note some related issues that have significant bioeconomic aspects below. Firstly, since the second half of the 20th century, the problem of pollution of the aquatic environment with plastic waste has become of particular concern, and its relevance in the 21st century has grown significantly. The level of plastic waste released into the ocean is shown in Figure 1.

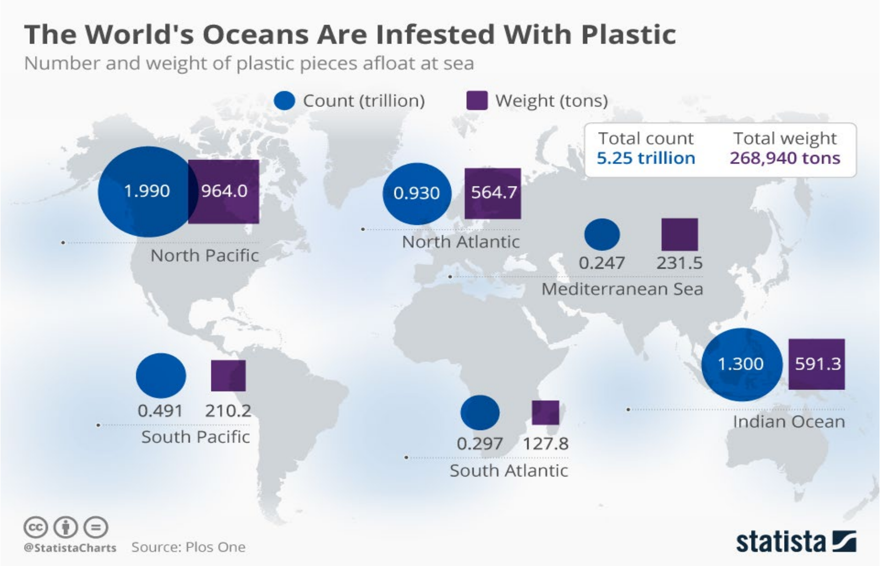

Fig. 1. The World's Oceans Are Infested With Plastic

If at first certain pieces of plastic were found in the stomachs of seabirds and in the bodies of other marine life, as well as in coastal areas, then after the impressive publication of Richard Thompson and co-authors in the journal Science, the term "microplastic" began to be actively used in the scientific literature. These authors studied pollution of the marine environment by a special plastic debris, which is actually microscopic in size, is present in bottom sediments and is very resistant to biodegradation [4]. Moreover, in model experiments, it was shown that many marine life are able to absorb this plastic with food. Thus, it became clear that microplastic pollution of marine waters is a serious global environmental problem. Currently, the term "microplastic" refers to any plastic particles with a diameter of 3 mm to 5 mm, and in addition, "nanoplastic" is distinguished - plastic particles with a diameter of 1 to 100 or 1000 nm. There is no doubt that these pollutants are formed from a wide variety of plastic industrial and domestic waste, which, as a result of anthropogenic activities, are present in many ecosystems. Currently, despite significant efforts to prevent the accumulation of microplastics and nanoplastics in marine waters, the spread of these pollutants continues rapidly. In particular, the high relevance of this problem is based on information about the almost universal presence of microplastics: in sea, river and lake water, in groundwater, in tap water, in bottled drinking water. It has been shown that microplastics and nanoplastics are already entering the human body from drinking water, many foods, and possibly even with inhaled air.

2 Research Methodology

Naturally, issues related to the effects of microplastics / nanoplastics on humans are of particular attention and interest. So, in 2021 and 2022 alone, 602 and more than 900 articles were published with the keywords “microplastics + human” based on the materials of the PubMed database, respectively. So, in the review of Ageel H.K. et al. (2022), based on the analysis of more than a hundred publications, it was concluded that microplastic / nanoplastic particles can enter the human body not only with water and food, but also by inhaling polluted indoor air. Recent reviews by a number of authors have discussed the mechanisms behind the toxic effects of microplastics/nanoplastics and in particular have raised concerns about the possible leaching of toxic chemicals used as additives to plastics (eg plasticizers and fire retardants) [5]. However, all these authors point to the need for further research on this issue in order to provide the knowledge base necessary to create regulations to protect human health and the environment from microplastics / nanoplastics. However, there is no doubt that these pollutants are formed from a wide variety of plastic industrial and domestic waste, which, as a result of anthropogenic activities, are present in many ecosystems. In addition, according to existing ideas, microplastics can persist in the environment for many years due to high chemical inertness and resistance to biodegradation. The impressive growth of attention to this problem is clearly evidenced by the publication activity indicators for the five years 2018-2022, shown in Fig. 2, which reflect the material available in the ScienceDirect database.

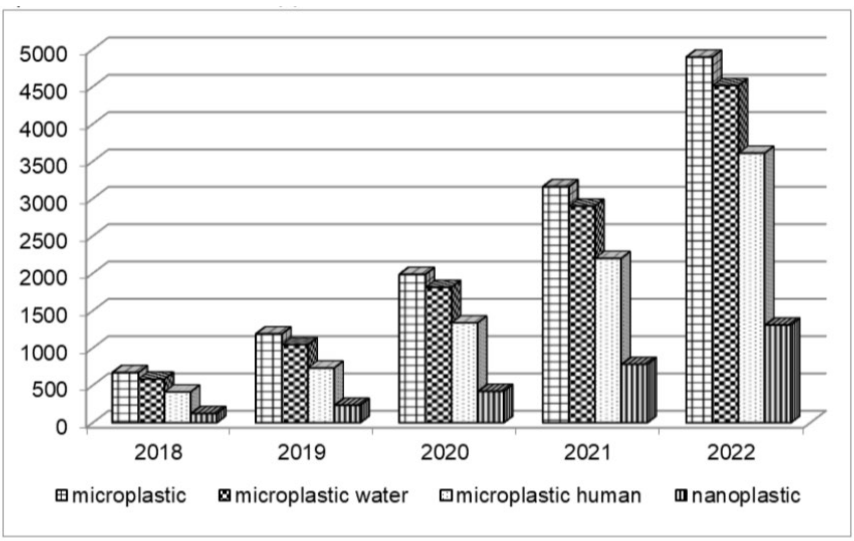

Fig. 2. Dynamics of publication activity for the five-year period 2018-2022, according to [ScienceDirect database]

There are reasons to believe that bioeconomics and bioengineering can have a targeted impact on the situation with the accumulation of microplastics / nanoplastics [6]. First, since the ability of some insects, bacteria and fungi to absorb synthetic polymers and convert them into environmentally friendly carbon compounds has been discovered, active work has begun to create appropriate effective technologies. In particular, it was noted that recent biotechnological advances, such as biostimulation, bioaugmentation, and enzymatic biodegradation, could find application in the removal of microplastics. Although there is still much to be done in this direction to reach a large-scale level, some authors, when considering the existing difficulties, write with a certain optimism about the possibility of overcoming them. For example, the title of one of the articles cited above characterizes the current situation very figuratively - "Biodegradation of microplastics: better late than never." Secondly, bioengineering (and then bioeconomics) can be essential for the problem under consideration, solving the problems of creating biodegradable polymers and gradually replacing them with the ubiquitous conventional synthetic plastic. Already in the first decade of the 21st century, the production of biodegradable polymers was seen as a promising way to solve the problem of environmental pollution with plastic waste. Such materials (bioplastics) were obtained from renewable raw materials, thereby reducing greenhouse gas emissions and characterized as environmentally friendly. It has been noted that the use of biodegradable plastics has a number of advantages over plastics made from petroleum. Bioplastics have been shown to improve soil fertility as well as reduce waste management costs and appear to be able to be processed into useful metabolites (monomers and oligomers) by microorganisms and enzymes. So, for several decades, various compounds belonging to the group of polyhydroxyalcanoates (“polyhydroxyalcanoates, PHA”) have been used as substitutes for synthetic plastics [7]. It has now been shown that PHAs constitute a structurally and functionally diverse group of storage polymers synthesized by many microorganisms, including bacteria and archaea (Cupriavidus necator, Haloarchaea, recombinant strains of Escherichia coli, some halophilic extremophiles, etc.). It is believed that PHAs are synthesized by specialized polymerases that use various monomers formed during cellular metabolism. Under physiological conditions, storage PHAs are depolymerized in cells by microbial PHA depolymerases for energy. The presence of these enzymes in natural niches also explains the ability to degrade the corresponding bioplastics.

3 Results and Discussions

For the bioeconomy, medium chain PHAs (mcl-PHAs characterized by C6-C14 branched monomeric chains) are commonly produced by strains of Pseudomonas and are considered promising materials with thermoplastic and elastomeric properties (thermoelastomers). It is also known that mcl-PHA can be further modified by introducing functional groups into the side chains. Such "functionalized" PHAs are produced either by using structurally related substrates subjected to beta-oxidation, or by using specific strains capable of converting sugars or glycerol into unsaturated PHAs de novo. "Functionalized" mcl-PHAs provide a bioplastic with modified mechanical and thermal properties that expand its applications in various fields, such as biomedicine. Microorganisms capable of synthesizing PHA and other types of bioplastics are considered as suitable models for developing strategies in which they can be used as cell factories [8]. At the same time, the so called haloarchaea are of particular interest, since some species of these microorganisms turned out to be able to produce compounds belonging to the PHA group in significant concentrations. Thus, it has been shown that the cultivation of certain haloarchaea, both on an experimental and industrial scale, provides several advantages over other bioplastic producers. Recently Simó-Cabrera L. et al. (2021) even presented protocols for the production/analysis of bioplastics using haloarchae on an industrial scale, producing a number of valuable products and minimizing environmental pollution from petroleum-derived plastics. Among the most promising representatives of PHA, significant attention is paid to polyhydroxybutyrate. It has been shown that this biocompatible and non-toxic polymer is synthesized and accumulated in specialized bacterial strains. It should be noted that polyhydroxybutyrate has been found to have desirable thermoplastic and mechanical properties, due to which it is already used in various fields of human activity, including biomedicine, fine chemicals, drug delivery, packaging and agriculture. At the same time, polyhydroxybutyrate can be biodegraded in certain active biological media, which is why some authors consider it a potential replacement for petrochemical polymers, in particular, such as high density polyethylene [9]. However, high production costs, the complexity of the production technology and the difficulties associated with the subsequent processing of polyhydroxybutyrate still remain, which together limit its role in the bioeconomy and market presence. Since the end of the 20th century, in the interests of bioeconomics and biomedicine, polylactides (polylactide, PLA) - polymers of lactic acid (2-hydroxypropanoic acid) and their various derivatives - have been studied as biodegradable plastics. PLA is characterized as biocompatible, thermoplastic polyesters, raw materials for the production of which are agricultural products such as corn, sugar cane, etc. The structural formula of PLA is shown in Fig. 3.

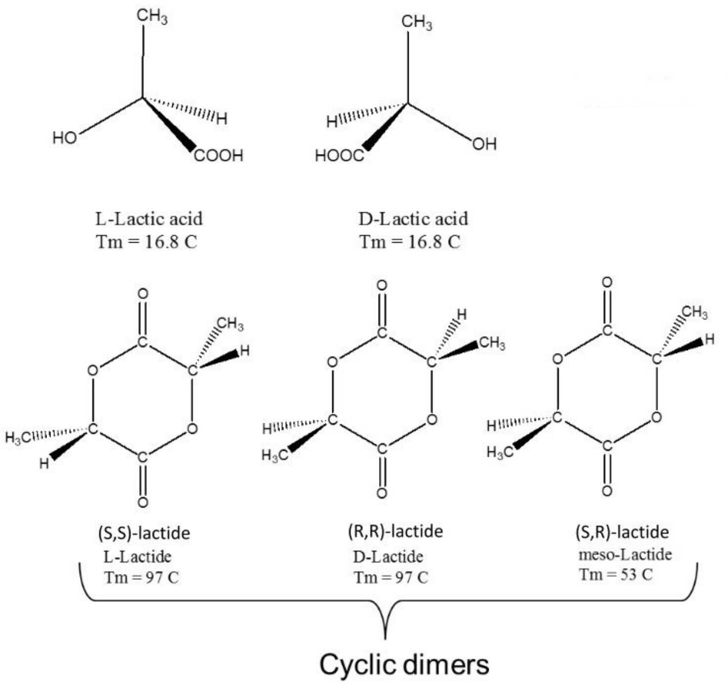

Fig. 3. Polylactic acid: structure, properties and uses

As one of the approaches to reduce the cost of production of biodegradable plastics, it was proposed to use the combination of this task with the production of other valuable chemicals. Thus, the successful co-production of PHA representatives with amino acids, some proteins, alcohols, hydrogen, biosurfactants, exopolysaccharides and other products has been demonstrated. It is important to note that many authors define the term "biodegradation" as the processes of mineralization of organic material by microorganisms (for example, fungi, archaea and bacteria) [10]. This should eventually lead to the formation of end products under aerobic conditions - water and carbon dioxide, which is a greenhouse gas. However, in the case of incomplete mineralization, the so-called biotransformation occurs, as a result of which various organic metabolites or transformation products are formed, suitable for use in a circular economy (economy based on renewable resources, "wasteless", circular). Thus, several strategies and related biotechnologies have now been developed, which allow us to hope that on the basis of bioeconomy in the near future it will be possible to overcome many problems associated with anthropogenic environmental pollution and, in particular, pollution of the aquatic environment with plastic waste.

4 Conclusions

Environmental problems are turning into one of the priority issues of international relations, along with international security and economic development. The coronavirus pandemic has only exacerbated this trend. One of the main strategic projects for the development of the European Union for the coming decades is the European Green Deal, which aims to achieve carbon neutrality by 2050. Even if this ambitious initiative is not fully translated into the proclaimed parameters, it is seen as a way both to get the EU out of the current economic crisis and to strengthen the EU's competitive position for the foreseeable future. In the United States, the Joseph Biden administration sees climate change as one of its top domestic and foreign policy priorities, and making the United States a leader on the climate agenda is an important way to restore American “global leadership” as a whole. Probably, already at the beginning of the Biden presidency, the goal of achieving carbon neutrality by 2050 will be announced. China has also begun to play an important role in the global environmental and climate agenda in recent years and has announced its intention to become carbon neutral by 2060. The issues of protecting the environment and combating climate change occupy an important place in the work of key institutions of global governance, including the G20 and BRICS.

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