NO limits

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A Planet to Recover

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NATURE
Does not Create Unnecessary Things

Zero waste is an idea challenging our way of thinking and functioning in the environment. It draws our attention to the fact that human activity should be associated with the responsibility for our lives and for the impact of our activities on the planet. The premise of zero waste is to minimize waste and to reuse the products we buy. Due to the fact that we use environmental resources, it is worth remembering that everything which is bought and consumed becomes waste. Hence, the emphasis on changing our habits and lifestyle is so important, but most of all it limits excessive consumerism.

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American biologist Barry Commoner formulated four laws of ecology in his 1971 book *The Closing Circle: Nature, Man, and Technology*. The second law states: "Everything must go somewhere." This is how our planet works – everything that is created is a source of energy and matter for another being. For example, carbon dioxide released by animals is essential for plants, whereas oxygen released by plants is detrimental for animal life. Nature does not create unnecessary things, and nothing is wasted in nature.

"The human species often misuses its wisdom. We have learned to create unnecessary things," says Prof. Piotr Skubała, a biologist at the University of Silesia, ecologist, environmental ethicist, popularizer of science, ecology educator, environmental conservationist, and climate activist.

A disturbing signal pertaining to our attitude to waste is its continuously growing amount. Currently we throw away 332 kg of waste annually per person. The average amount of municipal waste in Europe in 2018 was nearly 500 kg per inhabitant. In Denmark this figure was as much as 800 kg, in Norway and Switzerland – about 700 kg. Waste management on a national scale is not at its best, either. In total, 25% of our waste is recycled, 9% composted and fermented, 23% incinerated, and 43% finds its way to landfills.

Waste separation lulls our conscience. Research shows that people feel bad if they create unnecessary waste, and their well-being improves when they have the ability to recycle. This self-perception is becoming so positive that we buy an increasing number of products and throw away even more waste. This is demonstrated by an experiment conducted on a group of Boston college students, who were offered four different juices to taste. They had to pour these drinks themselves into disposable cups. A regular trash can was placed next to one group, and a plastic recycling garbage can next to the other group. Students who had the option to separate waste used an average of 3.5 cups; the rest used only 2.7 cups. Therefore, we use more if we know that the resources used will be recycled. However, we forget that the recycling process also uses environmental resources and energy. Above all, we should emphasize the rather high cost of recycling as well as the need to reduce the consumption of resources and to minimize the amount of things that each of us buys and throws away.

PLASTIC PLANET

Plastic is, of course, a classic example of human-made waste. It is a product that is literally flooding our planet, and nature has no tools to remove it.

In all parts of the world, the year 2020 will certainly be remembered as the year of the pandemic, but we should also bear in mind another aspect which pertains to it. This was the year when the amount of anthropogenic mass, the so-called anthropomass (mainly concrete, aggregate, e.g. gravel, but also bricks, asphalt, metals, waste, glass, plastic) equaled the amount of biomass on Earth.

As recently as the beginning of the 20th century, anthropogenic mass accounted for merely 3% of global biomass. About 120 years later, it began to dominate over the mass of living organisms. Since the 1970s, we have seen its exponential growth which doubles every 20 years. The mass of plastics (8 Gt) is now twice as high as the mass of animals. The mass of buildings and infrastructure (1100 Gt) is already higher than the biomass of trees and shrubs on the planet (900 Gt). On Earth, we have 1 km of concrete per square meter of the planet, including the oceans. Unfortunately, the forecasts for a further increase in the anthropogenic mass are not optimistic. If after the pandemic we continue to do *business as usual*, by 2040 this mass (including waste) will be three times the biomass on Earth.

The zero waste idea also calls for limiting consumerism. Of course, the level of consumerism is particularly high in rich countries or societies. However, this does not mean that there are no waste problems in poorer countries – quite the contrary. What is this paradox about? In richer countries, a certain amount of waste is recycled, while in poorer countries, mainly in Asia and Africa, there is hardly any control over waste, and barely any recycling takes place. Most of the plastics that end up in the oceans (because that is their final destination) come from countries such as China and India. The current situation in the world is that 9% of the plastics we have produced has already been recycled, which means that with about 90% nothing has been done, and it is located probably somewhere in the oceans. In Poland and in the European Union in general, the situation is a bit better, since we recycle about 30% of plastics, but this is not much either.

THERE IS WASTE OTHER THAN PLASTIC

We focus on an individual approach to waste and recycling, and this solves the problem of waste on a global scale merely to a small extent. As it turns out, industrial waste accounts for about 91% of waste generated in Poland. Mining (56%), manufacturing (24%), energy (12%), sewage and waste management (5%) and construction (3%) produce the most. As much as 45% of industrial waste remains on landfills. It includes all sorts of chemicals, including toxic ones, which are created as a byproduct of manufacturing processes.

Therefore, the economy must be radically transformed. Unfortunately, it is linear economy based on the principle "take, produce, consume, throw away" that currently prevails. We should strive to turn it into circular economy, a concept which says that products, materials, and raw materials should be left in economy as long as possible and waste generation should be minimized. In circular economy, it is essential that waste, after being produced, is treated as secondary raw materials.

THE APOCALYPSE

There are numerous predictions by scientists according to which the apocalypse is drawing nearer. One vision was created by Chilean computer scientists who work with mathematical simulations. They took into account one factor – deforestation – and calculated that at the current rate, human civilization will be annihilated in 20-40 years. Algorithms also calculated the chance that the human species will survive this apocalypse, and it turned out that it amounts to 10%.

We are living in a period of great species extinction. In a 2016 article in the journal *Nature*, scientists pointed out 10 factors of human activity that contribute to this situation ["The Ravages of Guns, Nets, and Bulldozers." Maxwell S.L., Fuller L.A., Brooks T.M., Watson J.E.M. 2016. Nature (536) 2016]. One of the factors is waste, which made it to the 5th place on the list of the so-called big killers. The first place was taken by the exploitation of environmental resources, logging, hunting, fishing, gathering; the second by agriculture, industrial production, farming, industrial livestock breeding; the third by urbanization and infrastructure, i.e. concrete and cement. On the subsequent places we find invasive species and diseases, environmental pollution (including municipal and industrial waste), changes in ecosystems, climate change, direct human activities (recreation, work, war), transport, and energy production.

"We are a civilization that creates artificial things and displaces what is valuable, that is, life," remarks Prof. Piotr Skubała. "Therefore, the idea of zero waste, next to the climate crisis, is now becoming a key issue. We are facing a significant amount of work to raise public awareness with regard to the importance of combating waste. However, it must be emphasized that our individual behaviors are important but not sufficient. Systemic action is needed above all.

On a global scale, we have produced **8.3 billion tons** of various types of plastics, of which **6.3 billion tons** are now plastic waste. Every year, **8 million tons** of plastic waste are thrown into the seas and oceans. It is as if we put 15 shopping nets filled with plastic on every square meter of coastline every year. There are now six great islands made of plastic waste on the surface of the oceans. The largest of these, **the Great Pacific garbage patch**, has an area of **1.6 million square kilometers**. This area is five times larger than the surface area of Poland, six times larger than the area of the UK, or slightly less than the area of Alaska, the largest US state.

Photo: Avigatorphotographer – Freepik.com

THE WORLD WITH AN ADMIXTURE OF MICROPLASTICS

Nowadays, plastic is the most popular synthetic product. Although this material's history is quite short – the first plastic was created in the mid-nineteenth century – its versatility has resulted in huge production around the world. The disposal of plastic waste cannot keep up with its milling, hence the growth of synthetic waste is constantly increasing. By means of their interventions, environmentalists hope to move the consciences of consumers who buy food in plastic packaging and are rather guided by convenience than care for the environment. How many of them actually know how dangerous the plastic that they purchase can be?

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Photo: Olena Sakhnenko (Ukrolenochka) – Freepik.com

British chemist and metallurgist Alexander Parkes worked on increasing the strength of metal alloys in the first half of the 19th century. By including phosphorus in their composition, he managed to achieve the expected result. At that time, rubber was also introduced to the processing industry. Contrary to what it might seem, this material has not been discovered recently, as it was already known to the pre-Columbian Maya and Aztec peoples (it was brought to Europe in the 15th century by Christopher Columbus). With the development of the processing industry in the 19th century, rubber began to increasingly attract attention. Parkes treated it chemically and hoped that it would be used to further his innovative metallurgical patents. In 1846, the inventor managed to mold it into a thin object – it was the first plastic to be discovered, a fact that made the year 1855 special. The real breakthrough, however, came 52 years later when Leo Baekeland developed Bakelite, the first mass-market plastic. From then on, many everyday products had the properties of plastics. Today, there are tiny admixtures of microplastic particles in almost everything.

Synthetic materials, commonly known as plastic(s), are considered to be one group of waste which, according to widely circulating information, decomposes for a thousand years. Although the topic of recycling, waste separation, and the decomposition time of plastics seems familiar, it has become surrounded by many myths and inaccuracies.

There are several groups of synthetic materials, ranging from those that are very well biodegradable to the hardest ones with a decomposition process of hundreds of years. Materials belonging to the latter group are the most problematic, since the question is how to degrade something that is practically not degradable?

“Several factors are responsible for the degradability of synthetic plastics,” says Dr. Bożena Nowak of the Faculty of Natural Sciences at the University of Silesia. “The first of these are polymers, i.e. substances with a very high molecular weight resulting from repeating units called mers. Whether a plastic will decompose depends, among other factors, on the molecular weight of the polymer, the type of mers that make up the polymer, and the chemical bonds. The second most important factor responsible for the decomposition of plastic is the environment it will eventually reach. Seawater, into which a lot of synthetic waste flows, is often unable to completely decompose them. Hydrolysis, or decomposition involving water molecules available to the aquatic environment, photodegradation associated with the action of sunlight and oxygen when waste floats on the surface of water, or mechanical decomposition due to wave impact are mostly insufficient, especially at the low temperatures of these environments, which is why nowadays seas and oceans are such polluted water bodies.”

The terrestrial environment is characterized by more favorable conditions. It has free access to oxygen necessary for decomposition, to water contained in the soil and atmospheric precipitation, and it is characterized by greater temperature variability. Moreover, it has a much greater variety of microorganisms, hence decomposition in the soil is much faster. By far the best environment for degradation is compost. In home compost, plastics should degrade by 90% up to a year, and in industrial compost this process should take no more than 6 months. In industrial compost, the factors supporting decomposition are the most favorable: water, oxygen and a variety of microorganisms, a temperature above 55 degrees Celsius in the initial phase, unattainable in other environments. Does this mean that we can degrade any material in industrial compost? Absolutely not. Only plastics bearing the symbol of a degradability certificate in a given environment can decompose in it. It should also be borne in mind that different requirements must be met by plastic that is susceptible to decomposition in either fresh water, salt water, soil, or compost.

The problem of waste in seas and oceans is very serious. The threat to fish and other organisms is sometimes fatal. According to the International Union for Conservation of Nature (IUCN), the most common sources of primary microplastic release into the oceans are synthetic textiles washed in washing machines, closely followed by microplastic rubbed off from tires while driving, and other dust and urban pollution. Secondary microplastic, in turn, is made from the breakdown of larger pieces of plastic into smaller ones. It accounts for 69%-81% of the microplastics floating in the seas and oceans. The polymer microparticles obtained in this manner range from 50 μm to 5 mm and become parts of sand in the seas and at coasts.

Assoc. Prof. Agnieszka Babczyńska from the Faculty of Natural Sciences at the University of Silesia, a specialist in the ecophysiology of animals in polluted environments, presents the dangers that can occur when fish ingest plastic particles or microparticles with their food.

“Plastic is not digested. Without bacterial symbionts to digest various molecules, including cellulose, organisms of vertebrates and invertebrates cannot digest it. However, even intestinal microorganisms can contribute to the degradation of plastic only to a very small extent. When this material passes through their digestive tract, it damages the active microcosms, either abrading them to a form resembling brushes or causing atrophy of digestive tract epithelium, or even its complete detachment. As a consequence, digestion and absorption are disturbed, and the bacterial flora is changed, making the animals malnourished, weaker, and unable to produce as many offspring as would be the case in healthy animals. Over the years, the population of species weakens and, consequently, disappears.

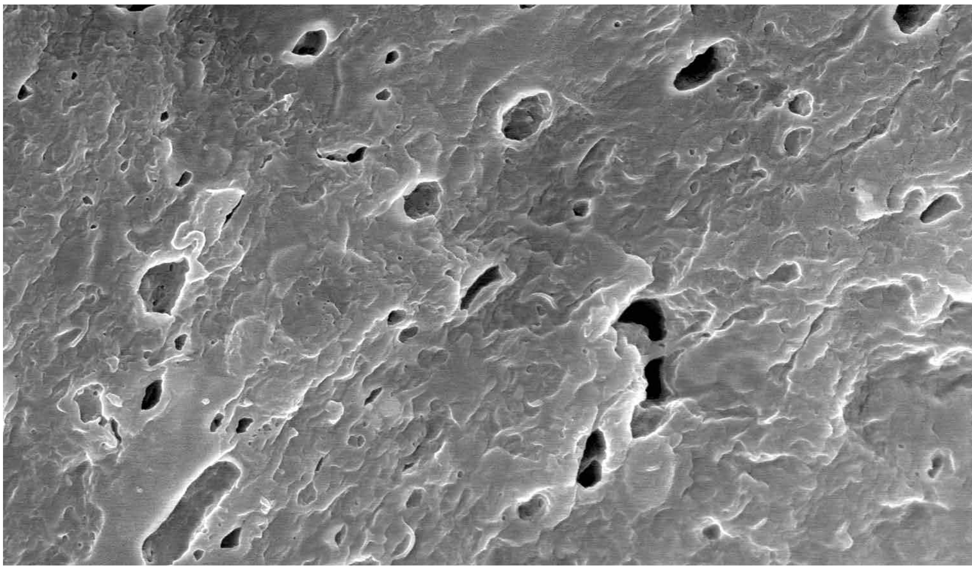
However, unfortunately this is not the end of all problems. Industrial microplastics used as ingredients to enhance elasticity or color contain plasticizers from which, upon decomposition, substances imitating female hormones (hormonomimetics) are released. By ingesting such substances with food, animals are exposed to compounds which, due to their properties, act mainly at the reproductive stage of an organism.

As a result, oocytes are undeveloped, spermatozoons are weaker, and the animals themselves exhibit abnormal behaviors due to the hormonal "treatment" they have received. Therefore, their organisms carry toxic chemical compounds and pathogens. Various fish and so-called seafood are caught in the sea and then served by restaurant owners as healthy and exquisite dishes, but along with their consumption in the human body, the level of harmful substances increases. After assimilation, they can lead to serious health complications, such as gastrointestinal lesions, liver problems, cancer, and endocrine disorders.

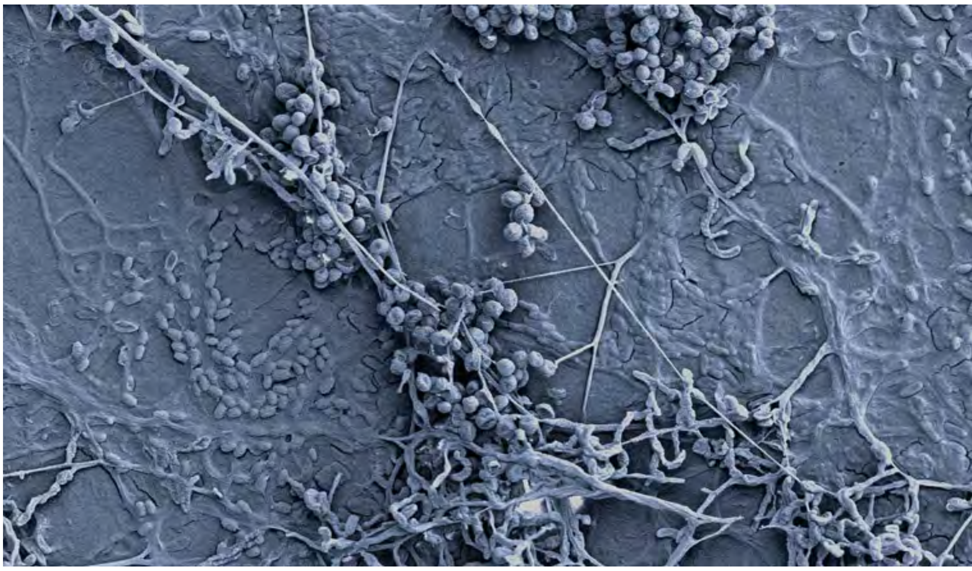
According to estimates, 2 to 5% of all plastic produced ends up in the seas. What can, therefore, be done to bring the ever-growing tide of accumulated plastic to a halt? Dr. Bożena Nowak states that the most effective way to get rid of excess used plastic is to recycle it immediately or limit its use.

"There is no other way to control the excessive build-up of synthetic waste," the researcher says. "There are many campaigns that mislead people instead of clearing the issue up. Plastics that have the same name are not identical. Producers often do not mark packagings or label them as biodegradable or eco-friendly without any proof, so that the average user is not able to independently determine whether a particular product of waste is subject to degradation or not."

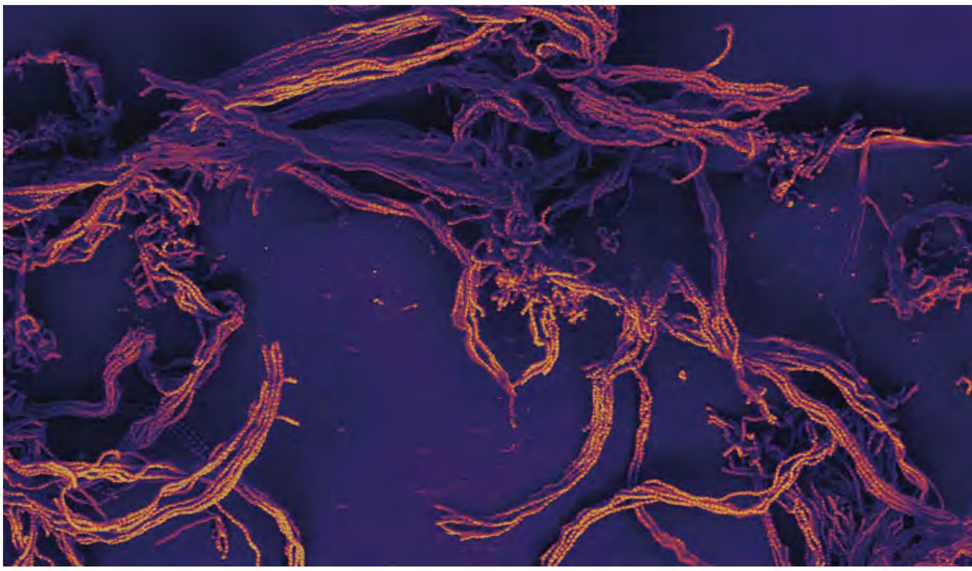
The dangers of uninformed synthetic waste management and widespread human ignorance do not merely threaten a narrow social group or animal species, but have become a real problem for everyone on our planet. Although nature tries to keep up with human progress, it is often unable to face all the difficulties on its own. It is therefore sensible to assume that humans are the protectors of the Earth, those responsible for the condition and situation of the surrounding world, and not merely a link in the evolutionary sequence with no obligation of responsibility.



Biodegradation of plastic surface (polyethylene film) by filamentous fungus *Absidia corymbifera*, magnification 10000× / Photo: Jagna Karcz



Biodegradation of plastic surface (polyethylene film) by microorganisms (bacteria, fungi, filamentous fungi), magnification 2000× / Photo and coloring: Jagna Karcz



Biodegradation of plastic surface (polyethylene film) by filamentous fungus *Aspergillus niger*, magnification 250× / Photo: Jagna Karcz, coloring: Bartosz Baran

WHAT DO YELLOW TRASH CONTAINERS HIDE?

text: Dr. Małgorzata Kłoskowicz

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Photo: Romanzaiets – Freepik.com

We do not know whether recycling will save us from environmental disaster. However, we do believe that segregating waste makes sense. From an early age, our children learn to associate the colors of the bins with different types of waste. Plastic bags and bottles, metal caps, aluminum cans, or milk cartons end up in yellow containers and bags every day. These few examples already show the diversity of these materials. There are as many as seven codes for marking only plastics, in accordance with the Resin Identification Code (RIC) introduced in 1988. Therefore, our segregated waste needs to be sorted once again before proper recycling is possible. How is this accomplished? It turns out that an appropriately designed camera is everything that is necessary.

We buy paper straws for drinks, cutlery made of avocado seeds, and plates made of bran. We can already purchase recycled clothes, and our body has become used to materials containing artificial additives, such as polyester, acrylic, or nylon. Filtering bottles and siphons are a great alternative to the billions of tons of water contained in PET bottles. The ecological lifestyle has become fashionable, and the same applies to promoting the idea of less waste – or even zero waste. It is also worth mentioning that countries of the European Union will be required to achieve a recycling level of 65% and composting municipal waste by 2035. This means that more than half of the waste collected will have to be given a second, third, or even fourth life. Despite so many changes, predictions related to the approaching environmental disaster are not particularly optimistic. The production of plastics in the world is growing. Billions of tons of polymer waste end up in the oceans, and scientists are wondering to what extent the microplastics permeating the human body pose a threat to our health and quality of life.

The Plastic Waste Makers report available on the website of Minderoo Foundation (www.minderoo.org) shows, among others, that only slightly more than a dozen corporations are responsible for over half of the amount of polymers produced annually on our planet. The two world powers, China and the USA, are by far the leaders of this "competition". However, every one of us is responsible for the state our world has found itself in, as it drowns in a sea of waste. We consistently separate waste, however, it is due to our consumer choices that the yellow bins are filled to the brim with colored plastic every day.

The floor must therefore be given to scientists who have already emphasized the importance of recycling at the design stage of new materials and continue to propose increasingly effective methods of dealing with the billions of tons of waste flooding us. The task is by no means easy. Polymers, mainly due to their very interesting properties, are still massively used in the production of most of the objects surrounding us – in clothes, cars, smartphones, and they work well in every industry. Moreover, they are not easily recycled. Their list is open, since new combinations of chemical compounds are constantly being created, and in the process of recovering these materials, the identification of individual elements from which they were built is of crucial importance. In practice, this means that the contents of yellow containers must be segregated again.

An interesting solution was proposed by scientists from the University of Silesia in Katowice – Prof. Michał Daszykowski and doctorate student Łukasz Pieszczek. Their approach resorts to the hyperspectral imaging method, which, according to research, allows for efficient and fast identification of certain groups of plastics.

"What makes various types of polymers different is their unique electromagnetic spectrum. We could compare it to fingerprints that enable us to identify an individual," says Prof. Michał Daszykowski.

Therefore, let us imagine that we are in a waste sorting plant. On the conveyor belt, tons upon tons of products collected daily in yellow bins are moving. It suffices to install a special camera that will record the hyperspectral image of every point of a given object. Not only this tell us whether we are dealing with polyethylene, acrylic, acrylic glass, polypropylene, etc. but also provide us information about possible contaminants. The described method allows for automatic segregation of plastics, which in turn can significantly accelerate and facilitate the recycling process and contribute to a more rational waste management.

"The reality shows that there will be more products made from plastic every year. However, we must learn to recover and reuse them wisely," argues Prof. Michał Daszykowski.

Scientists from the University of Silesia are currently working on improving the tool to identify individual groups of polymers, and testing its effectiveness in laboratory conditions. They are also ready to establish a cooperation with entities responsible for waste management and interested in introducing and testing the new technology in practice.

PET – A Problem on a Global Scale

text: Agnieszka Niewdana

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Photo: Freepik.com

We deal with plastics every day, since the possibilities of their application are very broad. We surround ourselves with these substances at home or in our workplaces; they are used in many industries, but also in everyday life. Versatility and ease of use are their main properties. Currently, the challenge is the possibility to use materials multiple times – that is, to subject them to recycling. Researchers from the Institute of Chemistry at the University of Silesia in Katowice are investigating these possibilities as part of the project titled *Methodology of continued synthesis of 1,3-dioxolanes along with the extension of the range of applicability of target products in the chemical industry*, led by Dr. Maciej Kapkowski.

The abbreviation PET is generally recognizable, but few people know what hides behind this acronym and concept. PET is a polymer which is popular on a global scale, used for plastic packaging and primarily associated with bottles for all kinds of beverages. Polyethylene terephthalate, since this is its name, is a thermoplastic polymer with high mechanical strength, belonging to the group of polyesters. It has insulating properties and a good chemical resistance to weak acids, oils, fats, and alkali solutions. In addition, it can be quite easily heat treated. It is characterized by high abrasion resistance, and most importantly, it is recyclable. Polyethylene terephthalate waste has the highest recycling rate of all plastics, yet much of it accumulates in ecosystems, posing a significant environmental problem and therefore conservation, Dr. Eng. Mateusz Korzec remarks.

Why is this the case? The source of a large amount of waste is PET packagings for storing and transporting food. These packages are quickly "consumable" i.e. their shelf life expires when the food in which they were stored or secured has been consumed. This happens, for example, after drinking water – the bottle becomes waste for recycling. Unfortunately, most recycled PET (rPET) is not approved for contact with food. This is due to the possibility that plasticizers, hardeners, or other chemicals from various recycling steps will be present in them. Contact of these contaminants with food can be a health hazard, and therefore the issue of rPET reuse in food packaging is approached with great caution. The companies that recycle PET for food contact have to meet stringent requirements, undergo appropriate procedures, and prove that their PET recycling method results in producing a material of the highest safety standard. The European Food Safety Agency (European Food Safety Agency), an institution responsible for the quality control of the obtained rPET, reviews the possibility of allowing a given recycling method for the production of packaging in contact with food in Europe. Currently, technologies are being developed to obtain rPET for the production of mineral water bottles in amounts not exceeding 70% of recycled PET. Research on obtaining the appropriate quality of rPET intended for contact with food is still being conducted, therefore, in the near future, recycled PET packagings will be used to a greater extent. PET waste is generated continuously and over short periods. Moreover, the possibilities of reusing it are still insufficient to fully manage rPET. This is a problem on a global scale. Therefore, research on the development of effective, ecological, and at the same time economically viable methods of PET recycling is being carried out. The essential goal is to obtain high purity material and increase the amount of

recycled material. Currently, work on new ways to apply the available rPET in other fields is also underway. It should also be borne in mind that recycling the same material several times may carry the risk of producing materials with increasingly worse quality parameters.

The recycling process is handled by specialized companies that predominantly obtain the original PET waste from industrial and municipal waste management companies. Waste separation is also an important issue. The waste is dealt with in sorting plants, where raw materials for recycling are recovered to some extent. Specialized companies subject PET materials to a complex process of treatment and processing, and thus become the main supplier of a wide range of polyester recyclates in the form of granules, powder, chips, or flakes. Subsequently, the recycled raw materials (polyester recyclates) can be used to produce e.g. polyester fibers, new packaging (mainly for chemicals), or polyester resins. Recycled PET can also be used in civil engineering projects, e.g. road construction, modification of asphalt, cement, or concrete – that is, in the production of broadly understood building materials. The addition of polymer allows to improve their selected physico-chemical parameters and to reduce the production of other plastics (used as additives). This is fully justified in terms of economy and environmental protection. Another use of rPET could be the production of filament for printing plastic materials (to replace filament made from polycarbonate-ABS). The interest in recycled materials (rPET) is relatively high, a circumstance related to the availability of this material in almost "unlimited" amounts and the need to protect the environment due to its low biodegradability.

What else can be done?

"The main three directions related to PET recycling are to conduct research in the development of efficient recycling methods, to increase the amount of global PET recycling, and to inquire into new uses for polyester recyclates," explains Dr. Eng. Sonia Kotowicz. "These directions are important from the point of view of economic, ecological, and rational management of the raw material. The inability to discard this material as well as the growing problem with its quantity, necessitates changes in the reuse and wider use of rPET for packaging intended for contact with food."

As part of the LIDER grant, financed by the Polish National Center for Research and Development, research is being conducted at the University of Silesia on the possibility of using rPET in organic electronics and in other fields. Research focuses on the area where the "time of use" will be relatively long, which will certainly contribute to a partial solution to the problem of the material's reuse for the benefit of human health and the environment. The solution being investigated is the use of rPET in photovoltaics. The most important part of the research is conducted by Dr. Mateusz Korc, a specialist in the recycling of materials, organic synthesis, and the fabrication of active layers for photovoltaic panels. Dr. Eng. Sonia Kotowicz deals with research on and characterization of active layers in photovoltaic panels, while Dr. Karina Kocot finalizes the activities, i.e. performs qualitative and quantitative analyses of nanomaterials as well as instrumental purity analyses of reaction products. The efforts of these young scientists could bring significant progress in partially solving the rPET problem, while opening up opportunities for further research.

PET bottles are subjected to the process of shredding and purification, which allows to obtain PET flakes that can be further processed into a film, obtaining substrates made of rPET (i.e. recycled PET) / Photo: Sonia Kotowicz

PLANTS BRAVELY FIGHTING METALS

Merely a dozen years ago, Silesia was the most powerful industrial center in Poland. Despite the fact that the emission of harmful substances into the environment has been reduced as the number of polluting plants has been diminished and the obligation to use appropriate filters has been introduced, the region still has to cope with the residues of heavy metals which remain in the soil, water, mining waste dumps, and in the air. Metals will not disappear on their own; they are absorbed by plants which, in turn, animals feed on, and these animals pass their "uninvited occupants" to each other. As a result, metals pose a threat to humans as well. Uncovered post-mining and post-manufacturing landfills around which housings are erected carry significant amounts of toxic dust which finds its way into human bodies. However, it turns out that there are plant species which attach themselves to contaminated areas and only occur where heavy metal concentrations are high.

text: Maria Sztuka

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Photo: Dr. Monika Jędrzejczyk-Korycińska

Buckler-mustard

Metallophytes have developed a predilection for e.g. zinc, lead, or nickel, and as a result of adaptation and evolution processes they have become perfectly adapted to life among toxins. The use of these properties is a challenge for scientists from various fields. One of the techniques gaining more and more supporters is phytoremediation (Old Greek: *phytón* – plant, Lating: *remedium* – remedy), i.e. technology using plants in the process of cleaning the environment: soil, groundwater and surface water, sewage sludge, and air. This method takes advantage of the physiological ability of certain plants to either exclude or accumulate contaminants present in the environment. Calamine grasslands (a mining term for oxidized zinc ores) are a testing ground for botanists, plant anatomists, embryologists, specialists dealing with plant physiology, and all those who focus their research on environmental protection. The researchers jokingly refer to themselves as a "heavy metal group."

In Europe, calamine grasslands are under special protection. In Poland, few of them have been left – in Lower Silesia (arsenic residues) and in the area of the Silesian-Cracow Upland (silver, lead, zinc). Old excavations, dumps, waste dumps left after the exploitation of various types of deposits, or remnants of metal smelting (there used to be over 100 smelters in the former Katowice Province) covered with grass, lichens, and flowering plants which do not mind metals, hide invaluable information for scientists.

SILESIAN "HEAVY METAL FANS"

Dr. Monika Jędrzejczyk-Korycińska from the Institute of Biology, Biotechnology and Environmental Protection at the Faculty of Natural Sciences at the University of Silesia, has been coordinating the project co-financed by the European Union called *Good practices for enhancing biodiversity and active protection of calamine grasslands in the Silesia-Cracow region; BioGalmans* since 2018. Works are carried out on calamine grasslands on the washing tip of the Fryderyk mine in Tarnowskie Góry, in three areas in Jaworzno and on two grasslands within the region *Natura 2000* in Bolesław: "Pleszczotka" and "Armeria". The project partners are the municipalities of Tarnowskie Góry and Jaworzno.

The researchers began their work with a huge cleanup. In order to protect the biodiversity of calamine grasslands and in accordance with the appropriate protective recommendations, the woody and shrub species that adversely affect the condition of the habitat had to be removed. Moreover, the fight against invasive and expansive species is underway, and the excess of organic matter has also been removed. Another extremely important element of the activities is the nature inventory, which includes species of vascular plants, mosses, lichens, as well as pollinators, ants, and spiders. The remaining part of the project has been taken over by the forces of nature, and their actions are being closely monitored. After just one year, the conservation efforts brought about surprising results.

"The habitat was filled with desirable vegetation, rich and colorful," Dr. Monika Jędrzejczyk-Korycińska explains. "Carthusian carnations, woodruffs, anemones, and cloves have proliferated tremendously. There has also been a significant increase in turf species, heliophytes, and also those that are fantastic at coping with nutrient deficiencies. It did not take long for pollinators to arrive, either. If the number of flower species on calamine grasslands grows, the level of biodiversity increases as well, which is an unequivocal invitation for insects and other animals. In Tarnowskie Góry, we discovered the violet carpenter bee (*Xylocopa violacea*), a species of *hymenoptera* that was thought to be extinct in Poland. The surrounding grassland plant species turned out to be a bee's feast.

Some may be surprised by the cutting of a significant number of trees and shrubs. It turns out, however, that they do not cope very well with the excess of heavy metals in the soil and contract diseases, which is best evidenced by their appearance. They are deformed and withering, only at the tips they managed to cover themselves with green needles. In Tarnowskie Góry, on the top of the dolomite heap grew only pine trees, and under them hairy sedge (Carex hirta). Only two plant species could be found per one square meter, alongside with some common lichens and mosses. After the trees were removed, 20-30 species of vascular plants accompanied by lichens, bryophytes, and a variety of animal species were soon found on the same site. Therefore, from an ecological point of view and in order

Calamine grasslands

Sea thrift

Bladder campion

to preserve the biodiversity of calamine grasslands habitats (habitats under special supervision), the cutting of e.g. pine trees was a necessity.

PHYTOSTABILIZATION AND PHYTOEXTRACTION

The elimination of heavy metals or the reduction of their toxic impact on the environment are certainly possible with the use of physical or chemical methods. Unfortunately, these activities are very expensive and not entirely safe. According to Dr. Monika Jędrzejczyk-Korycińska, phytoremediation, i.e. environmental remediation with the use of plants, is the least harmful and, above all, the cheapest one. There are two main groups of processes that plants use. The first is phytostabilization. It involves the use of plant species that, with their roots firmly anchored in the ground, not only accumulate heavy metals in the soil, but most importantly, immobilize them so that they do not penetrate the parts above the ground. Through intensive growth, these species reduce the dusting of toxic metal waste on which they thrive.

The second process is phytoextraction, which uses plants that can extract very large amounts of metal from the soil and inject them into the parts above the ground, including the leaves. However, there is strict specialization, since some plants extract gold, others platinum, and still others extract lead, zinc, or copper. When a plant laden with metals dies, the metals remain in the environment but are bound in plant tissues and can be used. Phytomining is the method resorted to in order to recover metals from plants referred to as hyperaccumulators. The small-sized *Pyrrophyta* algae or *Cardaminopsis* cress are insufficient for industrial-scale recovery, but the mighty *Reynoutria* or goldenrods (*Solidago*) are more promising in this respect. Notwithstanding this, our scientist remains skeptical. Phytomining looks forward to plants with large masses, but such species are few in number and also often dangerous. The same applies to invasive species with a negative impact on biodiversity.

"Science must accept such challenges with due consideration. Plants which cannot be controlled must not be introduced into the environment. Recovering metals from the soil is an issue which definitely has to be addressed, but to maintain biodiversity at appropriate levels is more important for the stability of the entire ecosystem. It is necessary to stabilize areas contaminated with heavy metals by using native species that can be further utilized in the changing climate," the researcher concludes.

METALLOPHYTES CAN SOON BECOME VERY USEFUL

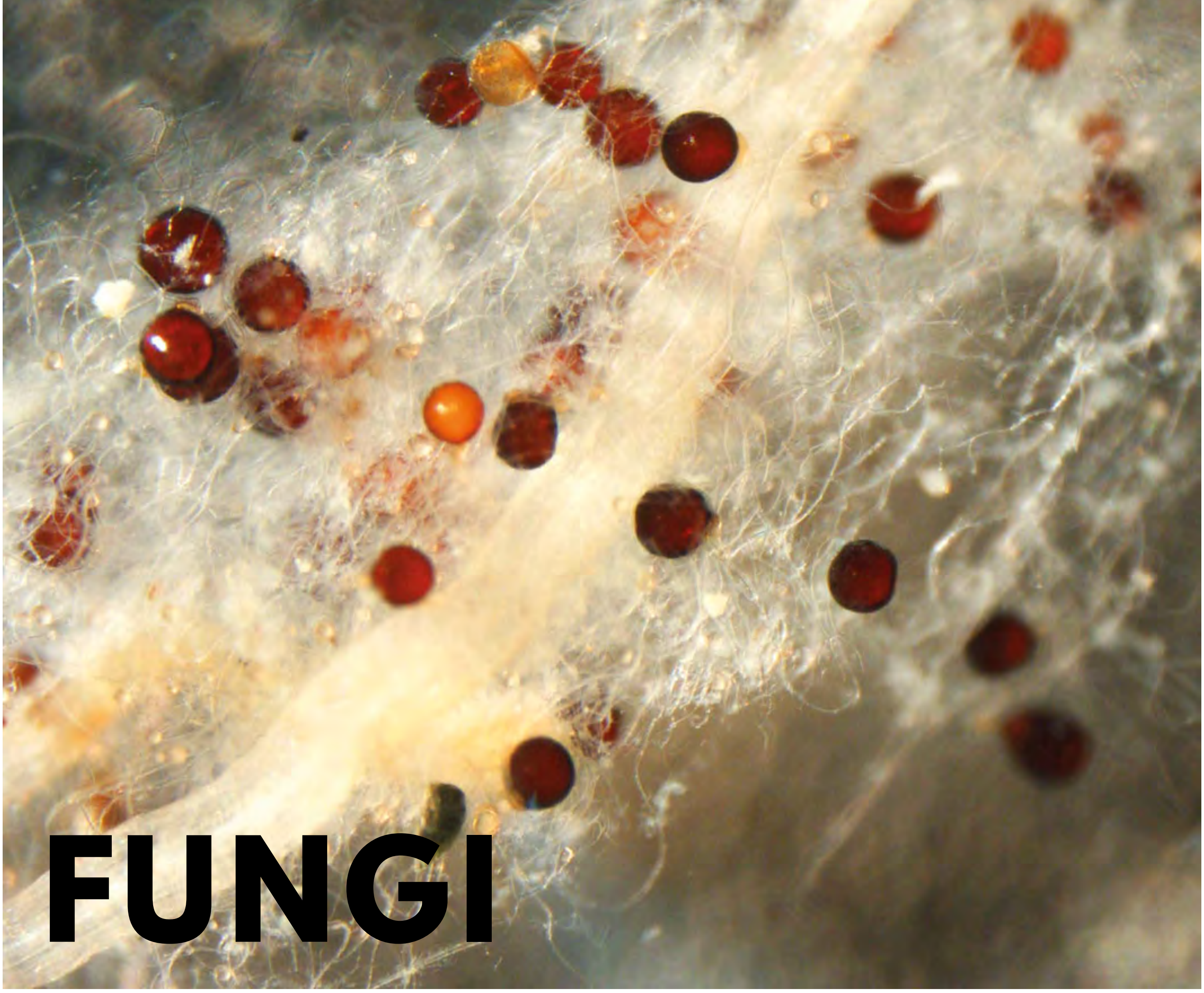
Plants that have grown fond of metals can cope with contaminated areas, are unafraid of mineral deficiencies, and have become perfectly adapted to physiological drought as well as to powerful insolation, i.e. intensive sunlight. Many grassland species, including grass, are now well accustomed to the difficulties they encountered, although they significantly differ from their brother or sister species in other regions of the country. The species popular in Poland, such as the sand rock-cress, sheep's fescue, bladder campion, or broad-leaved thyme, usually produce less matter on calamine grasslands; their leaves are small and have a xeromorphic structure, but they cope well with low substrate moisture, high sun exposure, poor nutrients, and high heavy metal concentrations. An interesting adaptation to such adverse conditions is e.g. an unusually elaborate root system coexisting with mycorrhizal fungi, since it allows them to increase their absorptive surface many times in order to collect water for the plant. In addition, species that grow on polluted areas are capable of flowering more than once, thanks to which they produce a huge number of seeds, a circumstance that gives them an advantage over other species.

These characteristics may soon prove to be extremely useful. The changing and increasingly warm climate as well as water scarcity plaguing all continents are a serious challenge to the environment, and some plant and animal species are threatened with extinction. Metallophytes preserved in calamine grasslands constitute an excellent gene pool that will be available once the ecosystem faces difficult times. Scientists are demanding the preservation of at least some of these valuable habitats, and their call is being implemented by European directives. Contaminated areas, which are usually mentioned in the context of neutralization and destruction, can be rehabilitated and used in a positive way," Dr. Monika Jedrzejczyk-Korycinska asserts.

Carthusian pink

Hyperaccumulator – Cardaminopsis halleri

Thymus



Septoglomus constrictum isolated from a mining waste dump, already known to science / Photo: Franco Magurno

FUNGI

in the Revitalization of Post-industrial Areas

text: Maria Sztuka

Climate change has become a fact, and people all over the globe can feel the effects of this process. Long-term droughts are particularly dangerous, since they not only negatively affect the development of plants, but also cause many diseases that are dangerous for them. The intensive use of fertilizers and pesticides or land reclamation, measures intended to support agricultural production, have proven to be extremely harmful to the soil. Moreover, in many places they have led to its degradation. A large part of the world is struggling with a lack of proper hydration, and the process of desertification is beginning to threaten all continents. The research results of interdisciplinary scientific teams who focus on countering the devastation of nature and restoring vital biodiversity are not only carefully followed, but also applied immediately if possible.

Due to the specific way natural deposits are exploited in Silesia, this region is a very promising research field. Mine waste dumps (tips) have become laboratories for scientists specializing in urban vegetation, post-industrial areas, plant physiology, and soil microbiology, including research on mycorrhiza. These remnants of mining attracted scientists' attention, since they make it possible to look for changes in plant cover under the influence of anthropopressure as well as for hint on supporting the process of revitalization of post-industrial areas.

The dumps will not disappear by themselves. Without human intervention, they are bound to become a huge threat to surface and deep water as well as to atmospheric air, and therefore these sites have a decisive impact on climate change and the quality of life on Earth. For many years, scientists from the Institute of Biology, Biotechnology and Environmental Protection of the Faculty of Life Sciences of the University of Silesia have been conducting research aimed at developing the most effective methods of reclamation and management of mine waste dumps. A research team led by Assoc. Prof. Gabriela Woźniak from the University of Silesia completed the implementation of a long-term research project (*System of supporting revitalization of post-mining waste dumps with the use of geoinformatic tools*). The specialists from various disciplines focused on the recognition of spontaneously occurring biological processes in the dumps, which allowed to identify the ways to strengthen and accelerate them.

The samples taken from the waste dumps contain an abundance of research material, and since plants living on these post-mining sites face similar problems as plants living in desert areas, they have to struggle for survival under the stress of water, micronutrients, and nutrient deficiencies. Therefore, the research results (concerning e.g. relations between plants, their abundance, diversity, biomass, and substrate) can be applied to equally difficult terrains on different continents.

Among other results, the research has enabled scientists to point out the special role of fungi in the revitalization process. This was the task of microbiologist Dr. Franco Magurno, whose research interests focus on mycorrhiza, the symbiosis between roots of vascular plants and some fungi. After isolating them from the dumps, the microbiologist will verify if they could be used in other areas.

The scientist focused particularly on arbuscular mycorrhiza, where the fungal hyphae penetrate the plant root cells. A characteristic element in this type of mycorrhiza is arbuscules produced as lateral branches of fungal hyphae inside plant cells. They have a tree-like shape and are tightly surrounded by a plant cell membrane, a circumstance that significantly increases the surface area constituting the zone in which partners exchange substances. According to several studies, arbuscular mycorrhiza is the most primordial type of mycorrhizal symbiosis occurring between fungi and plants. Moreover, this phenomenon is probably the reason why plants came out on land.

"Without these fungi, plants would not have been able to colonize easily the land. It turns out that a large part of the plant genome is genes responsible for the synthesis of proteins involved in the symbiosis. From the point of view of plants, mycorrhiza is very important, since this process helps them survive in difficult conditions, such as drought or lack of micronutrients," the microbiologist explains. One of the most important features of arbuscular fungi is the possibility to prevent infection by pathogenic fungi, since they are able to defend plants against many dangerous diseases.

It is worth noting that *Rhizoglomus silesianum* was added to the atlas of arbuscular fungi. Dr. Franco Magurno and Dr. Monika Malicka isolated this species from materials obtained at the Makoszowy mine waste dump, in an environment with high salinity and small amount of water, i.e. under conditions that prevail under the stress of drought. Hopefully *Rhizoglomus silesianum* will be useful for the production of inocula to replace synthetic fertilizers and pesticides. This feature makes it highly desirable for agriculture.

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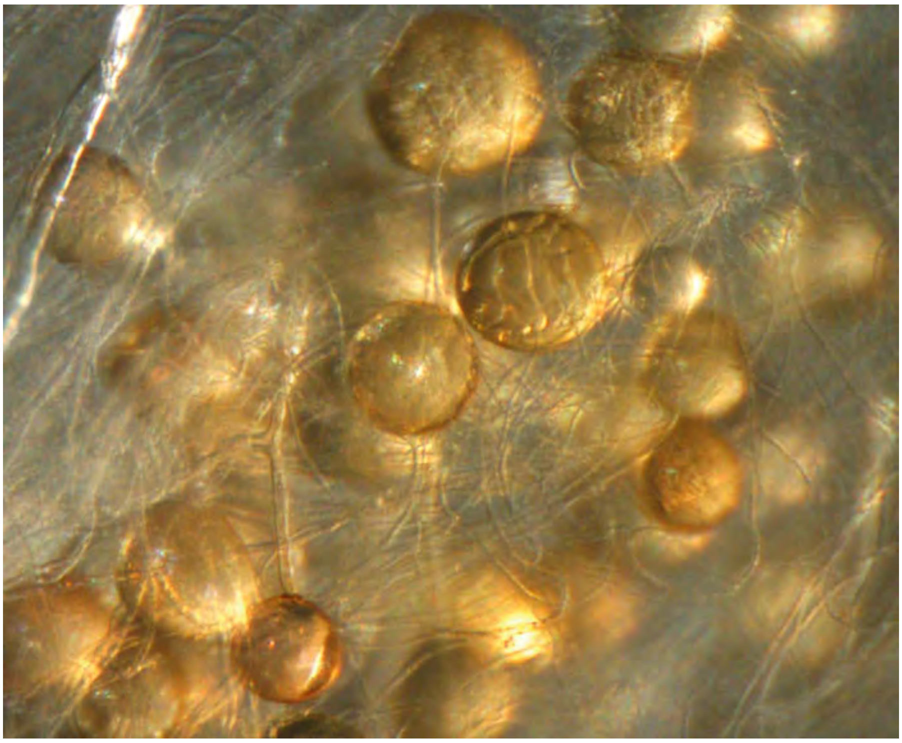
Rhizoglomus silesianum **/ Photo: Franco Magurno**



text: Dr. Małgorzata Kłoskowicz

PLANTS AND BACTERIA AS RESCUE FOR CONTAMINATED SOIL

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Photo: Pressmaster – Freepik.com

Let us imagine there had been a spill of heating oil in a single-family home. As a result of this incident, the area located under the building became contaminated. A ditch was dug around the building, appropriately selected bacteria were introduced into the soil by means of a drainage system, and then for several months the gradual cleansing of the soil was monitored. This is a Finnish example of using biological methods to clean up contaminated sites. At the University of Silesia, these methods are being developed by Dr. Magdalena Pacwa-Płociniczak and Assoc. Prof. Tomasz Płociniczak.

BIOLOGICAL CLEANING METHODS

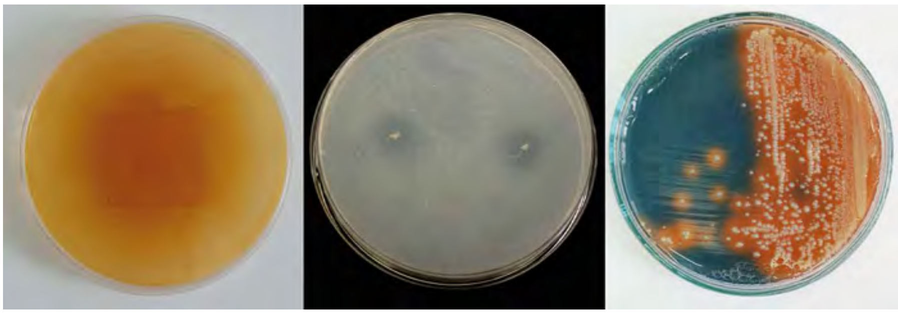
It is no secret that both bacteria and some plant species are able to survive in the most unfavorable, even extreme conditions. Such places certainly include areas contaminated with various compounds, both organic and inorganic, including hydrocarbons and heavy metals. According to research, some organisms thrive in such an environment and even... cleanse it naturally of contaminants.

Scientists try to learn as much as possible about these extraordinary abilities of certain bacterial strains and selected plant species in order to create a unique "arsenal" which would provide support in the remediation of contaminated areas.

In one of her projects, Dr. Magdalena Pacwa-Płociniczak analyzed the possibility of using different strains of bacteria for the purification of soil from organic compounds. The biologist isolated the bacteria and subsequently checked in the laboratory which of them have the greatest potential with regard to bioremediation and how they are able to survive even in very difficult conditions.

"My husband's interests are very similar. I knew that for a while he had been researching plants that could also support processes interesting for me. We joined forces and started working together to improve natural, biological methods to clean up areas contaminated with organic and inorganic compounds by using microorganisms and carefully selected plant species," the researcher says.

Scientists from the University of Silesia, on the one hand, conduct research to improve known methods, and on the other – intensively cooperate with companies, private owners, or local government units to use the acquired knowledge in practice and, on this basis, propose the best solutions tailored to clients' needs. The most important thing is to look for the most environmentally-friendly way to clean up the contaminated area in a non-invasive manner.



Left: ability to produce hydrocyanic acid (orange colored blotting paper).
Middle: dissolution of tricalcium phosphate (zones of translucency around the colony)
Right: ability to produce iron-binding siderophores (orange coloration around the colony)
/ Photo: Tomasz Plociniczak

A "SET" OF MICROORGANISMS AVAILABLE ON REQUEST

There are no two areas which would be the same in terms of the type and concentration of pollutants. Each environment also has a unique "set" of microorganisms that adapt to the given conditions. This is an important hint from nature. Moreover, various plant species which accelerate and support the remediation process may also grow in such an area. An additional necessary element is a little ingenuity to propose effective, environmentally-safe solutions.

"When an owner of an area to be cleansed contacts us and is interested in using biological treatment methods, we first have to carefully examine the area and consider what "kit" to offer," Dr. Magdalena Pacwa-Płociniczak says.

One of the people the scientists collaborated with asked for a solution designed for a contaminated area located in the Opole Voivodeship (province).

"An interesting fact is that this person was familiar with the potential of bioremediation methods. Maybe that is why we did not have to convince them about the benefits of using natural techniques," Dr. Tomasz Płociniczak adds.

Firstly, soil samples were collected and analyzed. The scientists had to identify the types of pollutants and their concentrations, and check what microorganisms were present in the area.

"This is one of the most important questions. In the method which is being developed, we try to use those microorganisms that already inhabit a given area. The introduction of other ones could lead to local "fights", and thus contribute to a decrease in the effectiveness of the method," Dr. Magdalena Pacwa-Płociniczak explains.

Moreover, the case in question required consultation with a geologist. It turned out that a nearby installation had lost its tightness and contamination was constantly flowing in, causing the concentration of soil contaminants to increase. Thus, a one-time cleanup of the area would not produce the expected and lasting results.

After learning the answers to the most important questions, Dr. Tomasz Płociniczak proposed to build six special wells.

"Contaminated water from the designated area was accumulated in them. There, we also applied useful microorganisms isolated from this area, which we knew could break down organic pollutants. The water was also aerated and heated so that conditions were conducive to the multiplication of the organisms selected by us," the scientist explains.

The water purified in this manner was then poured over the contaminated area. It infiltrated the soil and, along with the subsequent contamination, was returned to the well. Then, the entire process started all over again.

"Therefore, we proposed a closed system to biologically cleanse soil contaminated with organic substances, using water as a carrier of pollutants and beneficial bacteria at the same time," Dr. Tomasz Płociniczak adds.

MASTERING NATURE

In our country, biological methods of treating sites contaminated with organic and inorganic compounds are still not very popular. Biologists from the University of Silesia do not hesitate to point out four factors that may be relevant in this respect.

Firstly, it is not a universal solution. Scientists do not use ready-made biological “vaccines”, although there are some on the market. They treat each case individually and must first examine the contaminated area with regard to the type and concentration of contaminants and the microorganisms present in it. Sometimes the specificity of the area requires additional consultations, as in the case of the Opole Voivodeship, which may generate additional costs. They are tailor-made solutions, so the price goes hand in hand with quality.

Secondly, the activity of microorganisms and plants takes time. Sometimes it is the case that the client can wait for the biological method to become effective. A mining waste to be used as a recreational area for residents does not have to be made available in one month; its preparation can take several years if environmental concerns are the priority. The situation is different for the owners who want to start putting their plans into practice as soon as possible.

“How do they proceed? They rent trucks and drive several hundred times with the contaminated soil in order to transport it elsewhere. Subsequently, uncontaminated soil is brought to the site. Such action certainly takes less time, but is more expensive and, above all, it disrupts the natural biological balance. What is the gain? The removed soil does not disappear, it has to find a new place, and moreover, it is rarely the case that only the land intended for the construction of buildings is contaminated. As time passes, harmful organic or inorganic compounds make their way back to the site via various natural routes, and the landowner is back at the point where the problem started,” Dr. Tomasz Płociniczak comments.

Thirdly, efficacy. Scientists are aware of the challenges connected with the use of biological methods for cleaning up contaminated sites.

“We are not fully able to master nature. We “employ” plants and/or microorganisms to help us. Research is being conducted, and we continue to learn more about the mechanisms which allow organisms to survive in contaminated soil. Therefore, the bioremediation process must be monitored and may require various improvements or modifications. We are prepared for this,” Dr. Magdalena Pacwa-Płociniczak says.

And above all: awareness. Scientists regretfully admit that, in many parts of the world, including Poland, care for the environment is unfortunately still in the fledgling stage. “We would like to believe that in the future there will be no need to convince anybody of the superiority of biological over chemical and physical methods. The natural ways of remediating contaminated areas, chosen according to the specifics of the area, do not change its character and ultimately contribute to the preservation of valuable biodiversity,” the biologists from the University of Silesia conclude.

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UTILITARIAN PROBLEMS UNDER THE CONTROL OF ARTIFICIAL INTELLIGENCE

Photo: Vikornsarathailand – Freepik.com

In the past decades, technology and IT activities have completely dominated the global job market. Virtual reality created by humans is no longer controlled by us as closely as by artificial intelligence (AI). Many algorithms perform a sequence of tasks to make human work as efficient as possible. Among the areas of their activity, ecological waste management deserves special attention, since it requires an interdisciplinary approach to ensure high efficiency of the flow of raw materials, semi-finished, and finished products from the place of consumption to the place of origin.

text: Katarzyna Stołpiec

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René Descartes, a French philosopher and mathematician who lived in the 17th century, predicted that in the future machines would be able to make decisions and function in the likeness of humans. From today's perspective, it is possible to argue that the thinker was right. Artificial intelligence has a huge amount of information at its disposal which it processes and gives to humans as a finished product made with a single mouse click. One example of the application of AI is its use as computational intelligence in reverse logistics, a very important and integral component that falls within the scope of ecology's interests.

Krzysztof Szwarc, MSc Eng., a doctoral student at the Institute of Computer Science at the University of Silesia in Katowice, deals on a daily basis with the application of computational intelligence methods in the process of solving various utilitarian problems, such as the interdisciplinary issue of planning mobile waste collection, which lies in the area of interest of reverse logistics.

“Due to artificial intelligence algorithms, it is possible to effectively construct a list of points from which old or used equipment should be picked up and to arrange all routes in such a way that time and kilometers are saved while every reported location is visited. Moreover, CO_2 emission is reduced in correlation with the lesser distance to be covered,” the scientist says.

Storage of electro-waste is a less popular method of waste management. The European Parliament alarms that, in many member states, electrical and electronic equipment is being recycled at less than 40%. Poland's statistics are growing year by year, but it has still not been possible to surpass this relatively low threshold.

This type of waste is a growing problem around the world. The technology market, which continuously introduces new equipment, drives demand and consumption, at the same time affecting the growing amount of obsolete devices being discarded. Everyone likes to work on a new computer or smartphone that looks nice, is fast, and has been equipped with the latest applications that can improve our work or simply make its use more enjoyable. The attractiveness of new products is unfortunately one of the reasons why used equipment is replaced by newer models, although some of them are still functioning. Consumption is thus faster than product aging.

“When deciding to purchase new equipment, it is a good idea to keep social responsibility in mind and pay attention to the potential wastage of equipment or of the raw materials from which it is made. Unused equipment often ends up at the bottom of a drawer. From the ecological point of view, it seems more beneficial to e.g. resell unused electronics or to hand it over for specialized disposal, thus allowing for the recovery of some components that can be used further,” says Krzysztof Szwarc, MSc Eng.

One of the solutions made possible by artificial intelligence is the use of metaheuristics to optimize the collection plan for the returned equipment. They take into account various constraints such as the vehicle fleet, travel time, as well as the entire loading and unloading procedure. After receiving the most important information, they are able to provide a precise solution which guarantees a high level of customer service.

“If the user is to be willing to hand over their old equipment to a specialist outlet, they must feel encouraged to do so,” the doctoral student says. “A message about environmental protection is unfortunately not enough. Despite so many campaigns promoting an eco-friendly lifestyle, few people decide to use waste equipment in this way. To encourage them, mobile collections are organized, time windows are taken into account, and equipment can be collected.”

As it turns out, artificial intelligence supports humans in proportion to their effort. Without the human factor, virtual space alone cannot meet all the expectations set by the contemporary world. Despite these dependencies, AI offers opportunities that, in turn, would be impossible without its participation. May the cooperation of human intelligence with AI bring benefits that will make this world a better and cleaner place.

text: Tomasz Płosa

MECHANICAL ENERGY AT THE SERVICE OF ECOLOGY

When traveling by car, we are generally unaware that shock absorbers are largely responsible for our driving comfort. However, we rather quickly realize when they no longer fulfill their basic purpose, which is to absorb and dissipate the mechanical vibrations generated during our trip. So, what if we changed our approach and instead of dissipating vibrations, tried to use them to increase the energy efficiency of the car?

Scientists from the University of Silesia in Katowice and four other institutions in Spain, Ukraine, Great Britain, and Italy are working on such a concept. The composition of the consortium is completed by the American company Tenneco, the Industrial Partner. The project Electro-Intrusion is funded by the European Union Horizon 2020 program and belongs to the framework of the prestigious FET Proactive competition. The research team at the Silesian University consists of scientists from the Faculty of Science and Technology: Assoc. Prof. Mirosław Chorążewski (head of the project), Dr. Alexander Lowe, and Assoc. Prof. Monika Geppert-Rybczyńska.

The main goal of the project is to create a prototype of an automotive regenerative shock absorber sensitive to mechanical energy (from vibrations occurring while the vehicle is moving) which will transform it, along with thermal energy taken from the environment, into electricity. The conversion will be possible thanks to the phenomena of intrusion and extrusion, which will take place between the non-wetting liquid used in the shock absober and the nanoporous hydrophobic solid.

Imagine a moving car. Its movement will always be accompanied by mechanical vibrations that carry a certain amount of energy which will be absorbed by the suspension of liquid and solid inside the shock absorber. As a result, the liquid will be pushed into the nanoporous solid, i.e., the above-mentioned intrusion will take place. Liquids and solids differ in molecular strucutre and possessing strongly repulsive interactions. Therefore, intrusion requires the supply of mechanical energy, which in the case of our device would be taken from the car's vibrations. After being converted to electricity, this energy would be too small to hold the liquid in the nanopores, so the system would very quickly return to its initial natural state, a process called extrusion. The proper conversion of mechanical energy into electrical energy will be possible thanks to the phenomenon of nanotriboelectrification, in consequence of which an electric charge is generated as a nano-scale friction effect which occurs between the liquid and the solid during successive intrusion and extrusion processes. The electric current generated in this way will power the battery, increasing energy efficiency while driving. Electric cars equipped with regenerative shock absorbers will have an increased range.

"Until now, we have focused on looking for solutions to dissipate energy from car vibrations as efficiently as possible in order to reduce the damage that they can cause continuously," says Dr. Alex-

Photo: User4894991 – Freepik.com

ander Lowe. "What we are working on is a really new idea, an entirely innovative way of thinking about this problem. Since we operate in a nano-scale world, we still do not fully understand all the phenomena occurring in it. Therefore, apart from trying to design a specific device, we also try to thoroughly understand and accurately describe the physical processes that we want to use. Nanotriboelectrification is one of the most difficult processes to understand. The reasons for this are the scale at which it occurs as well as the need for specialized and unique apparatus in connection with computer simulations."

The team of scientists from the University of Silesia analyze the phenomena occurring at the interface between nanoporous solids and liquids, on which the designed shock absorber will be based in the future, in order to determine what materials will be best in this context. It is also important what amounts of mechanical energy (from vibrations) and thermal energy (from the environment) are necessary for the system to work efficiently.

"According to data from the European Environment Agency, a 4 percent drop in total electricity consumption by 2050 can be achieved by installing regenerative shock absorbers in city cars. Our initial estimation is that nanotriboelectric regenerative shock absorbers can reduce fuel consumption by about 9 percent," argues Assoc. Prof. Mirosław Chorążewski.

"The project will last until 2024, and during that time we have a realistic chance to build a working prototype of the shock absorber. Then it will be the task of engineers to transform the results of our research into a product with a final appearance and parameters," Dr. Alexander Lowe sums up.

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Zero waste is an idea challenging our way of thinking and functioning in the environment. It draws our attention to the fact that human activity should be associated with the responsibility for our lives and for the impact of our activities on the planet.

→ p. 4

NO limits

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cover: Katarzyna Main