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Unleasing Nature's Recyclers : Micro-Organisms As The Key Players In Biodegradation And Bioremediation

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ABSTRACT: Biodegradation is the breakdown of organic matter by microorganisms, such as bacteria and fungi.[a][2] It is generally assumed to be a natural process, which differentiates it from composting. Composting is a human-driven process in which biodegradation occurs under a specific set of circumstances.The process of biodegradation is threefold: first an object undergoes biodeterioration, which is the mechanical weakening of its structure; then follows biofragmentation, which is the breakdown of materials by microorganisms; and finally assimilation, which is the incorporation of the old material into new cells.In practice, almost all chemical compounds and materials are subject to biodegradation, the key element being time. Things like vegetables may degrade within days, while glass and some plastics take many millennia to decompose. A standard for biodegradability used by the European Union is that greater than 90% of the original material must be converted into CO_2, water and minerals by biological processes within 6 months. Bioremediation broadly refers to any process wherein a biological system (typically bacteria, microalgae, fungi, and plants), living or dead, is employed for removing environmental pollutants from air, water, soil, flue gasses, industrial effluents etc., in natural or artificial settings.[1] The natural ability of organisms to adsorb, accumulate, and degrade common and emerging pollutants has attracted the use of biological resources in treatment of contaminated environment.[1] In comparison to conventional physicochemical treatment methods bioremediation may offer considerable advantages as it aims to be sustainable, eco-friendly, cheap, and scalable.[1] Most bioremediation is inadvertent, involving native organisms. Research on bioremediation is heavily focused on stimulating the process by inoculation of a polluted site with organisms or supplying nutrients to promote the growth. In principle, bioremediation could be used to reduce the impact of byproducts created from anthropogenic activities, such as industrialization and agricultural processes.[2][3] Bioremediation could prove less expensive and more sustainable than other remediation alternatives.[4]UNICEF, power producers, bulk water suppliers and local governments are early adopters of low cost bioremediation, such as aerobic bacteria tablets which are simply dropped into water.[5]

KEYWORDS: biodegradation, bioremediation, micro-organisms, ecofriendly, sustainable, pollutants, bacteria, fungi

I.INTRODUCTION

Organic pollutants are generally more susceptible to biodegradation than heavy metals. Typical bioremediations involves oxidations. Oxidations enhance the water-solubility of organic compounds and their susceptibility to further degradation by further oxidation and hydrolysis. Ultimately biodegradation converts hydrocarbons to carbon dioxide and water.[6] For heavy metals, bioremediation offers few solutions. Metal-containing pollutant can be removed or reduced with varying bioremediation techniques.[7] The main challenge to bioremediations is rate: the processes are slow.[8]

Bioremediation techniques can be classified as (i) in situ techniques, which treats polluted sites directly, vs (ii) ex situ techniques which are applied to excavated materials.[9] In both these approaches, additional nutrients, vitamins, minerals, and pH buffers are added to enhance the growth and metabolism of the microorganisms. In some cases, specialized microbial cultures are added (biostimulation). Some examples of bioremediation related technologies are phytoremediation, bioventing, bioattenuation, biosparging, composting (biopiles and windrows), and landfarming. Other remediation techniques include thermal desorption, vitrification, air stripping, bioleaching, rhizofiltration, and soil washing. Biological treatment, bioremediation, is a similar approach used to treat wastes including wastewater, industrial waste and solid waste. The end goal of bioremediation is to remove or reduce harmful compounds to improve soil and water quality.[10]

The process of biodegradation can be divided into three stages: biodeterioration, biofragmentation, and assimilation.[3] Biodeterioration is sometimes described as a surface-level degradation that modifies the mechanical, physical and chemical properties of the material. This stage occurs when the material is exposed to abiotic factors in the outdoor environment and allows for further degradation by weakening the material's structure. Some abiotic factors that influence these initial changes are compression (mechanical), light, temperature and chemicals in the environment.[3] While biodeterioration typically occurs as the first stage of biodegradation, it can in some cases be parallel to biofragmentation.[4] Hueck,[5] however, defined Biodeterioration as the undesirable action of living organisms on Man's materials, involving such things as breakdown of stone facades of buildings,[6] corrosion of metals by microorganisms or merely the esthetic changes induced on man-made structures by the growth of living organisms.[6]

Biofragmentation of a polymer is the lytic process in which bonds within a polymer are cleaved, generating oligomers and monomers in its place.[3] The steps taken to fragment these materials also differ based on the presence of oxygen in the system. The breakdown of materials by microorganisms when oxygen is present is aerobic digestion, and the breakdown of materials when oxygen is not present is anaerobic digestion.[7] The main difference between these processes is that anaerobic reactions produce methane, while aerobic reactions do not (however, both reactions produce carbon dioxide, water, some type of residue, and a new biomass).[8] In addition, aerobic digestion typically occurs more rapidly than anaerobic digestion, while anaerobic digestion does a better job reducing the volume and mass of the material.[7] Due to anaerobic digestion's ability to reduce the volume and mass of waste materials and produce a natural gas, anaerobic digestion technology is widely used for waste management systems and as a source of local, renewable energy.[9]

In the assimilation stage, the resulting products from biofragmentation are then integrated into microbial cells.[3] Some of the products from fragmentation are easily transported within the cell by membrane carriers. However, others still have to undergo biotransformation reactions to yield products that can then be transported inside the cell. Once inside the cell, the products enter catabolic pathways that either lead to the production of adenosine triphosphate (ATP) or elements of the cells structure.[3]

Bioventing is a process that increases the oxygen or air flow into the unsaturated zone of the soil, this in turn increases the rate of natural in situ degradation of the targeted hydrocarbon contaminant.[12] Bioventing, an aerobic bioremediation, is the most common form of oxidative bioremediation process where oxygen is provided as the electron acceptor for oxidation of petroleum, polyaromatic hydrocarbons (PAHs), phenols, and other reduced pollutants. Oxygen is generally the preferred electron acceptor because of the higher energy yield and because oxygen is required for some enzyme systems to initiate the degradation process.[8] Microorganisms can degrade a wide variety of hydrocarbons, including components of gasoline, kerosene, diesel, and jet fuel. Under ideal aerobic conditions, the biodegradation rates of the low- to moderate-weight aliphatic, alicyclic, and aromatic compounds can be very high. As molecular weight of the compound increases, the resistance to biodegradation increases simultaneously.[8] This results in higher contaminated volatile compounds due to their high molecular weight and an increased difficulty to remove from the environment.

Most bioremediation processes involve oxidation-reduction reactions where either an electron acceptor (commonly oxygen) is added to stimulate oxidation of a reduced pollutant (e.g. hydrocarbons) or an electron donor (commonly an organic substrate) is added to reduce oxidized pollutants (nitrate, perchlorate, oxidized metals, chlorinated solvents, explosives and propellants).[6] In both these approaches, additional nutrients, vitamins, minerals, and pH buffers may be added to optimize conditions for the microorganisms. In some cases, specialized microbial cultures are added (bioaugmentation) to further enhance biodegradation.

Approaches for oxygen addition below the water table include recirculating aerated water through the treatment zone, addition of pure oxygen or peroxides, and air sparging.[13] Recirculation systems typically consist of a combination of injection wells or galleries and one or more recovery wells where the extracted groundwater is treated, oxygenated, amended with nutrients and re-injected.[14] However, the amount of oxygen that can be provided by this method is limited by the low solubility of oxygen in water (8 to 10 mg/L for water in equilibrium with air at typical temperatures). Greater amounts of oxygen can be provided by contacting the water with pure oxygen or addition of hydrogen peroxide (H_2O_2) to the water. In some cases, slurries of solid calcium or magnesium peroxide are injected under pressure through soil borings. These solid peroxides react with water releasing H_2O_2 which then decomposes releasing oxygen. Air sparging involves the injection of air under pressure below the water table. The air injection pressure must be great enough to overcome the hydrostatic pressure of the water and resistance to air flow through the soil.[13][14]

Bioremediation can be carried out by bacteria that are naturally present. In biostimulation, the population of these helpful bacteria can be increased by adding nutrients.[7][16]

Bacteria can in principle be used to degrade hydrocarbons.[17][18] Specific to marine oil spills, nitrogen and phosphorus have been key nutrients in biodegradation.[19] The bioremediation of hydrocarbons suffers from low rates.

Bioremediation can involve the action of microbial consortium. Within the consortium, the product of one species could be the substrate for another species.[20]

Anaerobic bioremediation can in principle be employed to treat a range of oxidized contaminants including chlorinated ethylenes (PCE, TCE, DCE, VC), chlorinated ethanes (TCA, DCA), chloromethanes (CT, CF), chlorinated cyclic hydrocarbons, various energetics (e.g., perchlorate,[21] RDX, TNT), and nitrate.[7] This process involves the addition of an electron donor to: 1) deplete background electron acceptors including oxygen, nitrate, oxidized iron and manganese and sulfate; and 2) stimulate the biological and/or chemical reduction of the oxidized pollutants. Hexavalent chromium (Cr[VI]) and uranium (U[VI]) can be reduced to less mobile and/or less toxic forms (e.g., Cr[III], U[IV]). Similarly, reduction of sulfate to sulfide (sulfidogenesis) can be used to precipitate certain metals (e.g., zinc, cadmium). The choice of substrate and the method of injection depend on the contaminant type and distribution in the aquifer, hydrogeology, and remediation objectives. Substrate can be added using conventional well installations, by direct-push technology, or by excavation and backfill such as permeable reactive barriers (PRB) or biowalls.[22] Slow-release products composed of edible oils or solid substrates tend to stay in place for an extended treatment period. Soluble substrates or soluble fermentation products of slow-release substrates can potentially migrate via advection and diffusion, providing broader but shorter-lived treatment zones. The added organic substrates are first fermented to hydrogen (H_2) and volatile fatty acids (VFAs). The VFAs, including acetate, lactate, propionate and butyrate, provide carbon and energy for bacterial metabolism.[7][6]

II.DISCUSSION

In practice, almost all chemical compounds and materials are subject to biodegradation processes. The significance, however, is in the relative rates of such processes, such as days, weeks, years or centuries. A number of factors determine the rate at which this degradation of organic compounds occurs. Factors include light, water, oxygen and temperature.[10] The degradation rate of many organic compounds is limited by their bioavailability, which is the rate at which a substance is absorbed into a system or made available at the site of physiological activity,[11] as compounds must be released into solution before organisms can degrade them. The rate of biodegradation can be measured in a number of ways. Respirometry tests can be used for aerobic microbes. First one places a solid waste sample in a container with microorganisms and soil, and then aerates the mixture. Over the course of several days, microorganisms digest the sample bit by bit and produce carbon dioxide – the resulting amount of CO_2 serves as an indicator of degradation. Biodegradability can also be measured by anaerobic microbes and the amount of methane or alloy that they are able to produce.[12]

It's important to note factors that affect biodegradation rates during product testing to ensure that the results produced are accurate and reliable. Several materials will test as being biodegradable under optimal conditions in a lab for approval but these results may not reflect real world outcomes where factors are more variable.[13] For example, a material may have tested as biodegrading at a high rate in the lab may not degrade at a high rate in a landfill because landfills often lack light, water, and microbial activity that are necessary for degradation to occur.[14] Thus, it is very important that there are standards for plastic biodegradable products, which have a large impact on the environment. The development and use of accurate standard test methods can help ensure that all plastics that are being produced and commercialized will actually biodegrade in natural environments.[15] One test that has been developed for this purpose is DINV 54900.[16]

The term Biodegradable Plastics refers to materials that maintain their mechanical strength during practical use but break down into low-weight compounds and non-toxic byproducts after their use.[18] This breakdown is made possible through an attack of microorganisms on the material, which is typically a non-water-soluble polymer.[4] Such materials can be obtained through chemical synthesis, fermentation by microorganisms, and from chemically modified natural products.[19]

Plastics biodegrade at highly variable rates. PVC-based plumbing is selected for handling sewage because PVC resists biodegradation. Some packaging materials on the other hand are being developed that would degrade readily upon exposure to the environment.[20] Examples of synthetic polymers that biodegrade quickly include polycaprolactone, other polyesters and aromatic-aliphatic esters, due to their ester bonds being susceptible to attack by water. A prominent example is poly-3-hydroxybutyrate, the renewably derived polylactic acid. Others are the cellulose-based cellulose acetate and celluloid (cellulose nitrate).

Under low oxygen conditions plastics break down more slowly. The breakdown process can be accelerated in specially designed compost heap. Starch-based plastics will degrade within two to four months in a home compost bin, while polylactic acid is largely undecomposed, requiring higher temperatures.[21] Polycaprolactone and polycaprolactone-starch composites decompose slower, but the starch content accelerates decomposition by leaving behind a porous, high surface area polycaprolactone. Nevertheless, it takes many months.[22]

In 2016, a bacterium named Ideonella sakaiensis was found to biodegrade PET. In 2020, the PET degrading enzyme of the bacterium, PETase, has been genetically modified and combined with MHETase to break down PET faster, and also degrade PEF.[23][24][25] In 2021, researchers reported that a mix of microorganisms from cow stomachs could break down three types of plastics.[26][27]

Many plastic producers have gone so far even to say that their plastics are compostable, typically listing corn starch as an ingredient. However, these claims are questionable because the plastics industry operates under its own definition of compostable:

"that which is capable of undergoing biological decomposition in a compost site such that the material is not visually distinguishable and breaks down into carbon dioxide, water, inorganic compounds and biomass at a rate consistent with known compostable materials." (Ref: ASTM D 6002)[28]

The term "composting" is often used informally to describe the biodegradation of packaging materials. Legal definitions exist for compostability, the process that leads to compost. Four criteria are offered by the European Union:[29][30]

1. Chemical composition: volatile matter and heavy metals as well as fluorine should be limited.
2. Biodegradability: the conversion of >90% of the original material into CO_2, water and minerals by biological processes within 6 months.
3. Disintegrability: at least 90% of the original mass should be decomposed into particles that are able to pass through a 2x2 mm sieve.
4. Quality: absence of toxic substances and other substances that impede composting.

Biodegradable technology is established technology with some applications in product packaging, production, and medicine.[31] The chief barrier to widespread implementation is the trade-off between biodegradability and performance. For example, lactide-based plastics are inferior packaging properties in comparison to traditional materials.

Oxo-biodegradation is defined by CEN (the European Standards Organisation) as "degradation resulting from oxidative and cell-mediated phenomena, either simultaneously or successively." While sometimes described as "oxo-fragmentable," and "oxo-degradable" these terms describe only the first or oxidative phase and should not be used for material which degrades by the process of oxo-biodegradation defined by CEN: the correct description is "oxo-biodegradable." Oxo-biodegradable formulations accelerate the biodegradation process but it takes considerable skill and experience to balance the ingredients within the formulations so as to provide the product with a useful life for a set period, followed by degradation and biodegradation.[32]

Biodegradable technology is especially utilized by the bio-medical community. Biodegradable polymers are classified into three groups: medical, ecological, and dual application, while in terms of origin they are divided into two groups: natural and synthetic.[18] The Clean Technology Group is exploiting the use of supercritical carbon dioxide, which under high pressure at room temperature is a solvent that can use biodegradable plastics to make polymer drug coatings. The polymer (meaning a material composed of molecules with repeating structural units that form a long chain) is used to encapsulate a drug prior to injection in the body and is based on lactic acid, a compound normally produced in the body, and is thus able to be excreted naturally. The coating is designed for controlled release over a period of time, reducing the number of injections required and maximizing the therapeutic benefit. Professor Steve Howdle states that biodegradable polymers are particularly attractive for use in drug delivery, as once introduced into the body they require no retrieval or further manipulation and are degraded into soluble, non-toxic by-products. Different polymers degrade at different rates within the body and therefore polymer selection can be tailored to achieve desired release rates.[33]

Other biomedical applications include the use of biodegradable, elastic shape-memory polymers. Biodegradable implant materials can now be used for minimally invasive surgical procedures through degradable thermoplastic polymers. These polymers are now able to change their shape with increase of temperature, causing shape memory capabilities as well as easily degradable sutures. As a result, implants can now fit through small incisions, doctors can easily perform complex deformations, and sutures and other material aides can naturally biodegrade after a completed surgery.[34]

III.RESULTS

During bioattenuation, biodegradation occurs naturally with the addition of nutrients or bacteria. The indigenous microbes present will determine the metabolic activity and act as a natural attenuation.[23] While there is no anthropogenic involvement in bioattenuation, the contaminated site must still be monitored.[23] Biosparging is the process of groundwater remediation as oxygen, and possible nutrients, is injected. When oxygen is injected, indigenous bacteria are stimulated to increase rate of degradation.[24] However, biosparging focuses on saturated contaminated zones, specifically related to ground water remediation.[25] Biopiles, similar to bioventing, are used to reduce petroleum pollutants by introducing aerobic hydrocarbons to contaminated soils. However, the soil is excavated and piled with an aeration system. This aeration system enhances microbial activity by introducing oxygen under positive pressure or removes oxygen under negative pressure.[26] Windrow systems are similar to compost techniques where soil is periodically turned in order to enhance aeration.[28] This periodic turning also allows contaminants present in the soil to be uniformly distributed which accelerates the process of bioremediation.[29] Landfarming, or land treatment, is a method commonly used for sludge spills. This method disperses contaminated soil and aerates the soil by cyclically rotating.[30] This process is an above land application and contaminated soils are required to be shallow in order for microbial activity to be stimulated. However, if the contamination is deeper than 5 feet, then the soil is required to be excavated to above ground.[14] Heavy metals become present in the environment due to anthropogenic activities or natural factors.[7] Anthropogenic activities include industrial emissions, electronic waste, and ore mining. Natural factors include mineral weathering, soil erosion, and forest fires.[7] Heavy metals including cadmium, chromium, lead and uranium are unlike organic compounds and cannot be biodegraded. However, bioremediation processes can potentially be used to reduce the mobility of these material in the subsurface, reducing the potential for human and environmental exposure.[31] Heavy metals from these factors are predominantly present in water sources due to runoff where it is uptake by marine fauna and flora.[7]

The mobility of certain metals including chromium (Cr) and uranium (U) varies depending on the oxidation state of the material.[32] Microorganisms can be used to reduce the toxicity and mobility of chromium by reducing hexavalent chromium, Cr(VI) to trivalent Cr (III).[33] Uranium can be reduced from the more mobile U(VI) oxidation state to the less mobile U(IV) oxidation state.[34][35] Microorganisms are used in this process because the reduction rate of these metals is often slow unless catalyzed by microbial interactions[36] Research is also underway to develop methods to remove metals from water by enhancing the sorption of the metal to cell walls.[36] This approach has been evaluated for treatment of cadmium,[37] chromium,[38] and lead.[39] Genetically modified bacteria has also been explored for use in sequestration of Arsenic.[40] Phytoextraction processes concentrate contaminants in the biomass for subsequent removal.

For various herbicides and other pesticides both aerobic- and anaerobic-heterotrophs have been investigated. Bioremediation can be used to completely mineralize organic pollutants, to partially transform the pollutants, or alter their mobility. Heavy metals and radionuclides are elements that cannot be biodegraded, but can be bio-transformed to less mobile forms.[41][42][43] In some cases, microbes do not fully mineralize the pollutant, potentially producing a more toxic compound.[43] For example, under anaerobic conditions, the reductive dehalogenation of TCE may produce dichloroethylene (DCE) and vinyl chloride (VC), which are suspected or known carcinogens.[41] However, the microorganism Dehalococcoides can further reduce DCE and VC to the non-toxic product ethene.[44] The molecular pathways for bioremediation are of considerable interest.[41] In addition, knowing these pathways will help develop new technologies that can deal with sites that have uneven distributions of a mixture of contaminants.[24]

Biodegradation requires microbial population with the metabolic capacity to degrade the pollutant.[24][42] The biological processes used by these microbes are highly specific, therefore, many environmental factors must be taken into account and regulated as well.[24][41] It can be difficult to extrapolate the results from the small-scale test studies into big field operations.[24] In many cases, bioremediation takes more time than other alternatives such as land filling and incineration.[24][41] Another example is bioventing, which is inexpensive to bioremediate contaminated sites, however, this process is extensive and can take a few years to decontaminate a site.[45]>

In agricultural industries, the use of pesticides is a top factor in direct soil contamination and runoff water contamination. The limitation or remediation of pesticides is the low bioavailability.[46] Altering the pH and temperature of the contaminated soil is a resolution to increase bioavailability which, in turn, increased degradation of harmful compounds.[46]

The compound acrylonitrile is commonly produced in industrial setting but adversely contaminates soils. Microorganisms containing nitrile hydratases (NHase) degraded harmful acrylonitrile compounds into non-polluting substances.[47]

Since the experience with harmful contaminants are limited, laboratory practices are required to evaluate effectiveness, treatment designs, and estimate treatment times.[45] Bioremediation processes may take several months to several years depending on the size of the contaminated area.[48]

There is no universal definition for biodegradation and there are various definitions of composting, which has led to much confusion between the terms. They are often lumped together; however, they do not have the same meaning. Biodegradation is the naturally-occurring breakdown of materials by microorganisms such as bacteria and fungi or other biological activity.[35] Composting is a human-driven process in which biodegradation occurs under a specific set of circumstances.[36] The predominant difference between the two is that one process is naturally-occurring and one is human-driven.

Biodegradable material is capable of decomposing without an oxygen source (anaerobically) into carbon dioxide, water, and biomass, but the timeline is not very specifically defined. Similarly, compostable material breaks down into carbon dioxide, water, and biomass; however, compostable material also breaks down into inorganic compounds. The process for composting is more specifically defined, as it is controlled by humans. Essentially, composting is an accelerated biodegradation process due to optimized circumstances.[37] Additionally, the end product of composting not only returns to its previous state, but also generates and adds beneficial microorganisms to the soil called humus. This organic matter can be used in gardens and on farms to help grow healthier plants in the future.[38] Composting more consistently occurs within a shorter time frame since it is a more defined process and is expedited by human intervention. Biodegradation can occur in different time frames under different circumstances, but is meant to occur naturally without human intervention.

Even within composting, there are different circumstances under which this can occur. The two main types of composting are at-home versus commercial. Both produce healthy soil to be reused - the main difference lies in what materials are able to go into the process.[37] At-home composting is mostly used for food scraps and excess garden materials, such as weeds. Commercial composting is capable of breaking down more complex plant-based products, such as corn-based plastics and larger pieces of material, like tree branches. Commercial composting begins with a manual breakdown of the materials using a grinder or other machine to initiate the process. Because at-home composting usually occurs on a smaller scale and does not involve large machinery, these materials would not fully decompose in at-home composting. Furthermore, one study has compared and contrasted home and industrial composting, concluding that there are advantages and disadvantages to both.[40]

The following studies provide examples in which composting has been defined as a subset of biodegradation in a scientific context. The first study, "Assessment of Biodegradability of Plastics Under Simulated Composting Conditions in a Laboratory Test Setting," clearly examines composting as a set of circumstances that falls under the category of degradation.[41] Additionally, this next study looked at the biodegradation and composting effects of chemically and physically crosslinked polylactic acid.[42] Notably discussing composting and biodegrading as two distinct terms. The third and final study reviews European standardization of biodegradable and compostable material in the packaging industry, again using the terms separately.[43]

The distinction between these terms is crucial because waste management confusion leads to improper disposal of materials by people on a daily basis. Biodegradation technology has led to massive improvements in how we dispose of waste; there now exist trash, recycling, and compost bins in order to optimize the disposal process. However, if these waste streams are commonly and frequently confused, then the disposal process is not at all optimized.[44] Biodegradable and compostable materials have been developed to ensure more of human waste is able to breakdown and return to its previous state, or in the case of composting even add nutrients to the ground.[45] When a compostable product is thrown out as opposed to composted and sent to a landfill, these inventions and efforts are wasted. Therefore, it is important for citizens to understand the difference between these terms so that materials can be disposed of properly and efficiently.

Implications

Plastic pollution from illegal dumping poses health risks to wildlife. Animals often mistake plastics for food, resulting in intestinal entanglement. Slow-degrading chemicals, like polychlorinated biphenyls (PCBs), nonylphenol (NP), and pesticides also found in plastics, can release into environments and subsequently also be ingested by wildlife.[46]

These chemicals also play a role in human health, as consumption of tainted food (in processes called biomagnification and bioaccumulation) has been linked to issues such as cancers,[47] neurological dysfunction,[48] and hormonal changes. A well-known example of biomagnification impacting health in recent times is the increased exposure to dangerously high levels of mercury in fish, which can affect sex hormones in humans.[49]

In efforts to remediate the damages done by slow-degrading plastics, detergents, metals, and other pollutants created by humans, economic costs have become a concern. Marine litter in particular is notably difficult to quantify and review.[50] Researchers at the World Trade Institute estimate that cleanup initiatives' cost (specifically in ocean ecosystems) has hit close to thirteen billion dollars a year.[51] The main concern stems from marine environments, with the biggest cleanup efforts centering around garbage patches in the ocean. In 2017, a garbage patch the size of Mexico was found in the Pacific Ocean. It is estimated to be upwards of a million square miles in size. While the patch contains more obvious examples of litter (plastic bottles, cans, and bags), tiny microplastics are nearly impossible to clean up.[52] National Geographic reports that even more non-biodegradable materials are finding their way into vulnerable environments - nearly thirty-eight million pieces a year.[53]

Materials that have not degraded can also serve as shelter for invasive species, such as tube worms and barnacles. When the ecosystem changes in response to the invasive species, resident species and the natural balance of resources, genetic diversity, and species richness is altered.[54] These factors may support local economies in way of hunting and aquaculture, which suffer in response to the change.[55] Similarly, coastal communities which rely heavily on ecotourism lose revenue thanks to a buildup of pollution, as their beaches or shores are no longer desirable to travelers. The World Trade Institute also notes that the communities who often feel most of the effects of poor biodegradation are poorer countries without the means to pay for their cleanup.[51] In a positive feedback loop effect, they in turn have trouble controlling their own pollution sources.[56]

The use of genetic engineering to create organisms specifically designed for bioremediation is under preliminary research.[49] Two category of genes can be inserted in the organism: degradative genes, which encode proteins required for the degradation of pollutants, and reporter genes, which encode proteins able to monitor pollution levels.[50] Numerous members of Pseudomonas have been modified with the lux gene for the detection of the polyaromatic hydrocarbon naphthalene. A field test for the release of the modified organism has been successful on a moderately large scale.[51]

IV.CONCLUSIONS

There are concerns surrounding release and containment of genetically modified organisms into the environment due to the potential of horizontal gene transfer.[52] Genetically modified organisms are classified and controlled under the Toxic Substances Control Act of 1976 under United States Environmental Protection Agency.[53] Measures have been created to address these concerns. Organisms can be modified such that they can only survive and grow under specific sets of environmental conditions.[52] In addition, the tracking of modified organisms can be made easier with the insertion of bioluminescence genes for visual identification.[54]

Genetically modified organisms have been created to treat oil spills and break down certain plastics (PET).[55]

The first known use of biodegradable in a biological context was in 1959 when it was employed to describe the breakdown of material into innocuous components by microorganisms.[57] Now biodegradable is commonly associated with environmentally friendly products that are part of the earth's innate cycles like the carbon cycle and capable of decomposing back into natural elements.

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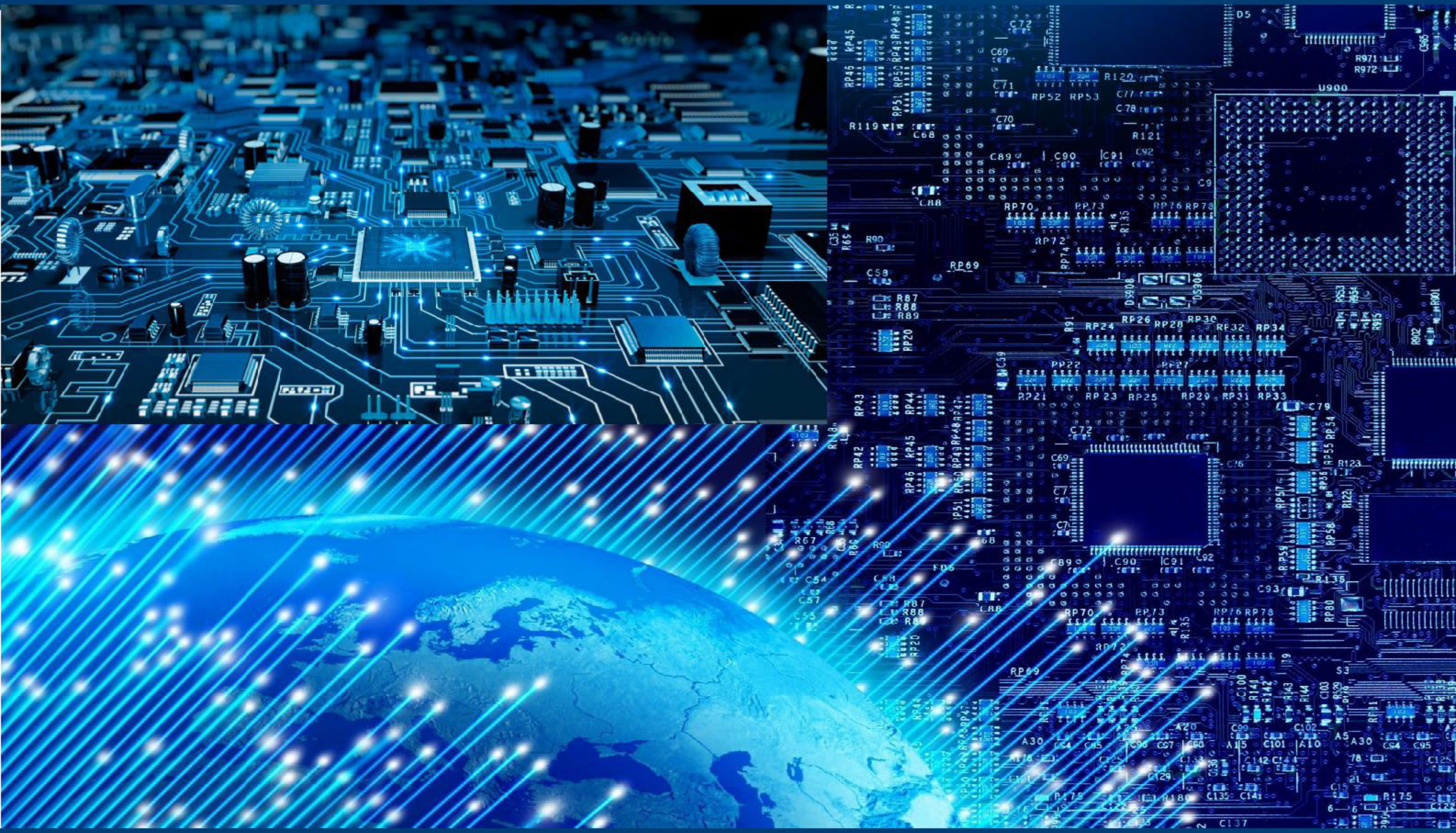

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