Eco. Env. & Cons. 29 (1) : 2023; pp. (314-320)
Copyright@ EM International
ISSN 0971–765X

DOI No.: http://doi.org/10.53550/EEC.2023.v29i01.046

Microplastic Hazards and Possible Mitigation

Pinak Dutta[1] and Mita Dutta[2*]

[1]Department of Chemistry, Bejoy Narayan Mahavidyalaya, Itachuna, Hooghly 712 147, W.B., India
[2]Department of Chemistry, Sreegopal Banerjee College, Bagati, Magra, Hooghly 712 148, W.B., India

(Received 5 August, 2022; Accepted 15 October, 2022)

ABSTRACT

Overuse of plastic that live on in nature has created a global crisis on our ecosystem and environment. Small particles of plastic of diameter upto 5mm called microplastics are found everywhere clogging the arteries of our mother nature. Microplastics absorb organic contaminants and act as vectors of potentially hazardous chemicals in living system. To save the flora and fauna of the earth from hazards of microplastics, the potential sources of microplastics should be identified and use of plastics be controlled and if possible terminated, Plastic litters should be recycled and reprocessed. To decrease our dependency on plastics, alternatives should be found. Research on plastic recycling and finding plastic alternatives should be scaled up. Most importantly common people should be made aware of the hazards of use of plastic. Public opinion in favour of termination of plastic use would be the most powerful weapon in saving the earth from this crisis.

Key words : *Microplastics, Environmental issues, Plastic alternatives*

Introduction

The invention of the first ever synthetic plastic in 1907 by Leo Baekeland was only just the beginning of a revolution. Plastics have slowly crept into all spheres of our life: clothing, furniture, coating, parts of vehicles, packaging of food products, cosmetics and what not as it is light weight, cheap, malleable and durable. With passage of time the durability factor of plastic is turning out to be a looming crisis on our ecosystem and environment. Plastics live on in nature even when it is discarded as it is not biodegradable. Some plastics which are called as biodegradable break down with a little more ease but are costly and have limited uses.

Microplastics and their whereabouts

Plastic debris found in the environment is of various sizes. In the early 1970's tiny fragments of plastic (polystyrene especially) were reported in the oceans. These small particles of plastic which increased in quantity over the years were termed as 'microplastic' (size upto 5 mm diameter) from around mid-2000. Plastics (including microplastics) form a major part of marine litter and is a major environmental issue (Bujnicki *et al.*, 2019; Barrett *et al.*, 2020; Alfaro-Núñez *et al.*, 2021; Gola *et al.*, 2021; United Nations Environment Programme, 2021).

Microplastics are now found everywhere literally everywhere - from mountain tops to seafloors, snows of Antarctica to the water we drink. Once plastic debris land in the oceans, it is carried by ocean circulation everywhere. Not only about half the global population lives within 100 kilometres of the coastline, even the population growth is highest in this area. Plastic debris is obviously highest in

([1]Associate Prof., [2]Associate Prof.)

these areas and with increasing population it will keep increasing. Hence plastics' being flushed into the ocean remains a dread until better land waste management is brought into force.

Sources of microplastics

Microplastics originate from various sources. Primarily microplastics are directly released in the environment from abrasion of large plastic objects while manufacturing, erosion of tyres while driving, abrasion of textile materials while washing or even from scrubbing agents in toiletries. Secondary microplastics originate from degradation of larger plastic pieces on exposure to weathering factors, photo degradation and mismanaged wastes like discarded plastic items, fishing nets etc.

Over the last seventy years the use of plastic has been exceptionally high. The production of plastic has gone up from 300 million metric tons to 360 million metric tons annually in the last five years (half of which is of single use). We are literally dumping the earth with plastic garbage. Of the total plastic produced only an estimated 9% has been recycled (Geyer *et. al.*, 2017), 4.8 to 12.7 million metric tons of microplastics enter the ocean (Jambeck *et al.*, 2015). Large plastics inspite of being readily visible have negative impacts on ecology (Thevenon *et. al.*, 2014), society and economy(GESAMP, 2015).

Microplastics either float or sink to the ocean floor depending on its density. Eventually significant amountof microplastics will accumulate in the deep seas (Woodall *et al.*, 2014) and even invade the food chain (Seltenrich *et al.*, 2015).

Hazards caused by microplastics

The risk perspective of microplastics in humans is yet to be studied and ascertained and there isn't sufficient evidence to quantify the hazards of microplastics yet. However, studies on effect of microplastics on aquatic animals are being done.

The physical effects of plastic debris when ingested by animals (terrestrial or marine) are quiet well understood. It clogs guts when ingested and even pose entanglement issues which cause hazards. Planktons, the most essential components of the marine habitat are also adversely affected by microplastics (Cole *et al.*, 2013),

In filter feeding marine organisms (mussels/ oysters), it is seen that particles including microplastics are found to induce a reaction within the tissue as they close the gut wall. These microplastics also have the capacity to affect the whale's filter-feeding system. Another matter of concern is that many types of plastics have the capacity to absorb organic contaminants (pesticides, biphenols). When these contaminated microplastics accidentally (with increase of microplastic load these accidents become common incidents) enter human system ', they can disrupt hormonal system, and even induce genetic changes and cause cancer. Marine animals too ingest these contaminated microplastics which leaches the toxins in the gut of these animals. Thus, these contaminated microplastics can act as vectors of potentially hazardous chemicals in the living systems.

A study on crabs of the Yorkshire coast showed that a plastic additive called oleamide causes hyperactivity in these animals (Greenshields *et al.*, 2021). These plastic additives which leach in the marine ecosystem is mistaken for chemical released by food sources during decomposition. Crabs travelling in search of food are finding plastic wastes instead. Zooplanktons are seen to grow more slowly and their reproduction is hindered in presence of microplastics.

In case of humans, a study by researchers at the University of New Castle in 2019 reported that humans on an average ingest 5 g of plastic weekly (Wit *et al.*, 2019). Though direct impact of these microplastics is yet to be assessed the chemicals used in plastic certainly can cause cancer, heart problem, poor foetal development, oxidative stress, respiratory distress and inflammation.

Even tinier speck of plastics known as nanoplastics (less than 1 micrometer) promise to wreak havoc to living beings. They may be formed from further disintegration of microplastics. They have capacity to enter cells and disrupt cellular activities.

These nanoplastics are capable of hanging around in tissues and cells. Since nanoplastic particles donot float or sink but remain suspended or dispersed in water, they are readily available for consumption by marine organisms. In a study on pregnant mice where they were deliberately made to inhale nanoparticles, it was seen that these particles were detected in almost all organs of the foetus (Lim *et al.*, 2021). So nanoplastics can easily enter food chain which is certainly not good news. Unlike large plastic pieces and even microplastics, nanoplastics cannot be scooped out of the marine system. Infact, it becomes impossible to distinguish the potentially harmful nanoplastics from other nano particles and thus removing them from the system becomes even more undoable. However, there is no doubt about their presence in the environment. Their presence in sea water sample collected from the Atlantic has been proved by Ter Halle and her team (Halle *et al.*, 2017).

Chemists all over the world harbour a guilt in their mind as being super polluters of the environment. They are striving to shift their activities to greener paths. But the domain of plastics is where they find themselves helpless. Use of plastics has smoothened human life yet it promises to roughen our future. The production of plastics is increasing in leaps and bounds globally. This in itself is against the principle of green chemistry which recommends control of production of hazardous substance rather than trying to clean up the waste after its creation. Having been enslaved by plastic, we are failing to rein the production of plastic. Plastic (large pieces, microplastics or nanoplastic) are omnipresent everywhere. The list where plastics are found is longer than a supermarket shopping list. We are consuming tiny servings of plastic in all we eat. Even babies consume microplastics through the milk prepared in plastic feeding bottles. Human placenta and poo too have traces of microplastic. However what effect it has on our health is still not determined. There is still lack of evidence to prove that they are hazardous to human health. But, as rightly observed by an expert on environmental contamination Prof. Mark Taylor of Macquarie University (Sydney): "But the absence of evidence is not evidence of absence".

So, what are we waiting for?

Maybe at the moment the level of microplastics and nanoplastics in the environment are low to affect human health, but projection by the researchers in September 2020 suggests that the amount of plastic beingadded to existing waste (be it carefully disposed in sealed landfills) would more than double to 380 million tons in 2040 from 188 million tons in 2016 (Lau *et al.*, 2020). Even if one does not take in account the particles being eroded from our existing waste, 10 million tons of new microplastic waste will be created. By then maybe will know that micro and nanoplastics are highly hazardous for human health, but we will by then lose our control on the situation leave aside reversing it. Very recent studies led by researchers from Woods Hole Oceanographic Institution finds that simple exposure to sunlight is not only capable of breaking plastics down, it can convert their base polymers and additives to a soup of new chemicals (Walsh *et al.*, 2021). This process often needs less than 100 hours of exposure. These sinister revelations that sunlight transforms plastics and its additives to new polymers as well as smaller chemical units that are easily soluble and are even airborne. That simply sun-baking can produce a sheer diversity of chemical products was not known till very recently and is enough to shake our belief that there is little proof of microplastics being harmful to us. So now is the time to act, we have no time to lose.

Now about what is being done and what needs to be done:

As per a report in 2016 (PEW) there are four sources of microplastics which accounts for 11% of total ocean plastic pollution.These sources are:

1. Broken down plastic fibres when synthetic textiles are washed.
2. Microbeads used in body care products (bodywashes and scrubs).
3. Plastic pelletsor nurdles used in production of almost all plastic products.
4. Wear and tear of tyres (this alone contributes to 78% of ocean microplastic pollution).

Breaking the plastic wave

To control the plastic pollution, fabrics need to be redesigned so that microfiber shredding can be minimized. An average of 700000 microplastic fibres are released with one load of laundry. In line filters if installed in washing machine can arrest these microfibers. To minimize nurdle pollution plans and procedures for pellet management must be strictly implemented. Microbeads used in personal care products can easily be replaced by natural biodegradable products like grounded nut shells. To control pollution from wear and tear of tyres, improving designs and quality of tyres is essential. A more holistic approach like use of public transport instead of private vehicles can be a game changer.

To tackle the superpolluting micro and nanoplastic problem we have to focus on controlling plastic pollution. This apparently has to be done through three simultaneous approaches:

1. Reducing and in some case terminating use of plastic
2. Cleaning up plastic litter and recycling or reprocessing it
3. Finding alternatives to plastics

Reducing and in some cases terminating use of plastic

Research and statistical analysis all over the world is clearly indicative that we need to gradually phase out and finally terminate use of plastics in certain catagories (Cousins *et al.*, 2019). The European Union has published an inventory of microplastics that are added to products, along with a proposal to restrict their use in nine product categories like detergents, commercial grade fertilizers and plastic coating for seeds. In the agriculture sector encapsulating pesticides in film coatings applied to agronomic seeds has become a widely used practice as it increases probability of seed germination and ensures overall health of the seedling. This method accounts for certain amounts of detached microplastic particles entering the soil. With agricultural activity accounting for 10% of total microplastic release, the search for biodegradable binders is now an important area of research. New generation of microplastic free seed coatings will become absolutely essential by 2027 in Europe as microplastic coatings will be banned from then. Other countries too are expected to follow suit. Such forceful banning actually effectively promotes sustainable product research.

With nearly 50% of the plastic produced annually being single use plastic, strict laws banning the production of these plastics should be robustly implemented. If this can be effectively done half the war can be won. Laws alone cannot achieve this, our will to comply with the law is of utmost importance.

Cleaning up plastic litter and recycling or reprocessing it

However, we cannot depend on law alone to tackle the microplastic adversity. We need to put in serious thoughts and research for methods to effectively remove or degrade microplastic which is omnipresent everywhere. Very recently a very innovative method to extract microplastics from the oceans and rivers by use of magnets has been proposed by Fiom Ferreiga, a young student of chemistry at Groningen University at the Netherlands. The Irish student has won the google's 2019 Science Fair with his innovative idea. Simply by observing oil spills in the sea being loaded with microplastic he stumbled upon the idea that oil could be used to attract microplastic. Mixing iron oxide with vegetable oil he created a ferrofluid. When microplastics attached themselves to the ferrofluid, he used a magnet to remove the ferrofluid with microplastics attached to them leaving back the water. This method has been found to be 87% effective. Currently he is designing a system which can be fitted to ships so that they can extract microplastics from the ocean as they sail.

Recycling plastic trash is another plausible way to handle the problem at hand. The search for plastic eating microbes is on around the globe. Bacteria capable of wielding enzymes that can break down plastics used for making water bottles and clothing have been found. The enzyme proteins produced by these microbes can speed up chemical reactions for recycling plastic and can be employed as a green approach compared to using chemicals for recycling (Yoshida *et al.*, 2016; Knott *et. al.*, 2020; Maurya *et al.*, 2020; Tournier *et al.*, 2020; Sadler *et al.*, 2021). Enzymatic degradation of plastic will be much more energy effective too.In fact, a company in France is building a demonstration factory which will use enzymes to turn plastic trash to raw material for new bottles. But what has to be kept in mind is that scaling up from laboratory to industry will require overcoming technical and economic hurdles even to keep minimum profits and it may so happen that new plastic can be cheaper than recycled one.

Plastic wastes are even being used to make sustainable building blocks (Antico *et al.*, 2017). Nathan Gay, a Newbury, U.S., based contractor runs a Home Factory, which use non-recyclable plastic wastes to create Eco Frienks. EcoBricks can be used to produce modular items like furniture, walls of garden, dog houses and non-dwelling projects. Re-plast is another example of building block made of machine compressed plastics (ocean litters) that looks like a unit of concrete but has no binding agent like glue or adhesive and hence have negative carbon foot print. Moreover, Re-plast blocks also have thermal and acoustic performance which traditional masonry fails to provide. Entrepreneur Gregor Gomory is the brain behind Re-plast. He however owns his inspiration from Peter Lewis, an engineer from New Zealand whose research pioneers the use of waste plastic as building material (da Silva *et al.*, 2021).

Another potential approach of reusing plastic is turning it into an energy carrier or feedstock for fuels. By heating waste plastic with air or steam (gasification) valuable industrial gas mixtures called synthesis gas (syngas) can be produced which can be used to produce diesel and petrol or directly be burned in boilers to generate electricity (Saebea *et al.*, 2020).

Pyrolysis of plastic, i.e., heating plastic waste in absence of oxygen can produce mixture of oil (crude oil). This can be further refined to produce transportation fuel. So, plastic incineration plants can be viewed as an alternative energy supply source and hence a modern way of driving a circular economy, especially where energy resources are scarce (Miandad *et al.*, 2019; Qureshi *et al.*, 2020).

Plastic Alternatives

We have become slave to plastics, we simply cannot do without it. It is this dependency that we have to come out of. So, we need to find potential alternatives to plastics. Innovation is the key to plastic replacement.

At present packaging industry has a few alternatives worth mentioning. Bioplastics are being made from corn, which is degraded to polylactic acid (PLA). This is highly sustainable as it is made from waste products from the production of corn (an easy to grow crop). Bottles and food grade containers can be made from PLA (Keziah *et al.*, 2018; Marichelyam *et al.*, 2019).

Bagasse, a by-product of sugarcane processing can easily be moulded into packaging for food services and delivery due to its malleability and sustainability. Sometimes it is used in combination with bamboo fibres. It is a compostable biodegradable alternative to polystyrene. It can also be used as reinforcements in composites (Hajiha *et al.*, 2015; Liu *et al.*, 2020). Bioplastics that are strong biodegradable and recyclable are being made from lignocellulosic material (Xia *et al.*, 2021; Leowa *et al.*, 2022). Palm leaves are being used to make oyster like cases for handmade soaps and even packaging for fresh fruits, vegetables, nuts etc. The palm leaves naturally shed by palm trees are collected and moulded into desired shaped containers. Many other agricultural products too are acting as raw materials for sustainable alternatives. Corn starch and sorghum are used to make biodegradable odour free and static free loose fills which are used for packing.

See weeds have successfully been used to create edible water bubble with the aim of making bottles providing the convenience of plastic bottles. The edible water blobs called Ooho are developed by UK based Skipping Rocks Lab, an innovative and sustainable packaging start-up founded by Imperial alumni Pierre Paslier and Rodrigo Garcia. Production of this biodegradable material is more energy efficient and cheaper than PET production. Edible packaging can help control plastic use as packaging material (Patel *et al.*, 2019).

Renowned cosmetic companies are trying to shift to sustainable packaging. Many national and international cosmetic brands are packaging their new eco-beauty range in recyclable containers the outside of which is compostable, glue-free, water resistant and inner liner made of recyclable plastic.

Stone paper, as the name suggests is paper made from stone, calcium carbonate in particular. The paper being printable, recyclable and water proof is a plastic alternative with good credentials. Stone papers can be used to make certified food-grade packaging, greaseproof paper wraps, ziplock bags etc (Ezcurra *et al.*, 2012; Chu *et al.*, 2019; Indriati *et al.*, 2020).

A sustainable alternative of cellophane has been made from FSC certified wood pulp (Nature Flex). These are uncoated and semi permeable and can be used as wraps for chocolates, confectionary, dairy, tea, coffee, bakery products etc (Ahmadzadeh *et al.*, 2020).

Even prawn and crab shells which usually are thrown away are used to make a material which has potential to replace plastic in packaging of food and drinks (Shamshina *et al.*, 2019; Niaounakis *et al.*, 2020).

Conclusion

The concluding statement to this article is straight forward. We need to act now. As we write this conclusion traces of microplastic have been reportedly detected in human blood stream. So, there is no doubt that human health and health of all species we share the earth with is at stake in this plastic storm. We need more and more initiatives to support policy making in favour of reducing and even terminating production of single use plastic. Government should take initiative to provide participatory research opportunities and education to groups of young people encouraging them to come up with innovative ideas regarding plastic waste removal, recycling and reusing and producing eco-friendly plastic alternatives. More than 60 countries have stressed on the necessity of a global framework for prevention and management of marine litter. But over everything it is we who have to vow to act responsibly to save our ecosystem.

Acknowledgement

Both PD and MD acknowledge their respective institutions for providing infrastructural and intellectual support.

Conflict of interest

Both the authors have no conflict of interest.

References

Alfaro-Núñez, A., Astorga, D., Cáceres-Farías, L., Bastidas, L., Villegas, C. S., Macay, K. C. and Christensen J. H. 2021. Microplastic pollution in seawater and marine organisms across the Tropical Eastern Pacific and Galápagos. *Sci. Rep.* 11: 6424. DOI: https://doi.org/10.1038/s41598-021-85939-3

Antico, F. C., Wiener, M. J., Araya-Letelier, G. and Gonzalez Retamal, R. G. 2017. Eco-bricks: a sustainable substitute for construction materials. *Revista De La Construcción. Journal of Construction.* 16(3): 518–526. DOI: https://doi.org/10.7764/RDLC.16.3.518

Barrett, J., Chase, Z., Zhang, J., Holl, M. M. B., Willis, K., Williams, A., Hardesty, B. D. and Wilcox, C. 2020. Microplastic Pollution in Deep-Sea Sediments from the Great Australian Bight. *Front. Mar. Sci.* 7: 576170. DOI: https://doi.org/10.3389/fmars.2020.576170

Bujnicki, J., Dykstra, P., Fortunato, E., Grobert, N., Heuer, R-D., Keskitalo, C. and Nurse, P. 2019. Environmental and health risks of microplastic pollution. *European Commission, Group of Chief Scientific Advisors, Scientific Opinion 6/2019*. Scientific Advice Mechanism (SAM). ISBN 978-92-76-02423-1. DOI: https://doi:10.2777/65378

Chu, C. and Nel, P. 2019. Characterisation and deterioration of stone papers. *AICCM Bull.* 40(1):37-49. DOI: https://doi.org/10.1080/10344233.2019.1672951

Cole, M., Lindeque, P., Fileman, E., Halsband, C., Goodhead, R., Moger, J. and Galloway, T. S. 2013. Microplastic Ingestion by Zooplankton. *Environmental Science & Technology.* 47(12): 6646–6655. https://doi.org/10.1021/es400663f

Cousins, I. T., Goldenman, G., Herzke, D., Lohmann, R., Miller, M., Ng, C. A., Patton, S., Scheringer, M., Trier, X., Vierke, L., Wang, Z. and DeWitt, J. C. 2019. The concept of essential use for determining when uses of PFASs can be phased out. *Environ. Sci.: Processes Impacts*. 21: 1803-1815. DOI: https://doi.org/10.1039/C9EM00163H

da Silva, T. R., de Azevedo, A., Cecchin, D., Marvila, M. T., Amran, M., Fediuk, R., Vatin, N., Karelina, M., Klyuev, S. and Szelag, M. 2021. Application of Plastic Wastes in Construction Materials: A Review Using the Concept of Life-Cycle Assessment in the Context of Recent Research for Future Perspectives. *Materials (Basel, Switzerland)*. 14(13): 3549. DOI: https://doi.org/10.3390/ma14133549

Ezcurra M. 2012. Terraskin® the paper made from stone: a study of a new writing support for forensic purposes. *Forensic Sci Int.* 220(1-3): 164–172. DOI: https://doi.org/10.1016/j.forsciint.2012.02.018

GESAMP 2015. Sources, Fate and Effects of Microplastics in The Marine Environment: A Global Assessment. 2015. GESAMP Reports & Studies No. 90 – Microplastics in the Ocean. DOI:10.13140/Rg.2.1.3803.7925

Geyer, R., Jambeck, J. R. and Law, K. L. Production, use, and fate of all plastics ever made. 2017. *Sci Adv.* 3(7):e1700782. *DOI:* 10.1126/sciadv.1700782

Gola, D., Tyagi, P. K., Arya, A., Chauhan, N., Agarwal, M., Singh, S. K. and Gola, S. 2021. The impact of microplastics on marine environment: A review. *Environ. Nanotechnol., Monit. Manage.* 16:100552. DOI: https://doi.org/10.1016/j.enmm.2021.100552

Greenshields, J., Schirrmacher, P. and Hardege, J. D. 2021. Plastic additive oleamide elicits hyperactivity in hermit crabs. *Mar Pollut Bull.* 169:112533. DOI: 10.1016/j.marpolbul.2021.112533

Halle, A. T., Jeanneau, L., Martignac, M., Jardé E., Pedrono, B., Brach, L.and Gigault, J. 2017. Nanoplastic in the North Atlantic Subtropical Gyre. *Environ. Sci. Technol.* 51(23): 13689–13697. DOI: https://doi.org/10.1021/acs.est.7b03667

Hajiha, H. and Sain, M. 2015. The use of sugarcane bagasse fibres as reinforcements in composites. *Biofiber Reinforcements in Composite Materials,* Publisher: Woodhead Publishing Ltd. Editors: O. Faruk, M. Sain. 525–549. DOI:10.1533/9781782421276.4.525

Indriati, L., Nugraha M. A. and Perng, Y. S. 2020. Stone paper an eco-friendly and free-tree papers. *Proc. 8th Int. Conf. Indonesian Chem. Soc. (ICICS)*. 2243(1): 030010-1-030010-12. DOI: https://doi.org/10.1063/5.0001753

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R. and Law, K. L. 2015. Plastic waste inputs from land into the ocean. *SCIENCE.* 347(6223): 768-771. DOI: 10.1126/science.1260352

Keziah, V. S., Gayathri R, Gayathri, R. and Priya, V. V. 2018. Biodegradable plastic production from corn starch. *Drug Invent. Today*. 10(7): 1315-1317.

Knott, B. C., Erickson, E., Allen, M. D., Gado, J. E., Graham, R., Kearns, F. L., Pardo, I., Topuzlu, E., Anderson, J. J., Austin, H. P., Dominick, G., Johnson, C. W., Rorrer, N. A., Szostkiewicz, C. J., Copié, V., Payne, C. M., Woodcock, H. L., Donohoe, B. S., Beckham, G. T. and McGeehan, J. E. 2020. Characterization and engineering of a two-enzyme system for plastics depolymerization. *Proceedings of the National Academy of Sciences of the United States of America*, *117*(41): 25476–25485. DOI: https://doi.org/10.1073/

pnas.2006753117

Lau, W. W. Y., Shiran, Y., Bailey, R. M., Cook, E., Stuchtey, M. R., Koskella, J., Velis, C. A., Godfrey, L., Boucher, J. and Palardy, J. E. 2020. Evaluating scenarios toward zero plastic pollution. *Science.* 369(6510): 1455-1461. DOI: 10.1126/science.aba9475

Leowa, Y., Sequeraha, V., Tan, Y. C., Yu, Y., Peterson, E. C., Jiang, C., Zhang, Z., Yang, L., Loh, X. J. and Kai, D. 2022. A tough, biodegradable and water-resistant plastic alternative from coconut husk. *Composites Part B: Engineering*. 241: 110031. DOI: 10.1016/j.compositesb.2022.110031

Lim, X. Z. 2021. Microplastics are everywhere — but are they harmful? *Nature.* 593: 22-25. DOI:https://doi.org/10.1038/d41586-021-01143-3

Liu, C., Luan, P., Li, Q., Cheng, Z., Sun, X., Cao, D. and Zhu, H. 2020. Biodegradable, Hygienic, and Compostable Tableware from Hybrid Sugarcane and Bamboo Fibers as Plastic Alternative. *Matter*. 3(6): 2066-2079. DOI: https://doi.org/10.1016/j.matt.2020.10.004

Marichelvam, M. K., Jawaid, M. and Asim, M. 2019. Corn and Rice Starch-Based Bio-Plastics as Alternative Packaging Materials. *Fibers*. 7(4): 32. DOI: https://doi.org/10.3390/fib7040032

Maurya, A., Bhattacharya M. A., and Khare, S. K. 2020. Enzymatic Remediation of Polyethylene Terephthalate (PET)-Based Polymers for Effective Management of Plastic Wastes: An Overview. *Front. Bioeng. Biotechnol*. 8: 602325.https://doi.org/10.3389/fbioe.2020.602325

Miandad, R., Rehan, M., Barakat, M. A., Aburiazaiza, A. S., Khan, H., Ismail, I. M. I., Dhavamani, J., Gardy, J., Hassanpour, A. and Nizami, A-S. 2019. Catalytic Pyrolysis of Plastic Waste: Moving Toward Pyrolysis Based Biorefineries. *Front. Energy Res.* 7:27. DOI: https://doi.org/10.3389/fenrg.2019.00027

Niaounakis, M. 2020. Recycling of Flexible Plastic Packaging. *Plastics Design Library, William Andrew*. ISBN: 978-0-12-816335-1. DOI: https://doi.org/10.1016/C2018-0-00076-6

Patel, P. 2019. Edible Packaging. Can you really have your cake and eat the wrapper, too? *ACS Cent. Sci.* 5 (12) : 1907–1910. DOI: https://doi.org/10.1021/acscentsci.9b01251

Qureshi, M. S., Oasmaa, A., Pihkola, H., Deviatkin, I., Tenhunen, A., Mannila, J., Minkkinen, H., Pohjakallio, M. and Laine-Ylijoki, J. 2020. Pyrolysis of plastic waste: Opportunities and challenges. *J. Anal. Appl. Pyrolysis*. 152 : 104804. DOI: https://doi.org/10.1016/j.jaap.2020.104804

Sadler, J.C. and Wallace, S. 2021. Microbial synthesis of vanillin from waste poly(ethylene terephthalate). *Green Chem.* 23(13) : 4665-4672. DOI: https://doi.org/10.1039/D1GC00931A

Saebea, D., Ruengrit, P., Arpornwichanop, A. and Patcharavorachot, Y. 2020. Gasification of plastic waste for synthesis gas production. *Energy Reports*. 6(supp. 1): 202-207. DOI: https://doi.org/10.1016/j.egyr.2019.08.043

Seltenrich, N. 2015. New link in the food chain? Marine plastic pollution and seafood safety. *Environ Health Perspect.* 123 (2): A34-A41. *Erratum.* 124(7) 2016. DOI: https://doi.org/10.1289/EHP465

Shamshina, J.L., Berton, P. and Rogers, R.D. 2019. Advances in Functional Chitin Materials: A Review. *ACS Sustainable Chemistry & Engineering*. 7 (7): 6444-6457. DOI: https://doi.org/10.1021/acssuschemeng.8b06372

Thevenon, F., Carroll, C. and Sousa, J. 2014. Plastic Debris in the Ocean. The Characterization of Marine Plastics and their Environmental Impacts, Situation Analysis Report. *IUCN (International Union for Conservation of Nature).* ISBN: 978-2-8317-1696-1. DOI:10.2305/IUCN.CH.2014.03.en

Tournier, V., Topham, C. M., Gilles, A., David, B., Folgoas, C., Moya-Leclair, E., Kamionka, E., Desrousseaux, M. L., Texier, H., Gavalda, S., Cot, M., Guémard, E., Dalibey, M., Nomme, J., Cioci, G., Barbe, S., Chateau, M., André, I., Duquesne, S. and Marty, A. 2020. An engineered PET depolymerase to break down and recycle plastic bottles. *Nature*. 580 (7802): 216–219. https://doi.org/10.1038/s41586-020-2149-4

United Nations Environment Programme. 2021. From Pollution to Solution: A global assessment of marine litter and plastic pollution. *Synthesis. Nairobi*. United Nations Environment Programme (UNEP) and GRID-Arenda. ISBN: 978-92-807-3881-0.

Walsh, A. N., Reddy, C. M., Niles, S. F., McKenna, A. M., Hansel, C. M. and Ward, C. P. 2021. Plastic Formulation is an Emerging Control of Its Photochemical Fate in the Ocean. *Environ. Sci. Technol.* 55(18): 12383–12392. https://doi.org/10.1021/acs.est.1c02272

Wit, W.J. and Bigaud, N. 2019. No plastic in nature: assessing plastic ingestion from nature to people. *Environmental Science*. An analysis for WWF by Dalberg and The University of New Castle Australia. ISBN 978-2-940529-95-7.

Xia, Q., Chen, C., Yao, Y., Li, J., He, S., Zhou, Y., Li, T., Pan, X., Yao, Y. and Hu, L. 2021. A strong, biodegradable and recyclable lignocellulosic bioplastic. *Nat. Sustain.* 4: 627–635. https://doi.org/10.1038/s41893-021-00702-w

Yoshida, S., Hiraga, K., Takehana, T., Taniguchi, I., Yamaji, H., Maeda, Y., Toyohara, K., Miyamoto, K., Kimura, Y. and Oda, K. 2016. A bacterium that degrades and assimilates poly(ethylene terephthalate). *Science*. 351(6278): 1196-1199. DOI: 10.1126/science.aad6359