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Recycling Of Plastic And Used Engine Oil For The Production Of Paving Bricks And Building Blocks

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ABSTRACT
The study looked at recycling of plastic and used engine oil for the production of paving bricks and building blocks. The plastic wastes are being gathered from the streets as well as dumpsites from locations at D\Line, Port Harcourt, Rivers States. Also, the used engine oil, from a mechanic workshop at D\Line, Port Harcourt, Rivers State. The waste plastic will be sorted, washed in water and dried properly. When dried, the plastic will be put into a shredder, to reduce the sizes; to aid the heating process as well as reduce the time required. The used engine oil will then be filtered to remove any solid impurities. The filtered used engine oil will be poured into a plastic waste melter. The shredded plastic will be poured in next. The plastic waste melter is a machine constructed to heat up to about 150oC and melt the plastic while it spins continually to ensure a proper mixture of both the used engine oil and melted plastic. The samples were tested for water absorption, bulk density and compressive strength. The specimens will be tested against the regular cement bricks. The specimen had a lower bulk density than the cement bricks. A lower bulk density could help in reducing the dead loads of structure and in turn improve the economy by lowering construction costs. The specimen had a lower water absorption rate. With a lower water absorption rate, these bricks were being more durable than the regular bricks. The bricks had a specified minimum compressive strength so that they can be used in construction works. The findings revealed that plastic bricks yield higher compressive strength or relatively comparable value to the conventional bricks. Finally, it was recommended that government should organize an effective waste management program to convert most condemn plastic to be used as bricks. This will enhance rural and urban infrastructural development.
Keywords: Recycling, Plastic, Engine Oil, Paving Bricks, Building Blocks

INTRODUCTION
Since the creation of numerous methods for producing polymers from petrochemical sources, the plastics industry has expanded significantly. In comparison to many other material types, plastics have significant advantages in terms of low weight, durability, and lower cost (Andrady & Neal 2009; Thompson et al. 2009). For all polymers, including thermoplastics, thermoset plastics, adhesives, and coatings, but excluding synthetic fibers, global polymer production was estimated to be 260 million metric tonnes annually in 2007 (Plastics Europe 2008b). This suggests an average annual growth rate of around 9%.
Two-thirds of this production is made up primarily of thermoplastic resins, and usage of these materials is increasing globally at a rate of 5% per year (Andrady 2003). Today, petrochemicals made from petroleum are almost entirely used to make plastic. Today, petrochemicals made from fossil fuels like oil and gas make up almost all of the materials used to make plastic. According to the British Plastics Federation (2008), 4% of the world's annual petroleum production is converted directly into plastics from petrochemical feedstock. Plastic production necessitates energy as well, which results in a corresponding

increase in the consumption of fossil fuels. However, it is also possible to make the case that the use of lightweight plastics can result in a decrease in the consumption of fossil fuels, for instance in transportation applications where plastics can be used in place of heavier conventional materials like steel (Andrady & Neal 2009; Thompson et al. 2009).

Between 20 and 25 percent of plastics are used for long-term infrastructure like pipes, cable coatings, and structural materials. The remaining 30 percent are used for durable consumer applications with intermediate lifespans, like in electronic goods, furniture, vehicles, etc. Approximately 50 percent of plastics are used for single-use disposable applications, such as packaging, agricultural films, and disposable consumer items. According to Plastics Europe (2008), the European Union (EU) produced 24.6 million tonnes of post-consumer plastic waste in 2007. The breakdown of plastics consumption in the UK in 2000 and its impact on waste production are shown in Table 1 (Waste Watch 2003).

Plastics have only been mass-produced for about 60 years, so it is uncertain how long they will last in the environment. The majority of polymers produced today will last for at least decades and probably for centuries or even millennia because the majority of plastic types are not biodegradable and are actually very durable (Andrady 1994). As rates of degradation depend on physical factors, such as levels of ultraviolet light exposure, oxygen content, and temperature (Swift & Wiles 2004), even degradable plastics may persist for a long time depending on local environmental factors. In contrast, biodegradable plastics require the presence of suitable microorganisms. As a result, degradation rates in landfills, terrestrial environments, and marine environments differ greatly (Kyrikou & Briassoulis 2007). Even when a plastic object deteriorates as a result of weathering, it first disintegrates into smaller pieces of plastic debris; however, the polymer may not always fully degrade over a period of time that is meaningful. Because of this, large amounts of end-of-life plastics are building up in landfills and as debris in the environment, which causes problems with waste management and environmental harm (see Barnes et al. 2009; Gregory 2009; Oehlmann et al. 2009; Ryan et al. 2009; Teuten et al. 2009; Thompson et al. 2009b). Recycling is undoubtedly a waste-management technique, but it can also be seen as one modern application of the idea of industrial ecology since there aren't any wastes in a natural ecosystem—only products exist there (Frosch & Gallopoulos 1989; McDonough & Braungart 2002). One way to lessen the impact on the environment and resource depletion is to recycle plastics. Fundamentally, high levels of recycling can enable a given level of product service with less material input than would otherwise be needed. This is true of reduction in use, reuse, repair, and re-manufacturing. Recycling can therefore result in improved eco-efficiency by reducing the amount of energy and materials used per unit of output (WBCSD 2000). It should be noted, however, that the ability to maintain whatever residual level of material input, along with the energy inputs and the results of external impacts on ecosystems, will determine the overall system's ultimate sustainability.

This paper reviews the current systems and technology for plastics recycling, life-cycle evidence for the eco efficiency of plastics recycling in Nigeria. The focus is on production and disposal of packaging, as this is the largest single source of waste plastics in Nigeria and represents an area of considerable recent expansion in recycling initiatives.

Problem of the Study

Plastics are durable and not expensive; hence their very high rate of production. Also, these plastics have chemical structures that make them resistant to the natural process of degradation. Due to these and a poor waste management, plastic pollution is high today.

Used engine oil is also a menace as they are poured directly into the soil and even in water bodies. When poured in the soil, they reduce the richness of the soil and the ease with which the soil will germinate crops while in water bodies; they can cause a great harm to the aquatic animals.

Another important part of this work is the provision of informal job opportunities for the unemployed youths as they will be engaged in the collection of the plastic waste as well as the used oil thereby reducing the unemployment rate in the society.

Objective of the Study

The primary objective of this work is to advance an efficient way of recycling plastic waste and used engine oil to reduce the accumulation of these hazardous wastes in the environment. This study will also help reduce the over dependence of cement for construction.

Literature Review

Concept of Waste Management

Waste is a product or substance which is no longer suited for its intended use. Whereas in natural ecosystems waste (i.e. oxygen, carbon dioxide and dead organic matter) is used as food or a reactant, waste materials resulting from human activities are often highly resilient and take a long time to decompose. Waste management involves the processes of waste collection, transportation, processing, as well as waste recycling or disposal. Sustainable waste management systems include advanced management strategies to minimize environmental challenges and protect resources (Demirbas, 2011). It was widely recognized that the 3R (reduce, reuse, and recycle) principle of waste management encourages the general public to reflect on the entire life cycles of products and services, and explore solutions to preserve more natural resources for our future generations. It arouses the design for resource-saving and long-life products. Waste reduction by minimizing the amount of waste at the source is the top priority, while recycling by using waste as raw materials for other purposes is another promising alternative.

The amount of waste produced is influenced by economic activity, consumption, and population growth. Waste generation, in most cases, represents inefficient use of materials. Tracking trends in the quantity, composition, and effects of these materials provides insight into the efficiency with which the nation uses (and reuses) materials and resources and provides a means to better understand the effects of wastes on human health and ecological condition (United States Environmental protection Agency, 2021).

Once generated, wastes must be managed through reuse, recycling, storage, treatment, energy recovery, and/or disposal or other releases to the environment. Waste management refers to the various schemes to manage and dispose of wastes. It can be by discarding, destroying, processing, recycling, reusing, or controlling wastes. The prime objective of waste management is to reduce the amount of unusable materials and to avert potential health and environmental hazards (World & Washington, n.d).

In the first scenario, actions that lessen the amount of materials used in products (such as replacing heavy packaging formats with lighter ones or downgauging packaging) can reduce the amount of material entering the waste-management system. Fewer products will enter the waste stream if they are designed to be reused, repaired, or remanufactured. Recycling is the process of using salvaged material to create a new product after it has entered the waste stream. The idea of recovery can also be extended to include energy recovery for organic materials like plastics, in which the calorific value of the material is used as fuel by controlled combustion. However, this has a lower overall environmental performance than material recovery because it does not involve recycling the material. The idea of recovery can be broadened for organic materials like plastics to include energy recovery, in which the calorific value of the material is used as fuel by controlled combustion; however, this has a lower overall environmental performance than material recovery because it does not lessen the need for new (virgin) material. The 4Rs waste management strategy, which stands for reduce, reuse, recycle (materials), recycle (energy), and recover (energy), with landfill as the least desirable management strategy, is based on this way of thinking.

Recycling Plastic Waste

Terminology for plastics recycling is complex and sometimes confusing because of the wide range of recycling and recovery activities. These include four categories: primary (mechanical reprocessing into a product with equivalent properties), secondary (mechanical reprocessing into products requiring lower properties), tertiary (recovery of chemical constituents) and quaternary (recovery of energy). Primary recycling is often referred to as closed-loop recycling, and secondary recycling as downgrading. Tertiary recycling is either described as chemical or feedstock recycling and applies when the polymer is depolymerized to its chemical constituents (Fisher, 2003). Quaternary recycling is energy recovery, energy from waste or valorization. Biodegradable plastics can also be composted, and this is a further example of tertiary recycling, and is also described as organic or biological recycling (Song et al. 2009).

It is possible in theory to closed-loop recycle most thermoplastics, however, plastic packaging frequently uses a wide variety of different polymers and other materials such as metals, paper, pigments, inks and adhesives that increases the difficulty. Closed-loop recycling is most practical when the polymer constituent can be effectively separated from sources of contamination and stabilized against degradation during reprocessing and subsequent use. Ideally, the plastic waste stream for reprocessing would also consist of a narrow range of polymer grades to reduce the difficulty of replacing virgin resin directly. For example, all PET bottles are made from similar grades of PET suitable for both the bottle manufacturing process and reprocessing to polyester fibre, while HDPE used for blow moulding bottles is less-suited to injection moulding applications. As a result, the only parts of the post-consumer plastic waste stream that have routinely been recycled in a strictly closed-loop fashion are clear PET bottles and recently in the UK, HDPE milk bottles. Pre-consumer plastic waste such as industrial packaging is currently recycled to a greater extent than post-consumer packaging, as it is relatively pure and available from a smaller number of sources of relatively higher volume. The volumes of post-consumer waste are, however, up to five times larger than those generated in commerce and industry (Patel et al. 2000) and so in order to achieve high overall recycling rates, post-consumer as well as post-industrial waste need to be collected and recycled. In some instances recovered plastic that is not suitable for recycling into the prior application is used to make a new plastic product displacing all, or a proportion of virgin polymer resin—this can also be considered as primary recycling. Examples are plastic crates and bins manufactured from HDPE recovered from milk bottles, and PET fibre from recovered PET packaging. Downgrading is a term sometimes used for recycling when recovered plastic is put intoan application that would not typically use virgin —e.g. 'plastic lumber' as an alternative to higher cost/shorter lifetime timber, this is secondary recycling (ASTM Standard D5033). Chemical or feedstock recycling has the advantage of recovering the petrochemical constituents of the poly- mer, which can then be used to manufacture plastic or to make other synthetic chemicals. However, while technically feasible it has generally been found to be uneconomic without significant subsidies because of the low price of petrochemical feedstock compared with the plant and process costs incurred to produce monomers from waste plastic (Patel et al. 2000). This is not surprising as it is effectively reversing the energy- intensive polymerization previously carried out during plastic manufacture. Feedstock recycling of polyolefins through thermal- cracking has been performed in the UK through a facility initially built by BP and in Germany by BASF. However, the latter plant was closed in 1999 (Aguado et al. 2007). Chemical recycling of PET has been more successful, as de-polymerization under milder conditions is possible. PET resin can be broken down by glycolysis, methanolysis or hydrolysis, for example to make unsaturated polyester resins (Sinha et al. 2008). It can also be converted back. Biodegradable plastics have the potential to solve a number of waste-management issues, especially for disposable packaging that cannot be easily separated from organic waste in catering or from agricultural applications. It is possible to include biodegradable plastics in aerobic composting, or by anaerobic digestion with methane capture for energy use. However, biodegradable plastics also have the potential to complicate waste management when introduced without appropriate technical attributes, handling systems and consumer education. In addition, it is clear that there could be significant issues in sourcing sufficient biomass to replace a large proportion of the current consumption of polymers, as only 5 percent of current European chemical production uses biomass as feedstock (Soetaert & Vandamme 2006). This is a large topic that cannot be covered in this paper, except to note that it is desirable that compo stable and degradable plastics are appropriately labelled and used in ways that complement, rather compromise waste-management schemes (Song et al. 2009).

Plastic Recycling System

Plastic recycling refers to the process of recovering waste or scrap plastic and reprocessing the materials into functional and useful products. The goal of recycling plastic is to reduce high rates of plastic pollution while putting less pressure on virgin materials to produce brand new plastic products. This approach helps to conserve resources and diverts plastics from landfills or unintended destinations such as oceans (Rick, 2020).

Plastic recycling is extremely important, both as a method to deal with our existing waste and as a component of both circular economy and zero-waste systems that aim to reduce waste generation and increase sustainability. There are social, environmental, and economic consequences surrounding our current waste generation and disposal habits. Many different standards discuss plastics recycling, composting, biodegradation, and other similar subjects, forming broad analytical background for decision-making and selection processes.

Plastic materials can be recycled in a variety of ways and the ease of recycling varies among polymer type, package design and product type. For example, rigid containers consisting of a single polymer are simpler and more economical to recycle than multi-layer and multi-component packages. Thermoplastics, including PET, PE and PP all have high potential to be mechanically recycled. Thermosetting polymers such as unsaturated polyester or epoxy resin cannot be mechanically recycled, except to be potentially re-used as filler materials once they have been size-reduced or pulverized to fine particles or powders (Rebeiz & Craft 1995). The process for the recycling of plastic has seen a massive improvement in recent years and can be broken down into six basic steps. Post-consumer recycling therefore comprises of several key steps: collection, sorting, cleaning, size reduction and separation, and/or compatibilization to reduce contamination by incompatible polymers.

Collection- The first step in the mechanical recycling process is the collection of post-consumer materials from homes, businesses, and institutions. It is taken to a Material Recovery Facilities (MRF), and/ or a Plastic Recovery Facility (PRF) ready to be sorted. The material may be bulked at a waste transfer station before being transported to these facilities. The collection of plastic is key for the recycling system to operate well. The more plastic suitable for recycling that is collected the more material available to be reprocessed and used back into new products (EPA, 2020).

Sorting - Sorting of co-mingled rigid recyclables occurs by both automatic and manual methods. Automated pre-sorting is usually sufficient to result in a plastics stream separate from glass, metals and paper (other than when attached, e.g. as labels and closures). Generally, clear PET and unpigmented HDPE milk bottles are positively identified and separated out of the stream. Automatic sorting of containers is now widely used by material recovery facility operators and also by many plastic recycling facilities.

Most local authorities or material recovery facilities do not actively collect post-consumer flexible packaging as there are current deficiencies in the equipment that can easily separate flexibles. Many plastic recycling facilities use trommels and density-based air-classification systems to remove small amounts of flexibles such as some films and labels. There are, how- ever, developments in this area and new technologies such as ballistic separators, sophisticated hydro cyclones and air-classifiers that will increase the ability to recover post-consumer flexible packaging (Fisher 2003).

Cleaning and washing- Washing is a crucial step in the plastic recycling process since it removes some of the impurities that can impede the operation, or completely ruin a batch of recycled plastic. The impurities targeted in this step commonly include things such as product labels and adhesives as well as dirt and food residue. While plastic is often washed at this stage, it is important to remember that this doesn't take away from the importance of ensuring plastics are as free from impurities as possible before disposal and collection.

Shredding- The plastic is then fed into shredders, which break it down into much smaller pieces. These smaller pieces, unlike formed plastic products, can be processed in the next stages for reuse. Additionally, the resized plastic pieces can be used for other applications without further processing, such as an additive within asphalt or simply sold as a raw material. Breaking down the plastic into smaller pieces also allows for any remaining impurities to be found. This is especially true of contaminants such as metal, which may not have been removed by washing but can be easily collected with a magnet at this stage (RTS, 2020).

Identification and separation of plastics- Here, the plastic pieces are tested for their class and quality. First, they are segregated based on density, which is tested by floating the particles of plastic in a container of water. This is followed by a test for what is known as the "air classification", which determines the thickness of the plastic pieces. It is done by placing the shredded plastic into a wind tunnel, with thinner pieces floating while larger/thicker pieces stay at the bottom.
Extruding + compounding- This final plastic recycling process step is where the particles of shredded plastic are transformed into a usable product for manufactures. The shredded plastic is melted and crushed together to form pellets. It is worth noting that it is not always possible to compound all types, classification, and qualities of plastic at a single plant, so different grades of plastic are sometimes sent to other recycling facilities for this final step (RTS, 2020).

METHODOLOGY

The plastics to be used in this experiment are plastic bottles and nylons. The plastic wastes are being gathered from the streets as well as dumpsites from locations at D\Line, Port Harcourt, Rivers States. Also, the used engine oil, from a mechanic workshop at D\Line, Port Harcourt, Rivers State.
The waste plastic will be sorted, washed in water and dried properly. When dried, the plastic will be put into a shredder, to reduce the sizes; to aid the heating process as well as reduce the time required. The used engine oil will then be filtered to remove any solid impurities. The filtered used engine oil will be poured into a plastic waste melter. The shredded plastic will be poured in next. The plastic waste melter is a machine constructed to heat up to about 150oC and melt the plastic while it spins continually to ensure a proper mixture of both the used engine oil and melted plastic. The resulting mixture will be transferred to a mould to give the required shape and size and left to cool off. After cooling it for 10 hours in the mould, the specimens will be demoulded and immersed in water for 24 hours before being removed for testing.

RESULTS AND FINDINGS

The samples were tested for water absorption, bulk density and compressive strength. The specimens will be tested against the regular cement bricks. The specimen had a lower bulk density than the cement bricks. A lower bulk density could help in reducing the dead loads of structure and in turn improve the economy by lowering construction costs. The specimen had a lower water absorption rate. With a lower water absorption rate, these bricks were being more durable than the regular bricks.
The bricks had a specified minimum compressive strength so that they can be used in construction works. The findings revealed that plastic bricks yield higher compressive strength or relatively comparable value to the conventional bricks.

Figure 1: Preparation of Plastic bricks

Table 1: Comparison of Maximum Compressive Strength and Maximum Principal Compressive Stress

S/N	Material utilized	Maximum Compressive Strength	Maximum Principal Compressive Strength
1	Concrete	19	7.23
2	Plastic Bricks	46.1	22.1

Findings from table 1 Showed that maximum compressive strength for concrete and plastic bricks is 19 and 46.1 respectively. The maximum principal compressive strength for concrete and plastic bricks is 7.23 and 22.1 respectively.

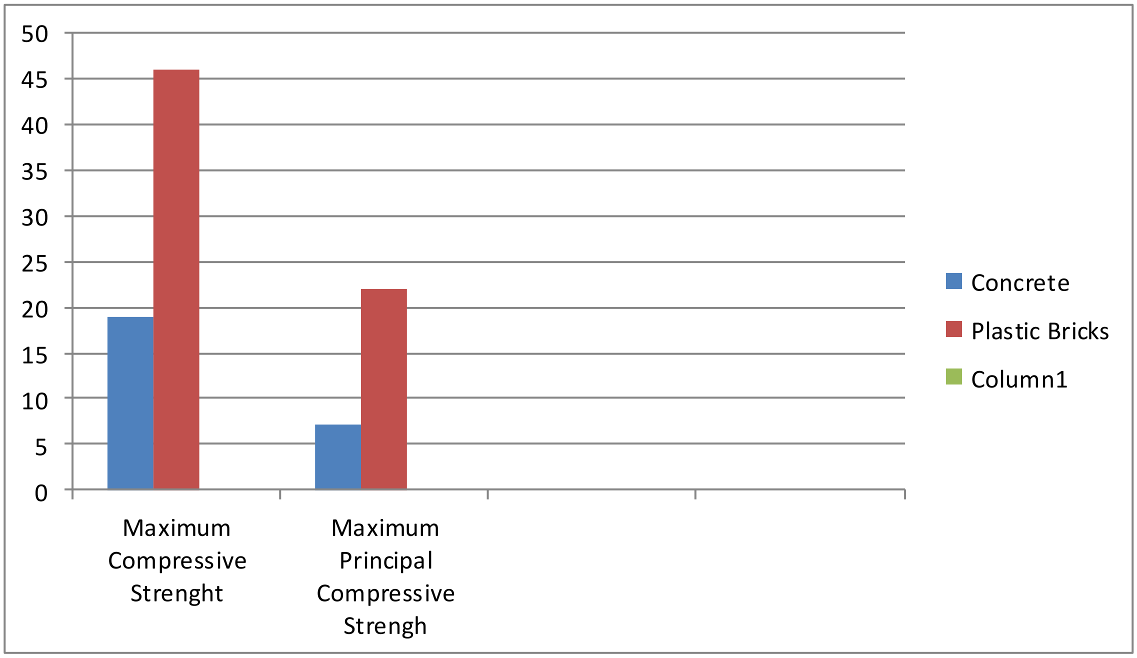

Figure 2: Chart of Maximum Compressive Strength and Maximum Principal Compressive Stress

Findings from figure 2 showed that the block made from recycled plastic had a higher maximum principal compressive strength when compared to the concrete block and can be used as a building material.

CONCLUSION

It can be concluded that recycling of waste plastic is highly needed to curb waste and in the production of plastic bricks that is cheaper and more efficient in building construction.

RECOMMENDATION

Finally, it was recommended that government should organize an effective waste management program to convert most condemn plastic to be used as bricks. This will enhance rural and urban infrastructural development.

REFERENCES

Aguado, J., Serrano, D. P. & San Miguel, G. 2007 European trends in the feedstock recycling of plastic wastes. Global NEST J. 9, 12–19.

Andrady, A. 1994 Assessment of environmental biodegradation of synthetic polymers. Polym. Rev. 34, 25–76.(doi:10.1080/15321799408009632)

Andrady, A. 2003 An environmental primer. In Plastics and the environment (ed. A. Andrady), pp. 3– 76. Hoboken, NJ: Wiley Interscience

Andrady, A. L. & Neal, M. A. 2009 Applications and societal benefits of plastics. Phil. Trans. R. Soc. B 364, 1977–1984. (doi:10.1098/rstb.2008.0304)

Barnes, D. K. A., Galgani, F., Thompson, R. C. & Barlaz, M.2009 Accumulation and fragmentation of plastic debris in global environments. Phil. Trans. R. Soc. B 364, 1985–1998. (doi:10.1098/rstb.2008.0205)

British Plastics Federation 2008. Oil consumption See http:/ www.bpf.co.uk/Oil_Consumption.aspx (20 October 2008)

Chanda, M. & Roy, S. 2007 Plastics technology handbook. 4th edn. Boca Raton, FL: CRC Press.

Drelich, J., Payne, J., Kim, T. & Miller, J. 1998 Selective froth floatation of PVC from PVC/PET mixtures for the plastics recycling industry. Polym. Eng. Sci. 38, 1378. (doi:10.1002/pen.10308)

EEA 2008 Better management of municipal waste will reduce greenhouse gas emissions. Copenhagen, Denmark: European Environment Agency

EPA (2020). Municipal Solid Waste - https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/#:~:text=Municipal%20Solid%20Waste%20(MSW)%E2%80%94,schools%2C%20hospitals%2C%20and%20businesses.

Fisher, M. 2003 Plastics recycling. In Plastics and the environment (ed. A. Andrady), pp. 563 –627. Hoboken, NJ:Wiley Interscience.

Gregory, M. R. 2009 Environmental implications of plastic debris in marine settings—entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. Phil. Trans. R. Soc. B 364, 2013–2025. (doi:10.1098/rstb.2008.0265)

Kyrikou, I. & Briassoulis, D. 2007 Biodegradation of agricultural plastic films: a critical review. J. Polym. Environ. 15,125 –150. (doi:10.1007/s10924-007-0053-8)

Park, C.-H., Jeon, H.-S. & Park, K. 2007 PVC removal from mixed plastics by triboelectrostatic separation. J. Hazard. Mater. 144, 470–476. (doi:10.1016/j.jhazmat.2006.10.060)

Marques, G. & Tenorio, J. 2000 Use of froth flotation toseparate PVC/PET mixtures. Waste Management 20,265–269. (doi:10.1016/S0956-053X(99)00333-5)

PlasticsEurope 2008a Eco-profiles of the European Plastics Industry. Brussels, Belgium: Plastics Europe. See http://lca.plasticseurope.org/index.htm (1 November 2008).

Frosch, R. & Gallopoulos, N. 1989 Strategies for manufacturing. Sci. Am. 261, 144 –152.

McDonough, W. & Braungart, M. 2002 Cradle to cradle: remaking the way we make things New York, NY: North Point Press.

Oehlmann, J. et al. 2009 A critical analyses of the biological impacts of plasticizers on wildlife. Phil. Trans. R. Soc. B 364, 2047–2062. (doi:10.1098/rstb.2008.0242)

Plastics Europe 2008b The compelling facts about Plastics2007: an analysis of plastics production, demand and recovery for 2007 in Europe. Brussels, Belgium: Plastics Europe.

Sinha, V., Patel, M. & Patel, J. 2008 PET waste management by chemical recycling: a review. J. Polym. Environ.(doi:10.1007/s10924-008-0106-7).

Soetaert, W. & Vandamme, E. 2006 The impact of industrial biotechnology. Biotechnol. J. 1, 756– 769. (doi:10.1002/ biot.200600066)

Song, J. H., Murphy, R. J., Narayan, R. & Davies, G. B. H.2009 Biodegradable and compostable alternatives to conventional plastics. Phil. Trans. R. Soc. B 364, 2127–2139. (doi:10.1098/rstb.2008.0289)

Swift, G. & Wiles, D. 2004 Degradable polymers and plastics in landfill sites. Encyclopedia Polym. Sci. Technol. 9, 40–51.

Rebeiz, K. & Craft, A. 1995 Plastic waste management in construction: technological and institutional issues.

Patel, M., von Thienen, N., Jochem, E. & Worrell, E. 2000 Recycling of plastics in Germany. Resour., Conserv. Recycling29, 65–90. (doi:10.1016/S0921-3449(99)00058-0) Resour., Conserv. Recycling 15, 245– 257. (doi:10.1016/0921-3449(95)00034-8)

Demirbas, A. (2011) Waste Management, Waste Resource Facilities and Waste Conversion Processes. *Energy Conversion and Management*, 52, 1280-1287. http://dx.doi.org/10.1016/j.enconman.2010.09.025

Ryan, P. G., Moore, C. J., van Franeker, J. A. & Moloney,C. L. 2009 Monitoring the abundance of plastic debris in the marine environment. Phil. Trans. R. Soc. B 364, 1999–2012. (doi:10.1098/rstb.2008.0207)

Thompson, R. C., Swan, S. H., Moore, C. J. & vom Saal,F. S. 2009a Our plastic age. Phil. Trans. R. Soc. B 364,1973–1976. (doi:10.1098/rstb.2009.0054)Teuten, E. L. et al. 2009 Transport and release of chemicals from plastics to the environment and to wildlife. Phil. Trans. R. Soc. B 364, 2027–2045. (doi:10.1098/rstb.2008.0284)

Thompson, R. C., Moore, C. J., vom Saal, F. S. & Swan, S. H.2009b Plastics, the environment and human health: current consensus and future trends. Phil. Trans. R. Soc. B 364, 2153–2166. (doi:10.1098/rstb.2009.0053)

Waste Watch 2003 Plastics in the UK economy. London, UK: Waste Watch & Recoup.

WBCSD 2000 Eco-efficiency: creating more value with less impact. See http://www.wbcsd.org/includes/getTarget.asp?type=d&id=ODkwMQ (1 November 2008).

World, T., & Washington, B. (n.d.). Decision Makers' Guide to Municipal Solid Waste Incineration. Retrieved from https://www.biologyonline.com/wp-content/uploads/attachments/DecisionMakers.pdf

United Nations Statistics Division (2017). Environment Statistics. *unstats.un.org*. *Archived from the original on 17 March 2017. Retrieved 3 March 2022.*

U.S. Environmental Protection Agency, EPA.(2021). Wastes. https://www.epa.gov/report-environment/wastes

Rick, L.(2020). An Overview of Plastic Recycling. https://www.liveabout.com/an-overview-of-plastic-recycling-4018761

RTS (2020).The complete plastics recycling process. https://www.rts.com/blog/the-complete-plastics-recycling-process-rts/