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Overview on Plastic Waste: The Philippine Perspective

Fabian M. Dayrit

National Academy of Science and Technology Philippines
Department of Chemistry, Ateneo de Manila University

ABSTRACT

Plastics are the most ubiquitous materials that modern society depends on and plastic waste has become one of the most serious challenges of modern society. The challenge of plastic waste encompasses industry, commerce, culture, and society. This paper is divided into four sections: I. What are plastics? II. How are plastics used in society? III. How can we manage plastic wastes? IV. How can the Philippines manage plastic waste under RA 9003? Plastics are the designer materials of the modern age. The properties of plastics can be controlled by the choice of polymer and chemical additives. Although there are numerous types of polymers, only six are clearly recyclable polymers. Because of its volume of use and visibility, particular attention has been focused on single-use plastics, in particular thin plastic bags and sachets. However, the COVID-19 pandemic has significantly increased the consumption of single-use plastic, in particular for medical applications. The other large group of polymers, called thermosets, are not recyclable. The major campaign to address plastic waste — the 3Rs, reduce, reuse, recycle – has been unsuccessful in addressing this problem because this campaign has been focused mainly on the consumer and plastics were not designed to be recyclable. Recently, several approaches have been proposed, such as extended producer responsibility (EPR), the circular economy, and the addition of recover and redesign to give the 5Rs. These approaches can be used to strengthen the Ecological Solid Waste Management Act (RA 9003) and prepare the Philippines for a circular economy.

Keywords:
stic waste, recycle, single-use plastic, 3Rs, 5Rs, extended producer responsibility (EPR), the circular economy, Ecological Solid Waste Management Act (RA 9003)

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Email: fdayrit@ateneo.edu

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INTRODUCTION

The ages of human civilization are often described by the materials that played an important role in their development, such as the Stone Age, Iron Age, Bronze Age, and so on. This also reflects the level of technology of that age. The modern age, from the start of the 20th century, has been described as the "Plastic Age" (Smithsonian Institution 1993), as plastics have become the most ubiquitous materials that modern society depends on. However, the wide use of plastics has brought about its own unique problems.

Plastic waste is one of the most serious challenges of modern society. Although it is usually described as a waste management problem, the challenge of plastic waste actually encompasses industry, commerce, culture, and society.

There are three areas of related concern: plastic pollution, plastic waste and recycling, and the proliferation of plastic products. While these areas overlap, each one focuses on different aspects of the problem and leads to different strategies to address them.

If one is primarily concerned with plastic pollution, then one tends to focus on the environment, garbage collection, and health impacts. If one is primarily concerned with plastic waste and recycling, then one tends to focus on the 3Rs and waste management. If one is primarily concerned with the proliferation of plastic products, then one tends to focus on consumerism, the modern lifestyle and alternatives to plastic products. This paper will focus on the issue of plastic waste and is divided into four sections:

I. What are plastics?
II. How are plastics used in society?
III. How can we manage plastic wastes?
IV. How can the Philippines manage plastic waste under RA 9003?

I. WHAT ARE PLASTICS?

The term ''plastic'' (from the Greek word ''plastikos'') emphasizes the characteristic of this class of materials as being moldable and malleable into a variety of shapes and sizes (Plastics Europe 2020). However, this description accounts for only part of the reason that plastics are so useful. Because plastics are organic compounds (that is, they are mainly carbon-based), they benefit from the large body of knowledge of carbon chemistry. This has enabled plastics to have other important characteristics, such as chemical stability, low cost and designability.

The basic materials that make up plastics are polymers (from "poly" = many; "mer" = parts), which are large molecules that are made up of many repeating units called monomers. The plastics are named according to the monomer that makes it up. A fundamental requirement for the management of plastic waste is knowledge of their monomer composition and their physico-chemical properties. This will enable us to understand their environmental and health impacts, the challenges of recycling, and the search for alternatives.

Polymers and plastics

There are two broad groups of plastics: thermoplastics and thermoset plastics (Table 1). In general, thermoplastics melt at lower temperatures and are softer, while thermoset plastics melt at higher temperatures and are rigid. The other important difference between thermoplastics and thermoset plastics is that thermoplastics are generally recyclable while thermoset plastics are not (see section III). The other important components of plastics are chemical additives that are added to polymers to produce plastics with desired properties.

It is important to appreciate the difference between plastics and polymers. Plastics describe the application or use of the material while polymers give the chemical nature of the basic material. The same polymer can be used in many plastic applications and their properties can be modified by chemical additives.

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Conversely, certain plastic applications can be met by different polymers. Table 1 lists some common polymers from petrochemical feedstocks and the plastics that can be made with them. Table 1 is not a comprehensive list and does not include co-polymers, which are mixtures of different polymers. What is apparent is that polymer science and technology have given rise to numerous types of plastics to meet different needs and applications. Plastics have replaced many natural materials, such as wood, leather, cotton, and metal, and have created new applications that did not exist before. Plastics are the designer materials of the modern age.

The other important observation is that recyclable polymers make up only a minority of all polymers produced: there are only six clearly "recyclable" polymers (Table 1). Only six thermoplastics have recycling codes, 1-6. Recycling code 7 is labeled as "Other" and includes many other polymers. There are many more thermoplastics that are not labeled and one cannot assume that unlabeled thermoplastics are recyclable. If the thermoset plastics are included, it is clear that most plastics are not recyclable. However, because thermoset plastics are used in durable goods, these are produced in smaller volumes and generate less waste. Nevertheless, the management of such waste should be considered. This will be discussed further in section III.

Table 1. Plastic products that can be made from polymers from petrochemical feedstocks. This is only a partial list.

Polymer	Plastic products that can be made
Thermoplastics [recycling code]	
Polyethylene terephthalate, PET [1]	disposable bottles (water, soda, juice, various food products, medicine, etc.), combs and other personal styling products, rope, tote bags, carpets, fiberfill material for winter clothing
High-density polyethylene, HDPE [2]	solid and liquid food containers (milk, juice), grocery bags, trash bags, various containers (motor oil, shampoo, soap, detergent, bleach, etc.), toys
Polyvinyl chloride, PVC [3]	electrical wires, pipes (plumbing, sewage, electrical), gutters and ducts, window frames, tiles, furniture cover, posters and streamers, imitation leather (shoes, belts, wallets, etc.), bags (tote bags, grocery bags), cling films, tents and shelters, toys
Low-density polyethylene, LDPE [4]	single-use plastic grocery bag, food packaging, cling wrap, sandwich bags, squeezable bottles for food condiments, grocery bags, flexible container lids
Polypropylene, PP [5]	plastic diapers and sanitary napkins, Tupperware, kitchenware, food containers (e.g., margarine tubs, yogurt containers), prescription bottles, bottle caps, drinking straws, take-out containers, disposable cups and plates, toys
Polystyrene, PS [6]	disposable coffee cups, plastic food boxes, plastic cutlery, packing foam

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Thermoplastics [no recycling code indicated]	
Acrylic	paints and coatings, cosmetics, adhesives (superglue)
Polyacrylonitrile (PAN)	hot gas filtration systems, outdoor awnings, sails for yachts, fiber-reinforced concrete. copolymers containing polyacrylonitrile are used in knitted fiber clothing, such as socks and sweaters, as well as outdoor products like tents and similar items.
Polyamide (Nylon)	cloth fabrics (all types, jackets, athletic gear), parachutes, rope, medical bandage, seat belts, machine belts and other parts, tents, streamers
Polycarbonate	computers, cell phones, plastic CDs and DVDs, baby bottles, large capacity water bottles, medical storage containers (autoclavable), eyeglasses, exterior lighting fixtures, toys
Polychloroprene (Neoprene™)	gaskets, corrosion resistant coatings, laboratory vials, waterproof covers, latex substitute
Polychlorotrifluoroethylene, PCFE	valves, seals, gaskets, etc.
Polyparaphenylene tere-phthalamide	bullet-proof material (vest), helmets (military, high performance, bicycle, recreational), airplanes and motor vehicles (reinforced body, brakes), high-performance ropes, electrical insulation (e.g., satellites), construction, (Kevlar™, Twaron™)
Polyfluoroalkyl substances, (PFAS)* / Polytetrafluoroethylene (PTFE)	cookware, pipes for corrosive fluids, water repellant coating, for special applications at high temperature, corrosive conditions, irradiation, engineering plastics (gaskets, washers, bearings, bushings, gears, nuts and bolts, precision parts), (Teflon™)
And many more …	
Thermoset plastics	
Phenol-Formaldehyde resins	electrical insulators, home appliances (telephones, kitchen use, electrical outlets and switches), computers, car bodies and parts (Bakelite™, Duroplast™)
Epoxy resins	adhesives, matrix component in many fiber- reinforced plastics (e.g., glass-reinforced, graphite-reinforced, electronics encapsulation), protective coatings and seals
Fiberglass	water tanks (domestic, commercial, industrial), cars and boats, windows (cars and trucks, home, building), pipes and other building applications, Personal protective equipment
Polyester (cross-linked)	sheet and bulk molding; protective coatings
Polyurethane	insulating foams and mattresses, coatings, adhesives, shoe soles, flooring, synthetic fibers, water-proof coating,
Silicone resin	matrix composite for thermoset polymers and ceramics
Urea-Formaldehyde	adhesives in plywood, particleboard, fibreboard
Vulcanized Rubber	tires, bumpers, other rubber products
And many more …	

*In December 2019, the European Union announced the phase out of PFAS due to its toxicity and extraordinary persistence (EU 2019).

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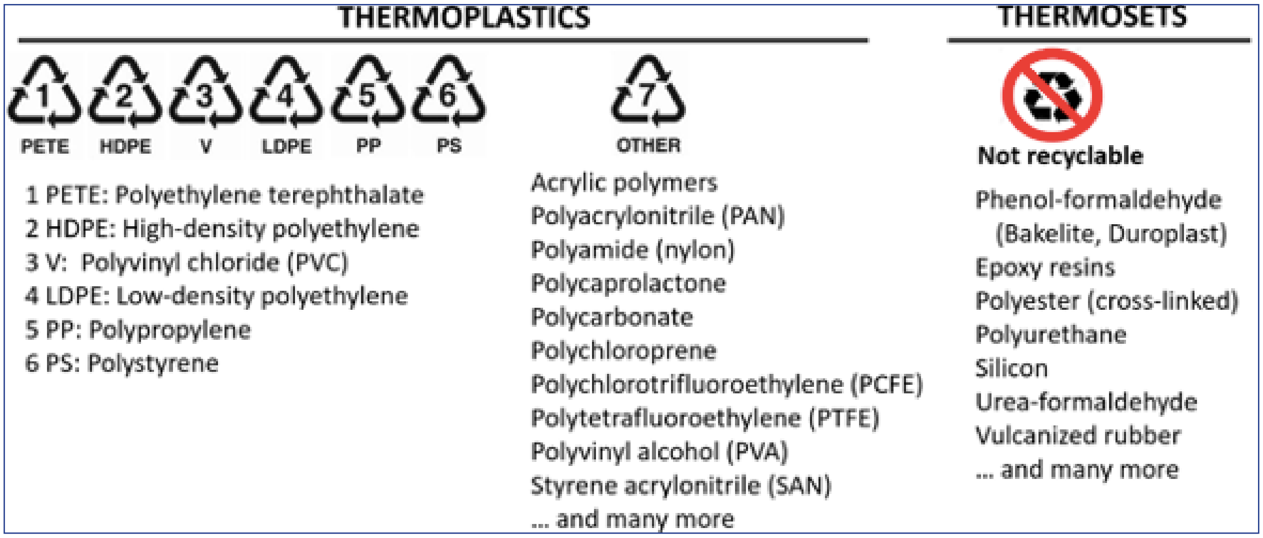

Figure 1. Recycling codes of polymers are technically known as resin identification codes (RIC).

Polymer additives

Polymer materials are not directly useful as is. Various chemicals need to be added to the polymer matrix to improve the processability, to impart particular properties, and to enhance the service life of the plastic product. Examples of these properties and the additives used include: flexibility (plasticizers), impact resistance (impact modifiers), viscosity (lubricants), low flammability (fire retardants), color (dyes, metals and colorants), and UV stabilizers (antioxidants) (Table 2). Despite their usefulness, additives can contaminate soil, air, water, and food. Additives can migrate and lead to human exposure through food contact materials, such as packaging. They can be released from the plastic material when it is disposed in the environment, during recycling, and during reuse (Hahladakis et al. 2018).

There are over 26,000 chemical additives that are used to modify or improve the properties of plastics. However, only a few additives, such as phthalates and bisphenols, have been studied for their health and environmental impacts. Phthalates are commonly used plasticizers which are hormone-disrupting compounds. Bisphenol A (BPA) is component of polycarbonate polymers which is found as an impurity in these materials. BPA binds to estrogen receptors in the human cell and can mimic the action of estrogen, thus interfering with natural development, especially in infants. The use of chemical additives has been generally unregulated and there is no requirement to list chemical additives in plastic products. The use of chemical additives in plastic products is largely covered by patents and trade secrets. Research on chemical additives is hampered by a lack of transparency and unavailability of information on their toxicity and their use so that substitutes can be developed (Groh et al. 2019). The impact of chemical additives on the recyclability of plastics will be discussed in section III.

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Table 2. Plastic properties and chemical additives. This is only a partial list.

Property	Chemical additives
Lubricant to improve processability	metallic soaps, fatty acids, paraffin waxes, low MW polyethylene
Plasticizer	phthalates, benzoic acid esters, adipic acid esters
Impact modifiers	elastomers such as butadiene rubber, and crosslinked acrylics; block copolymers, rubbers
Fillers / extenders	calcium carbonate, talc, silica, clay, mica, kaolin, calcium sulfate, glass fibers, glass beads, carbon black, aluminum hydroxide
Flame retardants	aluminum hydroxide, magnesium hydroxide, zinc borate, antimony oxide, polychlorinated and polybrominated aromatic compounds, organophosphates and organophosphonates
Antioxidants and other stabilizers	Salts of barium, cadmium, lead, zinc, hindered amine light stabilizers (HALS), UV light absorbers

Polymer feedstock

Most synthetic polymers are made from petrochemical feedstocks by refining to produce the most common raw materials: olefins, such as ethylene, propylene and other simple alkenes, and aromatics, such as toluene, xylenes, and styrenes. About 4% of the world's petroleum resources are used in plastics production and petrochemical feedstocks account for over 99% of plastics raw material (BPF 2019). The alternatives to petrochemical feedstocks are bio-based materials. Bio-based materials which are produced from biological renewable resources, such as various types of carbohydrate materials (e.g., starch, wood, seaweed), plant products (e.g., rubber, terpenes, vegetable oils), and fermentation products (e.g., polylactic acid) (Liang et al. 2017). The interest in bio-based alternatives is driven by two objectives: the first objective is the replacement of petroleum with renewable biomaterials as feedstock, and the second objective is to produce biodegradable plastics. These are different challenges.

Bio-based polymers are widely seen as an alternative to petroleum-based polymers. Market trends indicate the growth of biopolymers but whether these will be able to replace petrochemicals is still uncertain. The biopolymer industry demand is expected to reach only 2% of annual production of global thermoplastics. For example, although polylactic acid can be used to replace a number of petroleum-based polymers, the fermentation process to produce polylactic acid is much more expensive (Kuruppalil 2011). One consequence of a shift to bio-based polymers is the competition for the use of land and food crops to produce the biopolymers.

Although bio-based polymers are often assumed to be biodegradable, they can also be made into nonbiodegradable materials. For example, although natural rubber is an exudate from the rubber tree, vulcanization converts it into a nonbiodegradable material. Ethanol, a fermentation product from carbohydrate materials, can be converted to ethylene and produce the same petroleum-based polymers which are not biodegradable. Likewise, while most of the current petroleum-based polymers are nonbiodegradable, there are biodegradable polymers that can be produced from petroleum, such as polycaprolactone. Thus, bio-based polymers are not necessarily biodegradable, and petroleum can be used to produce biodegradable polymers.

Biodegradable materials are defined as those which can be degraded into CO_2 and H_2O. The process of biodegradation depends on the environmental

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conditions, such as temperature, and availability of water and oxygen (European Bioplastics 2018). However, because biodegradable plastics are not suitable for recycling, these wastes must be separated from recyclable waste. Currently, most biodegradable plastics are utilized for nondurable goods, such as packaging, disposable cups, and food utensils (Kuruppalil 2011). Recently, carrageenan was successfully blended with starch to produce a bioplastic with higher elastic modulus and tensile strength giving a product with higher mechanical strength (Suryanto et al. 2019).

The green plastics industry is still in its infancy and is not ready to replace petrochemical based plastics. At the same time this sector is preparing for growth and getting ready to meet increased demand. There are numerous challenges of improving material properties and processing before they can replace petroleum based plastics (Kuruppalil 2011).

II. HOW ARE PLASTICS USED IN SOCIETY?

The development of industry has been marked by "Industrial Revolutions." According to this analysis, the first industrial revolution (1760–1840) used water and steam power to mechanize production; the second industrial revolution (1870–1914) used electric power to create mass production; the third industrial revolution (1950s–2000s) used electronics and information technology to automate production; and the fourth industrial revolution (4IR) which is evolving today is characterized by a fusion of the biological, physical, and digital technologies (Schwab 2015).

Using the same periods of the industrial revolution, one can identify key developments in the evolution of the plastics industry. Coincident with the second industrial revolution, three important synthetic polymers were made. In the 1850s, cotton was combined with camphor to make celluloid, the first synthetic polymer. Celluloid was therefore made from biological raw materials, cotton and camphor. In the 1900s, chemists successfully synthesized Bakelite from coal tar, making this the first plastic to be made completely from fossil raw materials. This was followed in the 1930s with the synthesis of nylon, this time from petroleum. The manufacture of these plastics benefited from the advances of the second industrial revolution.

Plastics played a key role in providing the materials that were needed in the third industrial revolution. Electronics and computerization extensively used insulating plastic materials, such as LDPE, HDPE, PVC, PP, PTFE, and others, to make wires and cables, printed circuit boards, and the computer devices themselves. Likewise, modern plastic materials are an intimate part of the technologies of the fourth industrial revolution, such as the satellites and underwater cables, 3-D printing, flexible solar cells, and nanotechnology.

Just as plastics supported the industrial revolutions, they also changed our lifestyle and culture significantly. Many of the things that have enabled our lifestyle depend on plastic, such as household appliances, televisions, radios, and home computers, a significant proportion of supermarket products, especially fresh perishable food products; fast food and convenience foods, bottled water, juices and soda, most athletic wear and sports shoes, all vehicular transport that use vulcanized tires, and so on. A polymer can be used for different applications depending on the requirements of the product; conversely, a product classification can use different polymers, which may be recyclable or non-recyclable (see Table 3). The proposed bans on "single-use plastic" (SUP) are challenging to implement because different types of polymers are used for SUP and their uses vary from modifiable to necessary. During the COVID-19 pandemic, one of the most widely used single-use plastics (SUP) has been the face mask, a product that cannot be banned. Medical face masks are considered non-recyclable to prevent their reuse as face masks. The polymer used in most face masks are recyclable (polypropylene, polyacrylonitrile, polystyrene, polycarbonate, polyethylene, polyester), but not all are recyclable (e.g., polyurethane). As Table 3 suggests, each polymer finds use in many applications, and each application uses many types of polymers. This makes the recycling of polymers and products very challenging.

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Table 3. Polymers and their applications. Many polymers can be used for a particular application depending on the requirements of the product. This is only a partial list.

Application	Recyclable Thermoplastic (RIC 1-6)	Unclassified Thermoplastic (RIC 7)	Thermoplastic Not recyclable	Thermosets
Single-use	PET, HDPE, PVC, LDPE, PP, PS	PC	AC	PU, Si
Durable goods	PET, HDPE, LDPE, PP	Ple, PC	AC, PA, PTFE	PF, Ep, PU, Si, UF, VR
Clothing	PET, PET-PU (Lycra),	Ple	PA, PTFE	UF
Electrical	PVC, PP		PTFE	PF, Ep, Si UF
Home appliances	PVC, HDPE, PP	PC	PTFE	PF, Ep, UF
Automotive	HDPE, PVC, PP	ABS, PC	AC, PTFE, PA	PF, Ep, PU, UF, VR, Si
Construction	PVC, PP	ABS, PC	AC, PTFE, PA	Ep, PU
Engineering	PVC, PP	ABS, PC	AC, PTFE, PA	Ep, PU, Si
Optical fiber		Ple	AC, PTFE	Ep

RIC-resin identification code is officially recognized only for classes 1-6.

Acronyms:	PET- Polyethylene terephthalate [1] HDPE- High Density Polyethylene [2] PVC- Polyvinyl Chloride [3] LDPE- Low Density Polyethylene [4] PP- Polypropylene [5] PS- Polystyrene [6]	ABS- Acrylonitrile Butadiene Styrene Ple- Polyester PC- Polycarbonate	AC- Acrylic PA- Polyamide (nylon) PTFE- Polytetrafluoro-ethylene (Teflon)	Ep- Epoxy PF- Phenol formaldehyde PU- Polyurethane Si- Silicone UF- Urea formaldehyde VR- Vulcanized rubber

The role of plastic in the development of industry, commerce, and society cannot be denied. However, the role of plastic in the degradation of the environment and threats to human health also cannot be denied. It is clear from the history of plastics that these materials were developed to meet specific product requirements, function and costs, and the issue of plastic waste was not considered in their design.

III. HOW CAN WE MANAGE PLASTIC WASTE?

The amount of plastic waste that is produced worldwide is huge. It has been estimated that the weight of all plastic waste is equal to the weight all the people in the world (Statista 2020; UN 2015). Presented in another way, each person on the average generates as much plastic waste as his own weight (Figure 2).

The environmental movement began on April 22, 1970 as a citizen's initiative to raise awareness regarding the rise of waste. Here was born the triangular logo for the "3Rs" — reduce, reuse, recycle —which became the universal symbol against waste. However, the 3Rs were promoted mainly as the responsibility of the consumer. By this time many plastics — both thermoplastics and thermosets — were already being manufactured,

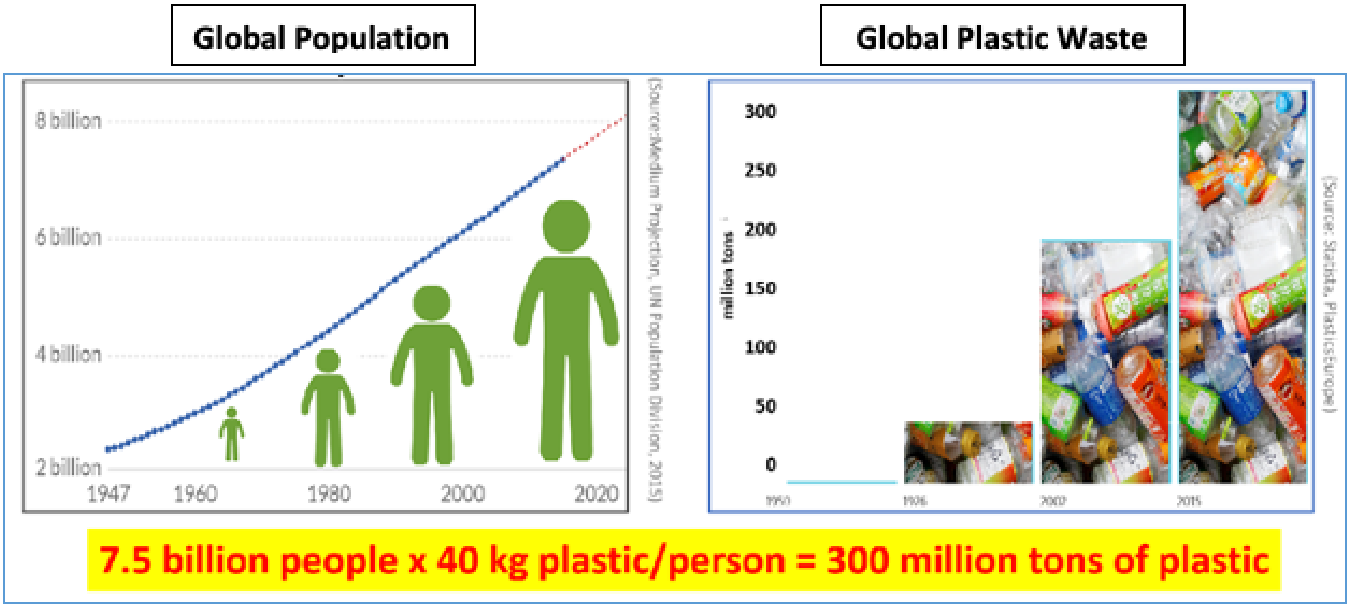

Figure 2. Global population compared with global plastic waste: each person on the average generates as much plastic as their own weight.

none of which was designed to be recycled. The resin identification code (RIC) which was meant to guide recycling for plastics was introduced in 1988 by the American Plastics Industry Association, but only for six thermoplastics and a group called "Other". Most of the plastics that were developed after 1988 were not designed to be recycled either. Recyclers and consumers use the RIC to help them identify and sort plastics for recycling but the global rate of recycling stands at only 18% (OECD 2018). Six thermoplastics — PE, HDPE, PVC, LDPE, PP, and PS — were identified as being recyclable, without consideration of the chemical additives that these plastics contained, most of which had not been assessed for their human and environmental toxicity. The production of plastics grew more than twenty times between 1964 and 2015 and this is projected to double by 2035 (STAP 2018).

The global production of plastics has grown continuously since the 1950s up to the present (Figure 3a) and so also has plastic waste (Figure 3b) (Geyer et al. 2015). It is readily apparent from Figures 3a and 3b that neither the 3R movement (in 1970) nor the adoption of the RIC (1988) did anything to reduce both plastic production and amount of plastic waste. Globally, less than 9% of plastic waste is recycled (d'Ambrières 2019). Despite its widespread awareness, the 3R movement has largely failed to solve the problem of plastic waste, in both developed and less developed countries, although for different reasons.

Ocean pollution from the Philippines

Because the Philippines is an archipelagic country where around 60% of the population lives along the shore, mismanaged plastic wastes easily find their way to the beaches and open seas. The magnitude of the Philippine plastic waste problem was recently highlighted by images of plastics waste littering beaches and whales and turtles that were killed by plastic waste (Figure 4). Such images have galvanized public opinion regarding the problem of plastic waste.

Jambeck and co-authors (2015) calculated

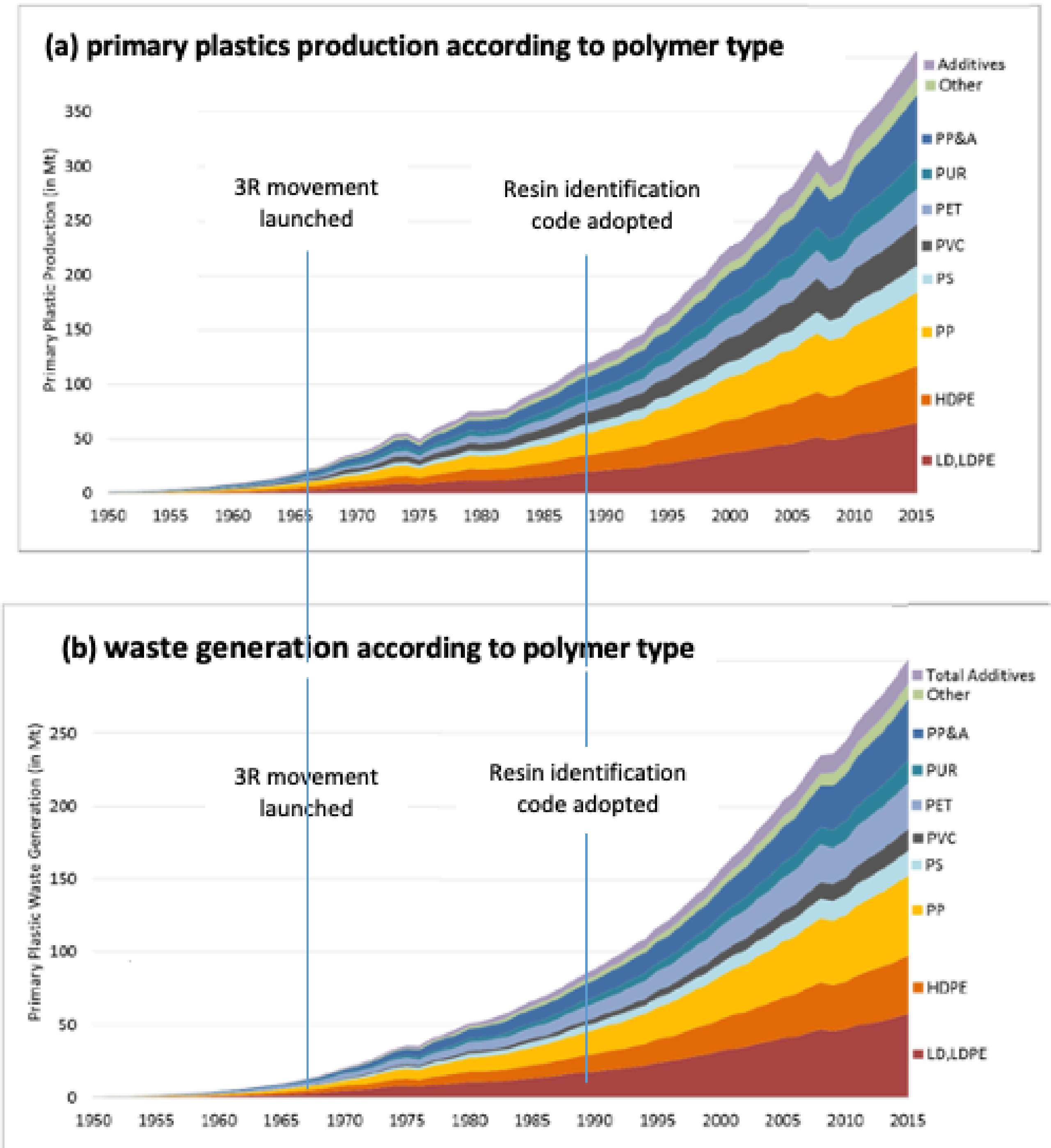

Figure 3. Global primary plastics production (a) and waste generation (b) according to <u>polymer</u> <u>type</u> from 1950 to 2015, in million metric tons (Geyer et al. 2017). Only a few polymers, such as PET, HDPE, and PVC, are economically recyclable.

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that in 2010, 275 million metric tons of plastic waste were generated in 192 coastal countries and about 5 to 13 million MT of this entered the ocean. The Philippines was ranked number three in this list of ocean polluters on the basis of <u>% of total mismanaged plastic waste</u> which was estimated to be 5.9%. However, another significant result of the Jambeck paper was the estimate that *83% of our waste is mismanaged* (Table 4). More recently, Meijer and co-authors (2021) identified the Philippines as the largest contributing country to riverine plastic emissions into the ocean with 4820 rivers emitting 356,371 MT per year from mismanaged plastic waste.

The main concerns regarding plastic waste are the health and environmental impacts which arise from chemical additives and from physical forms of waste (macroplastic, microplastics (<5mm), and nanoplastics (10^{-6} mm)). A study commissioned by the World Wildlife Fund estimated that an individual may be consuming about 21 grams of microplastic a month or about 250 grams a year. The main sources of plastic were drinking water and fish (WWF 2019). The full health impacts of micro- and nanoplastics themselves are still not known and need to be determined (Campanale et al. 2020). However, it is known that microplastics carry with them the chemical additives that were used in their manufacture (Smith et al. 2018). Micro- and nanoplastics may be more efficient vehicles that will carry chemical additives into the cells of the organisms (fish → humans) that ingest them.

Once plastic waste is released to the seas and oceans, it is virtually impossible to avoid these impacts. This is an active area of research to better understand the nature of the problem (GESAMP 2015), but it is clear that there is no viable solution known to solve this problem. The waste will remain in the oceans until they are degraded and over time, the macroplastics will breakdown into microplastics, then into nanoplastics.

In order to solve the problem of plastic waste, it is important to know which plastics are produced in largest amount and which uses generate the most plastic waste. A study by Geyer and co-workers (2017) estimated that packaging plastic accounted for the largest use of plastic (42%) and

(credit: Greenpeace)

(credit: National Geographic)

Figure 4. Images of plastic waste have galvanized public opinion regarding this challenge. (A) Freedom Island, Parañaque City, Metro Manila. (B) Ninety pounds of plastic waste were found inside a whale that died in the Davao Gulf.

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Table 4. Waste estimates for 2010 for the top 10 countries ranked by % of total mismanaged plastic waste (right most column) (ppd, person per day) (Jambeck et al. 2015).

	Application	Recyclable Thermoplastic (RIC 1-6)	Unclassified Thermoplastic (RIC 7)	Thermoplastic Not recyclable	Thermosets
1	China	1.10	11	76	27.7
2	Indonesia	0.52	11	83	10.1
3	Philippines	0.50	15	83	5.9
4	Vietnam	0.79	13	88	5.8
5	Sri Lanka	5.10	7	84	5.0
6	Thailand	1.2	12	75	3.2
7	Egypt	1.37	13	69	3.0
8	Malaysia	1.52	13	57	2.9
9	Nigeria	0.79	13	83	2.7
10	Bangladesh	0.43	8	89	2.5

that packaging waste accounted for an even larger proportion of total plastic waste (54%) (Figure 5). For these reasons, the main focus of the campaign on plastic waste has focused on packaging.

The main polymers that are used for packaging are: HDPE, LDPE, PET, PP, PS, and PVC (Kirwan et al. 2011; ACC 2020). Although these are recyclable thermoplastics, only PET, HDPE, and PVC are economically and technologically viable at this time. Packaging plastic can be seen as a primary area for reduction and reuse, as well as improvement for recycling. The science of recycling and the development of alternative materials, such as bioplastics, are important areas for R&D. This will address about half of the plastic waste that we produce (see Figure 5).

Failure of the 3Rs

An analysis of the 3Rs reveals its inadequacy in solving the problem of plastic waste (Dayrit 2019).

Reduce. Reduction is difficult in our modern economy that is increasingly consumption-driven, where consumers are constantly urged to consume more in order that the economy will grow.

Reuse. The reuse of plastic products usually involves a lower type of application. Also, the reuse of many plastic products may be limited by additives, such as plasticizers and flame-retardants, which pose hazards for reuse (Halden 2010). Reuse can only postpone the increase in plastic waste.

Recycle. Many plastics are not meant to be recycled or are uneconomic to recycle. Clearly, plastics recycling leaves much to be desired. In addition, additives make it difficult to recycle plastics.

Before plastic waste can be recycled, it must first be recovered. However, recovery of plastic waste requires an efficient waste management system. Further, recovery works only for plastic waste that retains some value, such as PET. The processing of waste plastic into new plastic products is more difficult and expensive compared to the use of virgin petroleum feedstocks (Nkwachukwu et al. 2013). This is where R&D are needed.

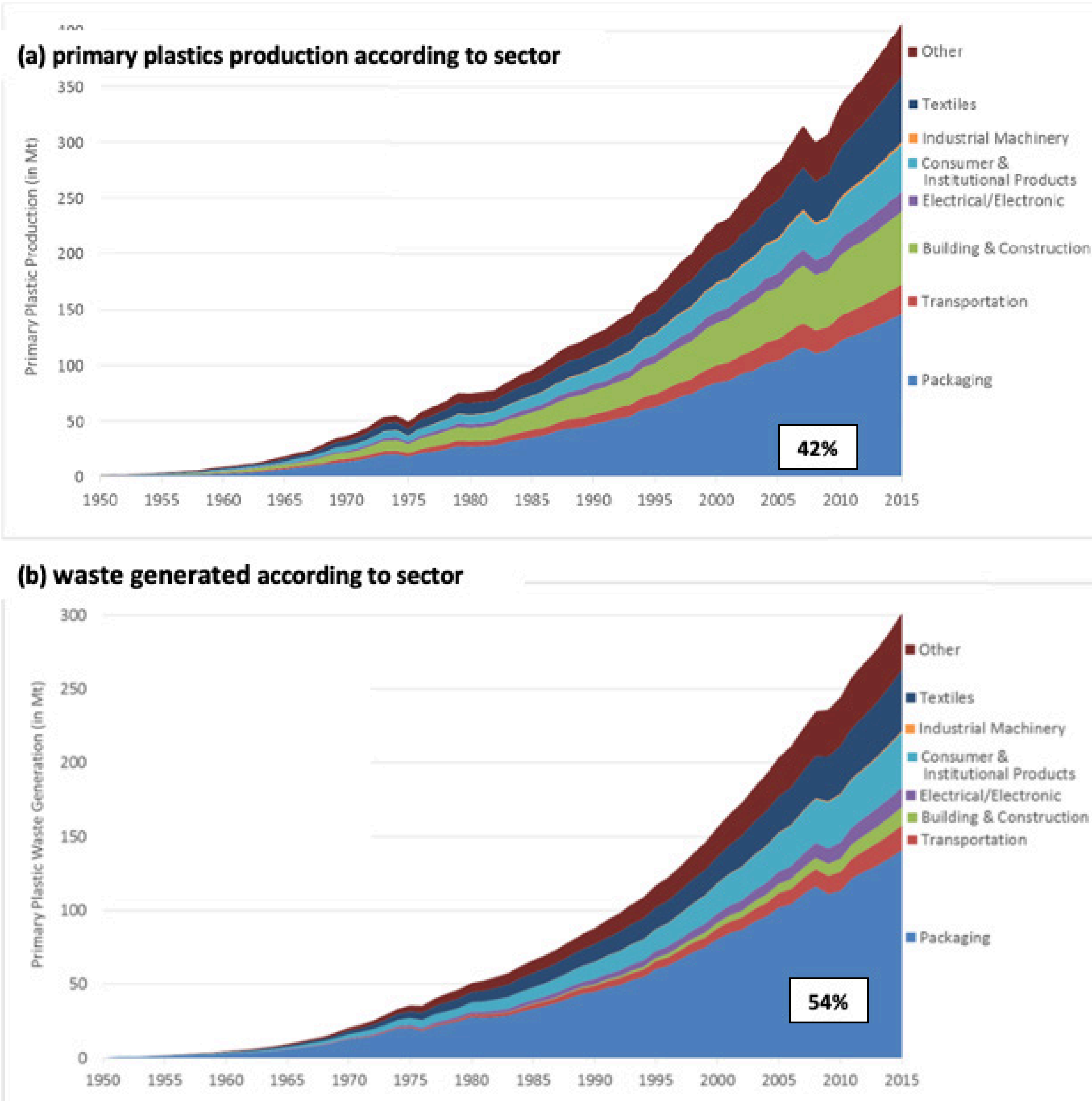

Figure 5. Global primary plastics production (a) and waste generation (b) (in million metric tons) by sector from 1950 to 2015 (Geyer et al. 2017).

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Clearly, the management of plastic waste should be a shared responsibility of the consumer, government and industry. While improvements from all sectors are needed, industry has failed to undertake sufficient recycling and to develop new plastics that are recyclable by design. Unless new recyclable materials are developed, plastic waste will continue to accumulate.

Single-use plastic

Single-use plastics are defined as plastic products that are intended to be used only once before they are discarded or recycled (UNEP 2018). It is the convenience of single-use plastic that has also made them so problematic. Single-use plastics cover a wide range of uses, products and types of plastics (Table 5) by people from all sectors of society (Figure 6). The COVID-19 pandemic has significantly increased the consumption of certain types of disposable single-use plastic. Consumers use more disposable lightweight plastic bags. Many medical implements use disposable single-use plastic to ensure sterility and minimize viral infection and transmission. Disposable diagnostic kits are almost exclusively single-use plastics. Most sample storage vials are likewise single-use plastic.

Table 5. Single-use plastics: uses, products, and types of plastics.

Uses	Products	Types of plastics
Consumer products	Carrier bag	HDPE, PVC
	Lightweight bag (sando bag)	LDPE
	Take-out bag (labo bag)	LDPE
	Plastic bottle and cap	HDPE, PET, PP
	Sachet	Aluminum foil, HDPE, PET
	Sanitary products (diaper, napkin)	LDPE
	Cosmetic packaging	HDPE, PP
	Food packaging	PET, LDPE, PP
	Fast food packaging, utensils, cups, straws	PET, PP, PS
	Petroleum and hardware products	HDPE
Industrial	Packaging	PS, PC
Medical products*	PPE (disposable gloves, face mask)	PET, Ep, Si, Latex rubber, Neoprene
	Disposable implements (syringe, vials)	HDPE, PP, VR
	Packaging for pharma products	HDPE, PVC

* The COVID-19 pandemic has significantly increased the use of single-use plastic in personal protective equipment (PPE), such as gloves, face masks, air-purifying respirators, goggles, face shields, respirators, and gowns.

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Figure 6. Single-use plastics are used in products and applications by all sectors of society.

There has been a global movement against single-use plastic in general. However, the main single-use plastic products of concern have been lightweight grocery bags, sachets, and fast food-related plastics. As of January 2020, 74 countries have introduced bans on lightweight plastic bags while 37 countries have imposed a charge per bag (Wikipedia 2020).

The Philippine chapter of the Global Alliance for Incinerator Alternatives (GAIA) conducted a survey that revealed that seven out of ten Filipinos were in favor of a nationwide ban on certain types of single-use plastic: lightweight bags (71 percent), plastic straws and stirrers (66 percent), take-out plastic "labo" bags (65 percent), polystyrene food containers (64 percent), sachets (60 percent), plastic drinking cups (56 percent), utensils (54 percent), plastic juice bottles (49 percent) and plastic water bottles (41 percent) (GMA News 2020). On July 28, 2021, the Philippine House of Representatives passed a bill regulating single-use plastic products.

Table 5 and Figure 7 provide some suggestions regarding which type of single-use plastic should be regulated or banned based on type of polymer material and product. Since LDPE is an uneconomic polymer to recycle, the following products can be selected for regulation or banning: light-weight bags, take-out bags, and sanitary products. A deposit system can be established for sachets whereby recovered or returned sachets is equivalent to a certain amount, much like the bottle deposit system of the past. This will provide an incentive for sachets to be collected for further recycling. Industry can include the cost of sachet recovery in the cost of the product. This is a form of extended producer responsibility. On the other hand, Table 5 and Figure 7 also show that it will be difficult to ban or regulate the all single-use plastics using a "one-size-fits-all" approach.

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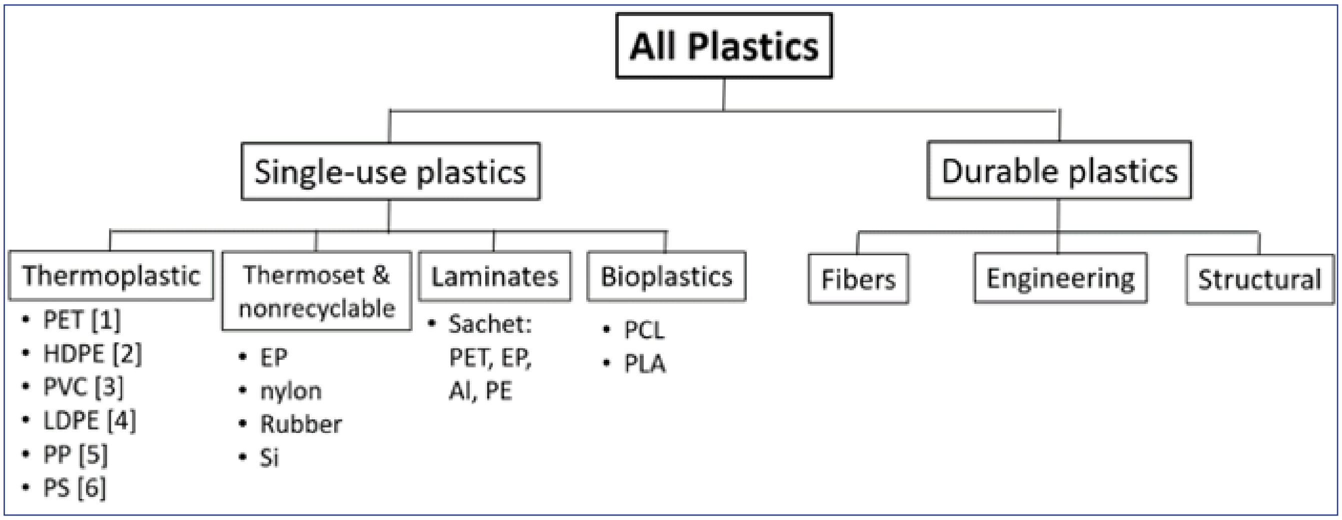

Figure 7. Single-use plastics and durable plastics: classification by type of polymer.

Life Cycle Assessment

Any decision made should be supported by evidence and a systematic cost-benefit analysis. Life cycle assessment (LCA) is a systematic method used to evaluate the environmental impact of a product through its life cycle, from extraction of raw material, transport, processing and manufacture, distribution, sale, use and reuse, recycling, waste management, landfill or litter. If the plastic waste is inappropriately handled, macro-, micro-, and nanoplastic will be found in the environment (Figure 8). LCA is specific to the location and country, in particular the impact of waste management.

LCA of paper bags, cloth bags, and three types of plastic bags — single-use polyethylene bags, reusable polyethylene bags, and reusable propylene bags — show that plastic bags have a lower environmental impact compared to paper and cloth bags mainly due to the amount of water required for processing of paper and cloth (Denmark 2018). However, this LCA did not completely consider the environmental impact of plastic waste, such as impact of chemical additives, macroplastics, microplastics, and nanoplastics. Although incomplete, this assessment suggests that paper and cloth processing bags should not be the automatic alternative to plastic bags.

Extended Producer Responsibility and the Circular Economy

Extended producer responsibility (EPR) is a policy where producer responsibility is extended to include waste treatment and disposal of their products after consumer use (OECD 2001). Recently, the EPR paradigm has been extended to include the entire lifecycle to encourage producers to redesign products and processes in consideration of the LCA including recycling and health and environmental impacts. However, the implementation of EPR requires a harmonization of regulations regarding standards for product quality, and laws on product accountability, waste management, and environmental impact, among others. EPR, which was adopted by the OECD in 2001 has been integrated into the concept of the circular economy, an idea that was first proposed by Walter Stahel in the 1980s and which he refined as follows (Stahel 2016):

> "A 'circular economy' would turn goods that are at the end of their service life into resources for others, closing loops in industrial ecosystems and minimizing waste. It would change economic logic because it replaces production with sufficiency: reuse what you can, recycle what cannot be reused,

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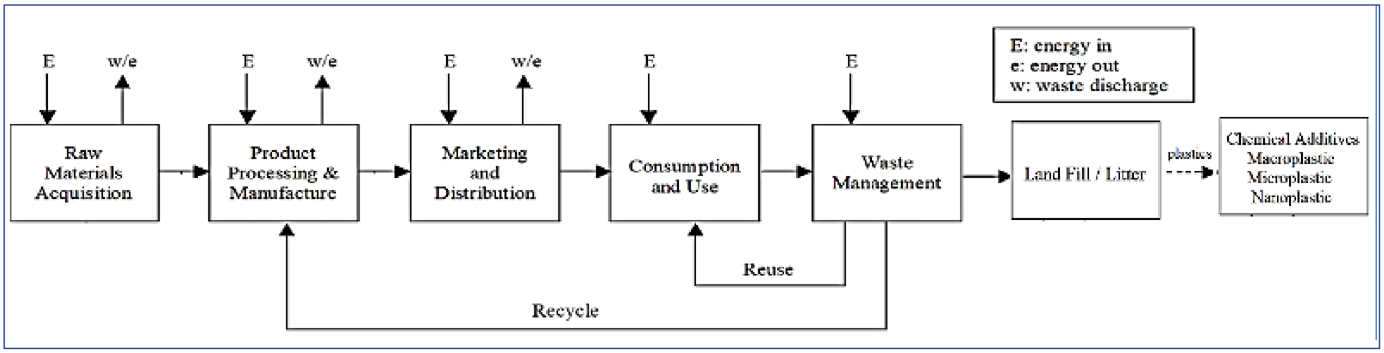

Figure 8. General scheme for Life Cycle Assessment (LCA) of products. LCA studies have shown that plastic bags have a more favorable LCA than paper and cloth bags. However, these analyses did not consider the health and environmental impact of chemical additives and macro-, micro-, and nanoplastics.

> repair what is broken, remanufacture what cannot be repaired."
>
> "Research and innovation are needed at all levels — social, technological and commercial."
>
> "Economists and environmental and materials scientists need to assess the ecological impacts and costs and benefits of products. Designing products for reuse needs to become the norm, making use of modular systems and standardized components, for instance."

The concept of the circular economy was discussed at the World Economic Forum in 2012 and in June 2018, the Scientific and Technical Advisory Panel (STAP) of UNEP issued a document promoting the application of the circular economy to plastics (STAP 2018). The circular economy is a holistic paradigm that seeks to decouple economic growth from waste generation and promotes eco-redesign that achieves higher rates of recycling and reduction of waste. This will encourage resource-efficiency, innovation and higher value-addition, and create new jobs and business opportunities in a new market. The circular economy integrates product lifecycles with society and the environment in a holistic way (Pouikli 2020).

From the 3Rs to the 5Rs

As discussed earlier, the paradigm of the 3Rs is insufficient and its implementation has been deficient as industry has failed to implement an effective recycling program. In hindsight, the 3Rs approach was bound to fail because the plastics were not designed with recycling as an objective. In addition, the 3Rs did not consider the difficulties of recovery of plastic waste. This situation was highlighted by the observation that the Philippines had an 83% level of waste mismanagement (Jambeck et al. 2015).

To address the weakness of the 3Rs, and to make it more consistent with the trend towards the circular economy, the concept of the 5Rs is proposed, which adds the crucial components of redesign and recovery.

Redesign. New polymer materials and plastic products, including chemical additives, must be redesigned by industry so that these are readily recyclable. Redesign of polymers and plastics is needed to produce circular plastics for the circular economy. This is a considerable challenge and will require support for R&D.

Recovery. New strategies for the efficient recovery of end-of-life plastic products should be devised. This should a multi-sectoral strategy

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involving industry and commerce, government, and the consumer.

The 3Rs can be expanded to the 5Rs to address the weakness of the former (Figure 9a). The concept of the 5Rs is consistent the circular economy (Figure 9b) (Lacy et al. 2018).

IV. HOW CAN THE PHILIPPINES MANAGE PLASTIC WASTE UNDER RA 9003?

The management of solid waste in the Philippines is covered by the "Ecological Solid Waste Management Act" (RA 9003), which was signed into law on January 21, 2001. The passage of RA 9003 was hastened by the Payatas landslide on July 10, 2000, which resulted in 218 deaths, with 300 persons unaccounted for. RA 9003 set an ambitious goal to establish "a systematic, comprehensive and ecological solid waste management program" (RA 9003, Sec. 2). This law gives most of the responsibility to the local government units to collect and dispose of municipal solid waste in landfills (Figure 10).

Unfortunately, RA 9003 is mandated to tackle solid waste as a whole and is unable to address the

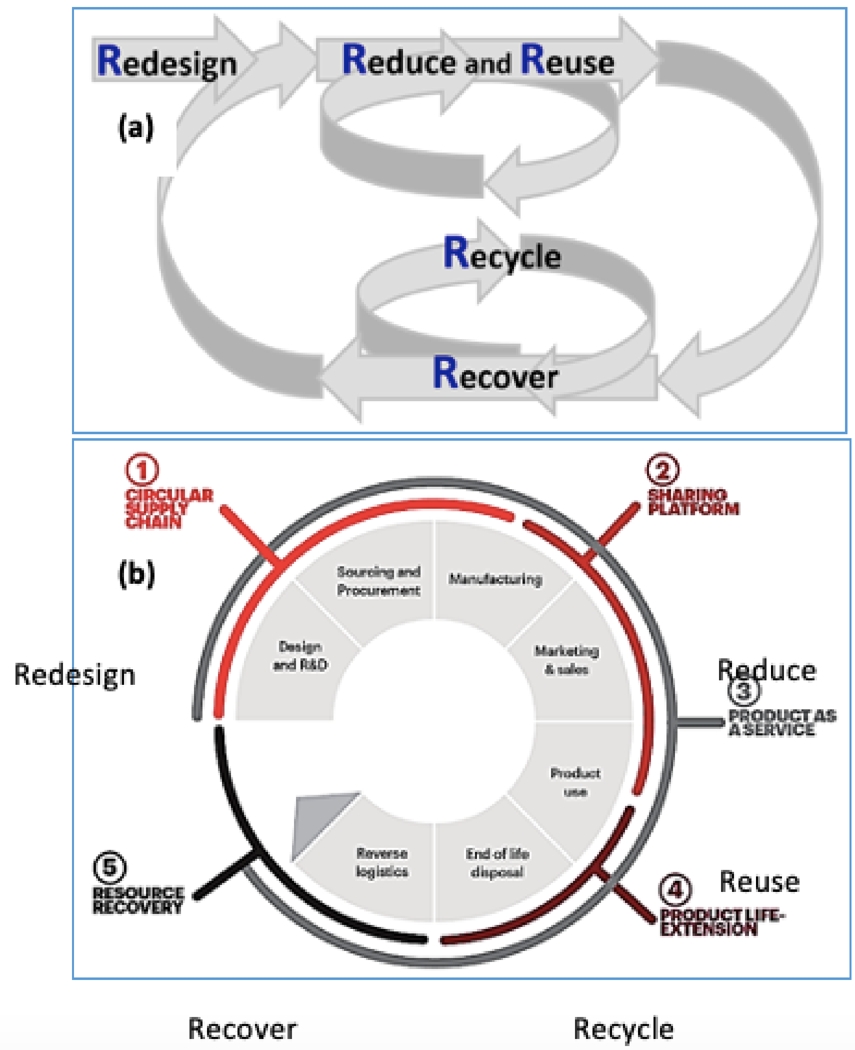

Figure 9. The 3Rs can be expanded to the 5Rs: Redesign, Reduce, Reuse, Recover, Recycle (a). The 5Rs is consistent the circular economy (b) (Lacy et al. 2018).

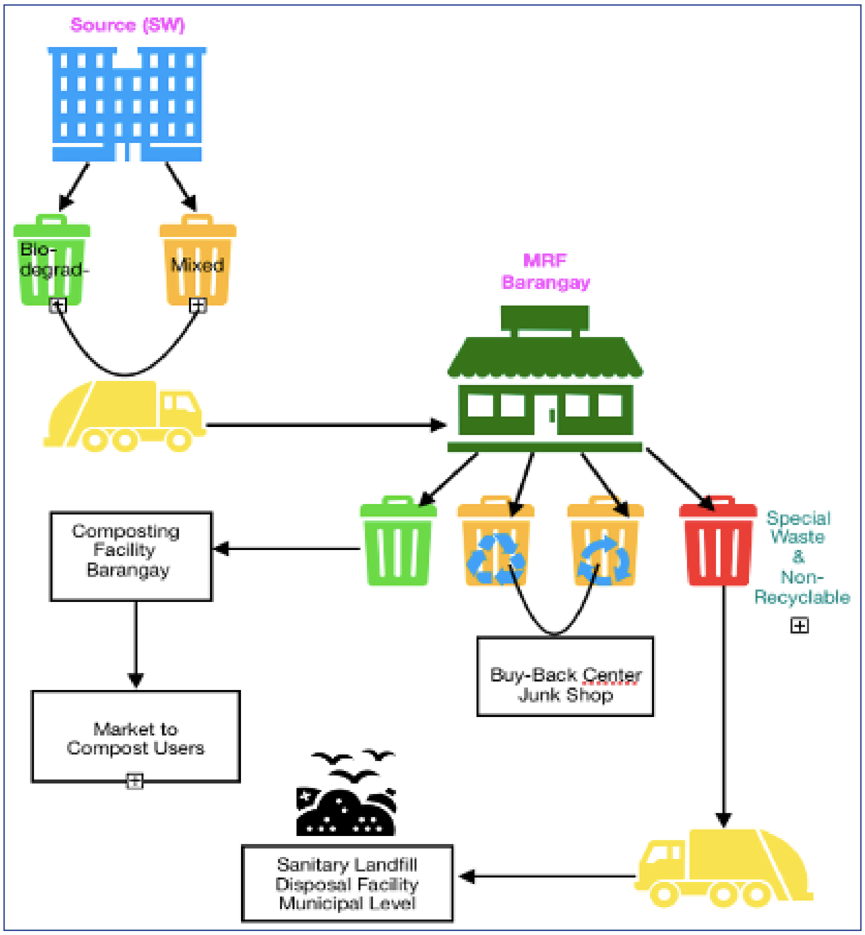

Figure 10. Scheme of the Ecological Solid Waste Management Act (RA 9003). RA 9003 is an end-of-pipe approach which depends heavily on the landfill, where plastic waste with no economic value accumulates (Drawing by Queenie Cunanan).

specific challenges of plastic waste, which makes up about 10% of total municipal solid waste (EMB 2018), in particular (Figure 11):

1. The management of plastic waste needs technical knowledge regarding the different types of plastic and the dangers of chemical additives, in particular when attempting to reuse and recycle plastic waste.

2. RA 9003 is based on "end of pipe" approach and dependence on landfills. This has resulted in the creation of mountains of non-biodegradable plastic waste which has no salvageable economic value.

3. An assessment of RA 9003 in 2012 identified ten strategies to improve implementation (Acosta et al. 2010). However, there was inadequate recognition of the need to adopt a separate strategy and technology for plastic waste. Although the materials recovery facility (MRF) at the barangay level is an important component of waste management, most LGUs are unable to implement technology solutions for plastic waste. The management of plastic waste requires a new approach, which includes new concepts that are only being developed today, such as extended

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producer responsibility, lifecycle assessment, circular economy, and the shift from the 3Rs to the 5Rs. The management of plastic waste requires the creation of a new industry.

4. The challenge of plastic waste requires a multi-sectoral approach involving the consumer, industry and commerce, and several government agencies, including DENR, DILG, DTI, and DOST.

5. There should be more incentives to develop a stronger plastics recycling industry.

6. Much more R&D is needed to find ways to recycle the plastic waste that is already there and to produce new plastics by redesigning polymers and chemical additives to make plastics recyclable by design.

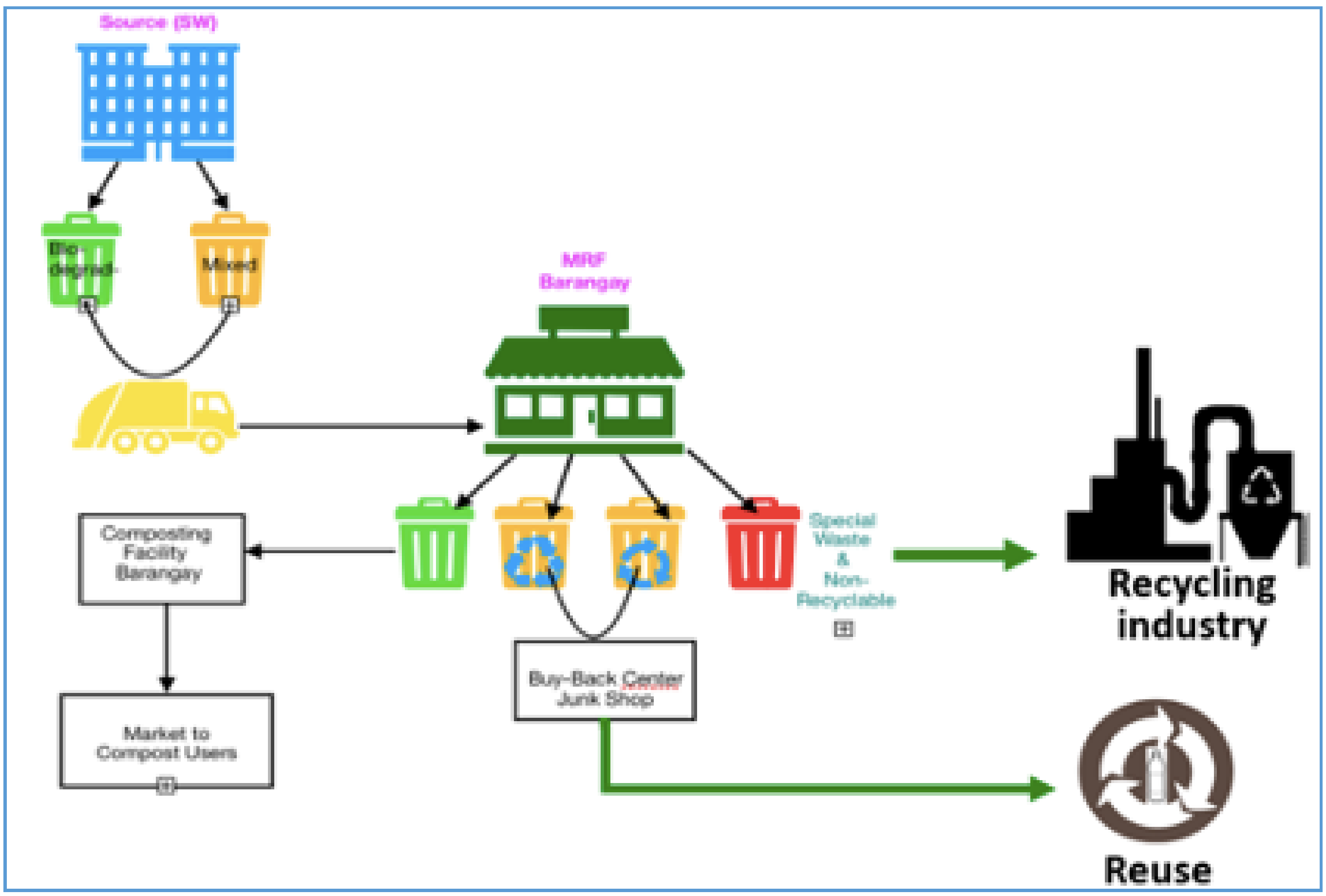

Figure 11. The Ecological Solid Waste Management Act can add provisions which give more incentives to develop a plastics recycling industry.

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The problem of single-use plastics is faced by all countries. The UN Environment Programme formulated recommendations that emphasize a multi-stakeholder and flexible approach.

UNEP recommendations on single-use plastics (UNEP 2018):

1. Target the most problematic single-use plastics by conducting a baseline assessment to identify the most problematic single-use plastics, as well as the current causes, extent and impacts of their mismanagement.
2. Consider the best actions to tackle the problem (e.g., through regulatory, economic, awareness, voluntary actions), given the country's socio-economic standing and considering their appropriateness in addressing the specific problems identified.
3. Assess the potential social, economic and environmental impacts (positive and negative) of the preferred short-listed instruments/actions. How will the poor be affected? What impact will the preferred course of action have on different sectors and industries?
4. Identify and engage key stakeholder groups – retailers, consumers, industry representatives, local government, manufacturers, civil society, environmental groups, tourism associations – to ensure broad buy-in. Evidence-based studies are also necessary to defeat opposition from the plastics industry.
5. Raise public awareness about the harm caused by single-used plastics. Clearly explain the decision and any punitive measures that will follow.
6. Promote alternatives. Before the ban or levy comes into force, assess the availability of alternatives. Ensure that the pre-conditions for their uptake in the market are in place. Provide economic incentives to encourage the uptake of eco-friendly and fit-for-purpose alternatives that do not cause more harm. Support can include tax rebates, research and development funds, technology incubation, public-private partnerships, and support to projects that recycle single-use items and turn waste into a resource that can be used again. Reduce or abolish taxes on the import of materials used to make alternatives.
7. Provide incentives to industry by introducing tax rebates or other conditions to support its transition. Governments will face resistance from the plastics industry, including importers and distributors of plastic packaging. Give them time to adapt.
8. Use revenues collected from taxes or levies on single-use plastics to maximize the public good. Support environmental projects or boost local recycling with the funds. Create jobs in the plastic recycling sector with seed funding.
9. Enforce the measure chosen effectively, by making sure that there is clear allocation of roles and responsibilities.
10. Monitor and adjust the chosen measure if necessary and update the public on progress.

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A multi-sectoral approach

Single-use plastics represent only one classification of plastics. Tackling the problem of single-use plastics is only the first step. However, this should be the opportunity to create the multi-sectoral approach that can be used for future concerns. The success of any waste management program depends on the sharing of responsibility by all concerned sectors: policy makers who craft the laws and regulations, the local government units that deal most closely with the people, the consumers, who should buy intelligently and dispose of used products responsibly, the R&D community, the waste management and recycling industries, the chemical and plastics industries, and the global community (Figure 11). Plastic waste is both a local and global problem and it needs a holistic solution.

V. SUMMARY OF RECOMMENDATIONS

1. Abandon the "end of pipe" approach to plastic waste; end dependence on landfills.
2. Move from 3Rs to 5Rs: Redesign, Reduce, Reuse, Recover and Recycle. The engagement of all stakeholders is essential: industry: Redesign and Recycle; government and LGUs: Recover; consumers: Reduce and Reuse.
3. Adopt extended producer responsibility (EPR) and the circular economy for plastics.
4. Education for a sustainable lifestyle and responsible consumption.
5. Eliminate non-essential plastic products, especially single-use plastics. Single-use plastic is only one aspect of the challenge of plastic management.
6. We need a more holistic plan for all types of plastics.

Figure 12. Multi-sectoral approach to plastics.

7. The management of plastic waste requires the creation of a new industry which must be supported through appropriate policies to make them economically viable.
8. R&D are needed for: recycling of plastic waste; new biodegradable materials; safe chemical additives; non-fossil fuel-based starting materials.
9. Harmonize our efforts with global programs to meet UN SDG's, in particular: Goal 12: Sustainable Consumption and Production.

REFERENCES

[ACC] American Chemistry Council. 2020. Resins and Types of Packaging. Downloaded from: https://www.plasticpackagingfacts.org/plastic-packaging/resins-types-of-packaging/.

Costa V, Paul J, Lao C, Aguinaldo E, Valdez MDC. 2012. Development of the Philippines National Solid Waste Management Strategy 2012-2016. Procedia Environmental Sciences 16: 9–16.

[BPF] British Petrochemical Foundation. 2019. Oil Consumption. Downloaded from: https://www.bpf.co.uk/press/oil_consumption.aspx

Campanale C, Massarelli C, Savino I, Locaputo V, Uricchio VF. 2020. A Detailed Review Study on Potential Effects of Microplastics and Additives of Concern on Human Health. International Journal of Environmental Research on Public Health 17: 1212. doi:10.3390/ijerph17041212.

D'Ambrieres W. 2019. Plastics recycling worldwide: current overview and desirable changes. Facts Reports Special Issue 19: Reinventing Plastics. Retrieved on 19 Nov 2019 from https://journals.openedition.org/factsreports/5102.

Dayrit FM. 2019. The Management of Plastic: The 3Rs are Not Enough. Philippine Journal of Science 148 (4): vii-viii.

[Denmark] Danish Environmental Protection Agency. 2018. Life Cycle Assessment of grocery carrier bags. Downloaded on April 20, 2020 from: https://www2.mst.dk/Udgiv/publications/2018/02/978-87-93614-73-4.pdf.

[EMB] Environmental Management Bureau. 2018. Solid Waste. Downloaded on April 18, 2020 from: https://emb.gov.ph/wp-content/uploads/2018/09/3-Solid-Waste-1.8.pdf.

[EU] European Union. 2019. Elements for an EU-strategy for PFASs. December 2019. Downloaded from:https://assets.documentcloud.org/documents/6586418/EU-Strategy-for-PFASs-FINAL-VERSION-December-19.pdf

European Bioplastics. 2018. What are bioplastics? Downloaded from: https://www.european-bioplastics.org/bioplastics/

GESAMP. 2015. Sources, fate and effects of microplastics in the marine environment: a global assessment. (Kershaw PJ, ed.). (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Rep. Stud. GESAMP No. 90, 96 p.

GMA News, Jan. 21, 2020. "71% of Pinoys want ban vs. single-use plastics, SWS survey shows." https://www.msn.com/en-ph/news/national/71percent-of-pinoys-want-ban-vs-single-use-plastics-sws-survey-shows/ar-BBZaq6Q?li=BBr8Mkn&ocid=UE07DHP#image=2

Geyer R, Jambeck JR, Law L. 2017. Production, use, and fate of all plastics ever made Science Advances. 3: e1700782 and Supplementary Materials.

Groh KJ, Backhaus T, Carney-Almroth B, et al., 2019. Overview of known plastic packaging-associated chemicals and their hazards. Science of the Total Environment 651: 3253–3268.

Hahladakis JN, Velis CA, Weber R, Iacovidou E, Purnell P. 2018. An overview of chemical additives present in plastics: Migration, release, fate and environmental impact during their use, disposal and recycling. Journal of Hazardous Materials 344: 179–199.

Halden RU. 2010. Plastics and Health Risks. Annual Review of Public Health 31: 179–194.

Jambeck JR, Geyer R, Wilcox C, et al. 2015. Plastic waste inputs from land into the ocean. Science 347 (6223): 768-771.

Kirwan MJ, Plant S, Strawbridge JW. 2011. Plastics in Food Packaging. In Food and Beverage Packaging Technology, 2nd ed. Coles R, Kirwan M, editors. Blackwell Publishing Ltd.

Kuruppalil Z. 2011. Green Plastics: An Emerging Alternative for Petroleum Based Plastics? Proceedings of the 2011 IAJC-ASEE International Conference. ISBN 978-1-60643-379-9.

Lacy P, Long J, Spindler W. 2018. The Circular Advantage. Accenture Strategy. Downloaded on April 19, 2020 from: https://www.accenture.com/t20150523t053139__w__/us-en/_acnmedia/accenture/conversion-assets/dotcom/documents/global/pdf/strategy_6/accenture-circular-advantage-innovative-business-models-technologies-value-growth.pdf

Liang Y, Li L, Scott RA, Kiick KL. 2017. Polymeric Biomaterials: Diverse Functions Enabled by Advances in Macromolecular Chemistry. Macromolecules 24; 50(2): 483–502.

Meijer LJJ, van Emmerik T, van der Ent R, Schmidt C, Lebreton L. 2021. More than 1000 rivers account for 80% of global riverine plastic emissions into the ocean. Science Advances. 7: eaaz5803.

Nkwachukwu OI, Chima CH, Ikenna AO, Albert L. 2013. Focus on potential environmental issues on plastic world towards a sustainable plastic recycling in developing countries. International Journal of Industrial Chemistry 4: 34.

[OECD] Organisation for Economic Co-operation and Development. 2001. Extended Producer Responsibility, A Guidance Manual for Governments. Downloaded on April 18, 2020 from: https://www.oecd-ilibrary.org/environment/extended-producer-responsibility_9789264189867-en

[OECD] Organisation for Economic Co-operation and Development. 2018. Improving Plastics Management: Trends, policy responses, and the role of international co-operation and trade. Downloaded on April 18, 2020 from: https://www.oecd.org/environment/waste/policy-highlights-improving-plastics-management.pdf

Plastics Europe. 2020. “What are Plastics?”. Downloaded on April 18, 2020 from: https://www.plasticseurope.org/en/about-plastics/what-are-plastics

Pouikli K. 2020. Concretising the role of extended producer responsibility in European Union waste law and policy through the lens of the circular economy. ERA Forum 20: 491–508.

Republic Act 9003, Ecological Solid Waste Management Act of 2000, Sec. 2 p.26.

[STAP] Scientific and Technical Advisory Panel to the Global Environment Facility. 2018. Plastics and the circular economy. Washington, DC.

Schwab K. 2015. The Fourth Industrial Revolution: what it means, how to respond. Foreign Affairs. Dec. 12, 2015. Downloaded on April 18, 2020 from: https://www.foreignaffairs.com/articles/2015-12-12/fourth-industrial-revolution.

Smith M, Love DC, Rochman CM, Neff RA. 2018. Microplastics in Seafood and the Implications for Human Health. Current Environmental Health Reports 5: 375–386.

Smithsonian Institution National Museum of American History. The Bakelizer, A National Historic Chemical Landmark, November 9, 1993. American Chemical Society.

Transactions NAST PHL 41 No. 2 (2019)
doi.org/10.57043/transnastphl.2019.1953

Stahel WR. 2016. The circular economy. Nature (comment) 531 (7595): 435–438.

Statista. 2020. Global plastic production from 1950 to 2018. PlasticsEurope. Downloaded on April 17, 2020: https://www.statista.com/statistics/282732/global-production-of-plastics-since-1950/

Suryanto H, Rahmawan AW, Solichin, Sahana RT, Muhajir M, Yanuhar U. 2019. Influence of Carrageenan on the Mechanical Strength of Starch Bioplastic Formed by Extrusion Process. IOP Conf. Series: Materials Science and Engineering 494: 012075. doi:10.1088/1757-899X/494/1/012075

[UN] United Nations. 2015. World Population Prospects. Downloaded from: https://population.un.org/wpp/Publications/Files/WPP2015_DataBooklet.pdf

[UNEP] United Nations Environment Program. 2018. Single-Use Plastics: A Roadmap for Sustainability. Downloaded on April 18, 2020 from: https://wedocs.unep.org/bitstream/handle/20.500.11822/25496/singleUsePlastic_sustainability.pdf.

[WWF] World Wildlife Fund. 2019. Assessing Plastic Ingestion from Nature to People. Downloaded from: http://awsassets.panda.org/downloads/plastic_ingestion_press_singles.pdf

Wikipedia. 2020. Phase-out of lightweight plastic bags. Downloaded on April 19, 2020 from: https://en.wikipedia.org/wiki/Phase-out_of_lightweight_plastic_bags