EXPLOITING LOCALLY SOURCED POLYMERS FROM RENEWABLE RESOURCES FOR CONTROL OF PLASTIC WASTES

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Abstract
In Nigeria, the problem of environmental pollution by synthetic plastics used as packaging materials has been eliciting great concerns by the citizenry, especially Federal Environmental Protection Agency (FEPA). This pollution arises from indiscriminate disposal of the plastics after the contents are enjoyed. The problem is worsened by the fact that there is absence of all embracing integrated approach in terms of policy by successive governments to minimize the plastic wastes problem. In any progressive waste minimization hierarchy, the 'four Rs', namely reduction, reuse, recycling and recovery (energy) options must be fully exhausted before disposal is considered. This paper is aimed at awakening the national conscience to the technology of waste reduction by the exploitation of locally sourced polymers from renewable resource (PFRRs). PFRRs are gaining recognition as ideal solution to problem of wastes from synthetic plastics due to their ability to reduce carbon emissions, reduce landfill resource they are biodegradable, combustible and are less dependent on oil.

Introduction
A polymer is a substance, whose molecules consist of a large number of low molar mass base units or monomer residues, which are connected by primary bonds (Greek *poly meros* = many parts). If A is a monomer molecule and –A- the base unit, then a polymer molecule is represented by $–[A]_n-$, where n is an integer, called the degree of polymerization of this polymer molecule, and –A- is also called the repeating unit (Challa, 1993). Polymers are either found naturally or prepared synthetically (man-made) in the laboratory. Until recently (for developed countries) or till now (for developing countries, such as Nigeria) the synthetic polymers were usually prepared from raw materials derived only from petroleum. Table 1 presents examples of some polymers with their respective uses (URL1).

Table 1: Some common addition polymers and their characteristics

Names	Formula	Monomer	Properties	Uses
Polyethylene low density (LDPE)	$–(CH_2\text{-}CH_2)_n–$	ethylene $CH_2=CH_2$	soft, waxy solid	film wrap, plastic bags
Polyethylene high density (HDPE)	$–(CH_2\text{-}CH_2)_n–$	ethylene $CH_2=CH_2$	rigid, translucent solid	electrical insulation bottles, toys
Polypropylene (PP) different grades	$–[CH_2\text{-}CH(CH_3)]_n–$	propylene $CH_2=CHCH_3$	atactic: soft, elastic solid isotactic: hard, strong solid	similar to LDPE carpet, upholstery
Poly(vinyl chloride) (PVC)	$–(CH_2\text{-}CHCl)_n–$	vinyl chloride $CH_2=CHC$	strong rigid solid	pipes, siding, flooring
Poly(vinylidene chloride) (Saran A	$–(CH_2\text{-}CCl_2)_n–$	vinylidene chloride $CH_2=CCl_2$	dense, high-melting solid	seat covers, films
Polystyrene (PS)	$–[CH_2\text{-}CH(C_6H_5)]_n–$	styrene $CH_2=CHC_6H_5$	hard, rigid, clear solid soluble in organic solvents	toys, cabinets packaging (foamed)
Polyacrylonitrile (PAN, Orlon, Acrilan)	$–(CH_2\text{-}CHCN)_n–$	acrylonitrile $CH_2=CHCN$	high-melting solid soluble in organic solvents	rugs, blankets clothing
Polytetrafluoroethylene (PTFE, Teflon)	$–(CF_2\text{-}CF_2)_n–$	tetrafluoroethylene $CF_2=CF_2$	resistant, smooth solid	non-stick surfaces electrical insulation
Poly(methyl methacrylate) (PMMA, Lucite, Plexiglas)	$–[CH_2\text{-}C(CH_3)CO_2CH_3]_n–$	methyl methacrylate $CH_2=C(CH_3)CO_2CH_3$	hard, transpar-nt solid	lighting covers, signs skylights
Poly(vinyl acetate) (PVAc)	$–(CH_2\text{-}CHOCOCH_3)_n–$	vinyl acetate $CH_2=CHOCOCH_3$	soft, sticky solid	latex paints, adhesives
cis-Polyisoprene natural rubber	$–[CH_2\text{-}CH=C(CH_3)\text{-}CH_2]_n–$	isoprene $CH_2=CH\text{-}C(CH_3)=CH_2$	soft, sticky solid	requires vulcanization for practical use
Polychloroprene (cis +trans) (Neoprene)	$–[CH_2\text{-}CH=CCl\text{-}CH_2]_n–$	chloroprene $CH_2=CH\text{-}CCl=CH_2$	tough, rubbery solid	synthetic rubber oil resistant

Polymers have permeated virtually every aspect of living in so far-reaching a manner that they have become indispensable in modern living. From clothing, to food, shelter, transportation, communication, medicine and surgery, as well as other conveniences of modern life, polymers are encountered and have touched our lives as does no other class of materials, with no end to new uses and improved products in sight. Even in the field of electronics, what would you do without insulation? And there you come back to polymers again." Well for one thing, your body is made of them. DNA, the genetic blueprint that defines people and other living things, is a polymer. So are the proteins and starches in the foods we eat, the wheels on our skateboards and in-line skates, and the tyres on our bikes and cars (Ochigbo, 2011).

In useable forms, polymers are encountered in daily experience as plastics, rubbers (elastomers), and fibres (Figure 1). However, there is no firm dividing line between the categories. A polymer normally used as a fibre may make a perfectly good plastic if no attempt is made to draw it into a filament. Similarly, a plastic, if used at a temperature above its glass transition and suitably crosslinked, may make a perfectly acceptable elastomer. Elastomers are polymers that readily undergo deformation and exhibit large reversible elongations under small applied stresses, *i.e.* they exhibit elasticity (Cowie, 1973).

Figure 1: Some examples of the different classes of polymers

Among the three categories of polymers stated earlier above, plastics are the most versatile, presumably because of their flexibility to be adapted to any desired applications. A number of business outfits where plastics have found increasing applications include IT and telecommunications, car manufacturing and construction, which accounted for 34 percent and then packaging, 40 percent of the total plastic consumption in Western Europe in 1999 (Chemistry in Britain, 2001). Lee (1990) reported that a third of all plastic produced worldwide is used for packaging. In Nigeria, packagings industry appears to be the largest consumer of plastics. Commodity plastics most commonly used in Nigeria for such applications include low density polyethylene (LDPE), linear low density polyethylene (LLDPE), high density polyethylene (HDPE), polypropylene (PP), polystyrene (PS), polyvinyl chloride (PVC) and polyethylene terephthalate (PET).

Plastics used for packaging and several disposable products that are meant only for a single use, which implies that such products may only be used once and then discarded. As a large number of such products are being utilized this is creating serious environmental issues as people run out of room for trash and start disposing them indiscriminately, sending them to landfill or burning them. This paper examines the impacts of plastics *vis-a-vis* their environmental issues and suggests the way out of the logjam.

Overview of the Problems of Plastic Wastes Disposal

1. *Global perspective*

Historically, many eras were characterized by the materials that were then important to human society (e.g. Stone Age, Bronze Age and Iron Age). The 20th century can best be described as the Plastic Age. During this period no technological advancement, other than the delivery of electrical power to every home, has impacted our lives more than the widespread use of synthetic plastics in our clothes, dishes, construction materials, automobiles, packaging, and toys, to name a few. The development of materials that we now call plastics began with rayon in 1891, continuing with Bakelite in 1907, polyethylene in 1933, Nylon and Teflon in 1938, polypropylene in 1954, Kevlar in 1965, and is continuing. Plastics are, in general, inexpensive, light weight, strong, durable and, when desired, flexible. Plastics may be processed by extrusion, injection-moulding, vacuum-forming, and compression, emerging as fibres, thin sheets or objects of a specific shape. They may be coloured as desired and reinforced by glass or carbon fibres or other fillers and some may be expanded into low density foams. With all these advantages it is not surprising that much of what you see around you is plastic. Many modern adhesives involve the formation of a plastic bonding substance. Plastics have replaced an increasing number of natural substances. In the manufacture of piano keys and billiard balls plastics have replaced ivory, assisting the survival of the elephant. Plastics have been used in the manufacture of bulletproof vests, credit cards, slinky spandex pants. It has led to breakthroughs in medicine, aerospace engineering, and computer science (URL1). The ubiquitous benefits of plastics are undeniable! The American Plastics Council in one of its recent press releases, titled "Plastic Bags-A Family's Trusted Companion," reads: "Very few people remember what life was like before plastic bags became an icon of convenience and practicality-and now art. Remember the 'beautiful' [sic] swirling, floating bag in American Beauty?" Indeed, the low cost, light weight, strength and design adaptability of plastics to meet a variety of applications have resulted, year after year, in strong growth in their production and use, which is likely to continue (Figure 2) (Casey, 2007).

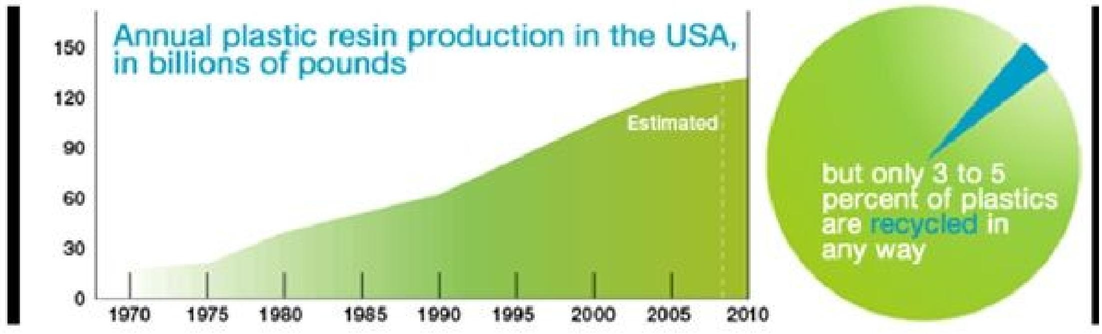

Figure 2: Growth rate of plastic production in USA in the 20th century (Casey, 2007).

However, the advantageous durability and relative low cost of plastics have unfortunately resulted in serious environmental pollution as used items and wrappings are casually discarded and replaced in a never ending cycle. The major reason much wastes are generated lies in the fact that, every year about several tons of plastics are produced, and much of these are employed in disposable products meant only for a single use. About 7 years ago, it was estimated that annual consumption of plastic products in Western Europe approaches 100kg per person to give a total of over 39 million tons. It was estimated that this level of plastics consumption could ultimately result in a 22 million tonne waste stream (APME, 2004; Keane, 2007; Chandra and Rustgi, 1998).

In developed countries, much of these plastics wastes have found their ways into oceans. Charles Moore, an American oceanographer, in 1997, discovered an enormous stew of trash, estimated at nearly 100 million tons, floating in the Pacific Ocean between San Francisco and Hawaii. Named the "Great Pacific Garbage Patch", this stew of trash is composed largely (80%) of bits and pieces of plastic that outweighed the plankton 6: 1, in a region over twice the size of Texas. Although some of this flotsam originates from ships at sea, at least 80% comes from land generated trash.

At the same time, all over the globe, there are signs that plastic pollution is doing more than blighting the scenery; it is also making its way into the food chain via the ocean deposits. Some of the obvious victims are the dead seabirds that have been washed ashore in startling numbers, their bodies packed with plastic: things like bottle caps, cigarette lighters, tampon applicators, and coloured scraps that, to a foraging bird, resemble baitfish (one animal dissected by Dutch researchers contained 1,603 pieces of plastic.) More than a million seabirds, 100,000 marine mammals, and countless fish die in North Pacific each year, either from mistakenly eating this junk or from being ensnared in it and drowning. Once inside the animal, the plastics remain there without decomposing because the material's molecular structure resists biodegradation (Figure 3). The situation calls for urgent measures to address this life-threatening problem.Twenty-three countries, including Germany, South Africa, and Australia, have banned, taxed, or restricted the use of plastic bags because they clog sewers and lodge in the throats of livestock. Like pernicious Kleenex, these flimsy sacks end up snagged in trees and snarled in fences, becoming eyesores. They also trap rainwater, creating perfect little breeding grounds for disease-carrying mosquitoes (Casey, 2007).

Figure 3: A seabird with body packed with plastics wastes

1. Nigerian perspective

One of the major problems confronting Nigeria today is poor solid waste management. In almost every town and city, several tons of municipal solid waste is left uncollected on the streets each day, clogging drains, creating breeding ground for pests that spread disease and creating a myriad of health related and infrastructural problems (Nwachukwu, 2009; Nabegu, 2010). From a number of research/survey carried out, several reasons are adduced for this poor state of environmental problems. Udeh (2009) opined that Nigerians are ignorant of effect of pollution by industries on their surroundings. Toxic wastes are indiscriminately dumped by industries besides the various incidents of offshore and onshore oil spillage that has been going on. For instance, in June 1988, the news of the dumps of drums of toxic wastes at Koko port, took the nation by surprise. This discovery prompted the Federal Government of Nigeria to establish Federal Environmental Protection Agency (FEPA) by Decree No. 58 of 1988. In June 1999, the Ministry of Environment was created and FEPA became its subsidiary. Most State Governments in a similar manner created full-fledged Environmental Ministries to replace their existing Environmental Protection Agencies. There is also in existence an environmental sanitation edict that requires that one Saturday in a month be used for cleaning the environment for 3 hours. Despite this move, the state of affairs regarding wastes disposal in Nigeria is still appallingly embarrassing. Ubani (2003) noted that in almost all cities and rural areas in Nigeria, the menace of solid waste has posed great environmental problems due to the inability of the solid waste management agencies to carry out their responsibility. The guidelines provided by these Agencies are flagrantly disobeyed. Ene-Ita (1984) agreed with this position when she wrote, "Looking at the state of affairs, it appears as if little or no cognizance is taken of the existing laws since there is no mechanism to enforce them by the government".

During the last few decades, Nigeria has experienced an upsurge of "plastic packages boom", through especially provision of package 'pure' water in bottles and sachets. The packaging of water in these forms is a thriving business in Nigeria today and is triggered by lack of potable water for majority of Nigerian teeming population. Thus, the packaged waters that are usually perceived as pure by an average person in need of drinkable water have become a big attraction with unabated demand for it by the populace. Majority of household wares are also dominated by plastics (Figures 4 a-c). Although, these products offer a lot of conveniences to Nigeria populace, their blessings have, however, somewhat become a “curse” to our environment. Due to inefficiencies of our environmental regulations, wastes from these products are littered in every available space.

When dry, at times, these plastic wastes are burnt indiscriminately, resulting in the release of obnoxious gases which constitute greater hazards than the plastic wastes themselves. For example, incineration of PVC is problematic as it falls into category of Principal Organic Hazardous Constituents that are inherently difficult to combust. Complete combustion of such compounds occurs at such high temperatures (>1700k), that it is economically prohibitive, while the formation of hazardous by-products (polychlorodibenzodioxins and polychlorodibenzofurans), known as carcinogens included on the EPA Persistent Bioaccumulative Toxics List, can result from incomplete incineration (Hagenmaier *et al.*, 1991; Costner 1998).

Figure 4a: Plastic bottled water

Figure 4b: Water packed in plasticsachets

Figure 4c: Plastic household wares


Figure 5a: Wastes treatment pattern at Minna Trade Fair in 2011


Figure 5b: Waste treatment pattern scene on Port Harcourt-Warri expressway

Figure 5c: Wastes treatment dumpsite with uncontrolled burning in Port-Harcourt

Figure 5d: Water drainage with pieces of plastic wastes in Bosso, Minna

Researching Solution to Plastic Wastes Using Pfrrs

The problem of environmental pollution by synthetic plastics has also elicited great concern in developed countries, to the point where countries such as Taiwan and Italy have enacted strict laws against the use of petroleum-based, single-use items, particularly packaging, bowls, eating utensils and wraps [Tremblay, 2003]. There are a number of European Directives in place (notably the Waste Packaging, End of Life Vehicle and Electrical/Electronic Equipment Directives) that set increasingly stringent standards to minimize environmental impact due to waste plastic (Aguado et al, 2006). These Directives particularly target a decrease in plastic waste sent to landfill and encourage an integrated approach to encompass prevention of waste at the production stage (reduction), reuse to extend productive lifetime, recycling and energy recovery (4 R's options).

In Nigeria, reuse option is about the only means being used, out of these three options, to decrease plastic wastes apart from those that are either burnt or sent to landfills. Reuse system is carried out by the activities of informal waste collectors ("scavengers"). In Nigeria, they are very common (Nwachukwu, 2009). In Kano, for example, it is reported that there are roughly 25,000 waste pickers in the city whose average per capita collection is about 15 kilograms per day. Collecting about 312 tonnes of waste per day, the waste collectors recover about 10% of waste generated (Nabegu, 2010). However, reuse cannot go on endlessly. The more often a plastic is re-used, the greater the chances of its posing harm to the consumers. This is because the additives, some of which are very dangerous to health, used in compounding the plastics initially gradually leach away and enter into the content and eventually into human bodies. This is the situation when, for example, plastic bottles are reused frequently for water packaging. Recycling of plastics is a very complicated issue. It would entail sorting out the plastic wastes into their different classes. The plastic trash from most households, even with some user separation, is a mixture of unidentified pieces. One serious problem in recycling is posed by the many additives found in plastic waste. These include pigments for colouring, solid fibres in composites, stabilizers and plasticizers. Besides, only very few plastics, in particular PET and HDPE, have satisfactory value after recycling, yet they need to be complemented with virgin corresponding plastics for that value to be realized. Energy recovery involves burning the plastics in order to generate heat that would be further channelled to provide steam for power generation. As noted earlier, this can result in release of obnoxious gases, some of which are carcinogens. Moore (Casey, 2007) routinely found half-melted blobs of plastic in the ocean, as though the person doing the burning realized pathway through the process that this was a bad idea, and stopped (or passed out from the fumes).

Those that are dumped into holes in the ground (landfill waste disposal) remain there for centuries. This represents a waste of energy and oil (since plastics are made from oil or petroleum). It is also very expensive to collect and dispose of waste. Only a few types of plastic can be converted back to oil.

What then is the holistic way out of escaping the ecological problems of plastic wastes? Green architect and designer William McDonough proposed a standard known as “cradle to cradle” in which all manufactured things must be reusable, poison-free and beneficial over the long haul. For all intent and purpose, the only technology which more or less comes near to achieving this safe target is the development of biodegradable polymers using polymers from renewable resources. “Biodegradable plastics are polymeric materials which are changed into lower molecular weight compounds where at least one step in the degradation process is through metabolism in the presence of naturally occurring organisms” (Fukuda, 1992). Biodegradable polymers are sourced from polymers from renewable resources (PFRRs). Polymers from renewable resources (PFRR) are polymers that can be derived wholly or partially from living substances. Generally, PFRR can be classified into three groups: (1) natural polymers, such as starch, protein and cellulose; (2) synthetic polymers from natural monomers, such as polylactic acid (PLA); and (3) polymers from microbial fermentation, such as polyhydroxybutyrate (PHB). Polymers from renewable resources have attracted an increasing amount of attention over the last two decades, predominantly due to two major reasons: firstly environmental concerns, and secondly the realization that our petroleum resources are finite. Several advantages abound through investing in PFRRs. Like numerous other petroleum-based polymers, many properties of PFRRs can also be improved through blending and composite formation (Yu *et al*., 2006). The development will save fast depletion of the finite petroleum reserve from which raw materials for synthetic plastics are derived. The huge amount of financial resources being spent in collecting and disposal of plastic wastes will then also be saved.

Nigeria has potentials to invest in the development of PFRRs. One of the most useful of the natural polymers is natural rubber, obtained from the sap of the *hevea* tree. (Rubber was named by the chemist Joseph Priestley who found that a piece of solidified latex gum was good for rubbing out pencil marks on paper. In Great Britain, erasers are still called “rubbers”.) This polymer is very abundant in Nigeria, with large plantation concentrated around Niger Delta region. Products from NR include contraceptives, tires, carpet lining, diving gear and adhesives. NR blends and composites are in the forefront of research activities today for various engineering applications. Other examples of natural polymers such as starch, proteins, cotton and wool are largely cultivated in Nigeria. PLA also known as poly (lactate) or poly (lactide) is made from agricultural products and is readily biodegradable. Lactide is a cyclic dimer prepared by controlled depolymerisation of lactic acid, which in turn can be obtained by fermentation of corn, sugar cane, sugar beet (Yu et al., 2006).

PHB and its copolymer, poly (hydroxybutyrate-*co*-hydroxyvalerate) come under the class of polyesters which are synthesized biochemically by microbial fermentation and bacteria accumulate them in granular form in their body as an energy storage material (Ha and Cho, 2002). PHB can be fermented from a variety of sources such as sugars and molasses or from hydrogen and carbon dioxide, depending on the bacteria used. Upon degradation under certain environmental conditions and with enzymes, these polymers become nontoxic residues of carbon dioxide and water. The Young's modulus of PHB is usually about 3.5 GPa, which is comparable with poly (propylene) or poly (ethylene terephthalate) (Ha and Cho, 2002). The agricultural products from which these polymers are sourced are cultivatable in Nigeria. They can, therefore, be exploited to help avoid completely/reduce to barest minimum the endemic plastic wastes problem in Nigeria.

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