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Sustainability in PET Packaging

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Abstract In this work, source reduction of poly ethylene terephthalate (PET) packaging are discussed as aspect of sustainability, such as reuse, refill and recycling through the various treatment methods and historical studies for municipal solid waste (MSW) disposal. Since PET has good chemical, physical and mechanical properties, and provides good oxygen and carbon dioxide barrier properties, PET is one of the most widely used thermoplastic polyester in the U.S. and around the world. As the demand for non-renewable PET is increasing, several approaches have been developed to meet economical feasibility and environmental responsibility without degrading material performance. Several companies, such as Coca-Cola Co., Easterform Packaging Co. and Kraft, have tried to develop lightweight PET bottle, and some of lightweight PET bottles are already commercialized. Reuse and refilling for PET container is well developed in Europe, such as Denmark, German and Netherland by supportive legislation and policies. Recycling process is the best way to economically reduce PET waste. In consequence, advanced technique and further development must be provided due to increasing PET packaging waste.

Keywords Sustainability, Source reduction, PET packaging, Recycling of PET

Introduction

1. Environmental concerns to solid waste management

In the mid 1980s, the majority of municipal solid waste (MSW) management was landfill, accounting for 88.6% of total MSW. Soon, the land used for MSW became a public environmental issue, and plastic packaging industries were a major target of proposed legislation due to large fraction by volume of materials and poor biodegradability[1)]. Furthermore, in some other countries such as most European countries and Japan in Asia, this problem was much more serious than in the U.S. due to lack of available land. One of attempts to solve the problem was to look for ways to minimize MSW generation, and another was to seek alternatives to landfill disposal, including incineration and recycling. Many countries studied the combustion system to deal with MSW disposal. However, in the late 1980s and early 1990s, the effort on the incineration resulted in many failures due to public concern about heavy metals in incinerator ash, and the poor economical efficiency to build and manage these facilities. In consequence, source reduction and recycling were rapidly increased, and packaging materials were the primary initial target. The recycling rate was greatly increased until the end of 1990s. Composting has grown significantly from the end of last century, which is managed by a biodegradable process and produced to finished compost that can be used as a soil amendment or able to used as fuel like that occurring in a landfill. Given in Fig.1, it indicates that total MSW generation of U.S. is about 254 million tons of trash with recycled and composted 85 million tons of this material, equivalent to a 33.4% recycling rate. Among 85 million tons, 63 million tons were recovered through recycling, representing 1.9 million tons more than that of year 2006. Composting recovered almost 22 million tons of waste[2)]. The recovery of recycling including composting is continuously increased and combustion with energy recovery and landfill are steady or somewhat decreased since mid-1980s. The historical trends of managements to municipal solid waste are shown in Fig. 2[2)].

Packaging in MSW

Data of waste generated in 2007 by product items by weight is shown in Fig. 3[2)]. Containers and packaging made up the largest portion of waste generated, 30.9%, or 78 million tons.

Among the 11.7% recovery of plastic packaging waste, PET soft drink bottle (including water bottles) was the highest portion in recovery rate as 36.6%, and HDPE milk and water bottle were the next highest recovery rate as 28%[2)]. Compared to recovery rate of glass, steel, aluminum and paper, plastic

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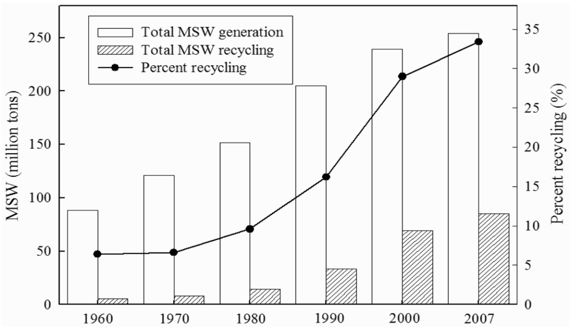

Fig. 1. MSW generation, recyclig and percent recycling in U.S., 1960 to 2007[2].

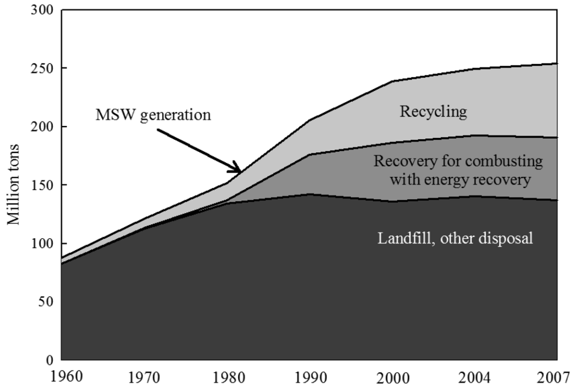

Fig. 2. Municipal solid waste management, 1960 to 2007[2].

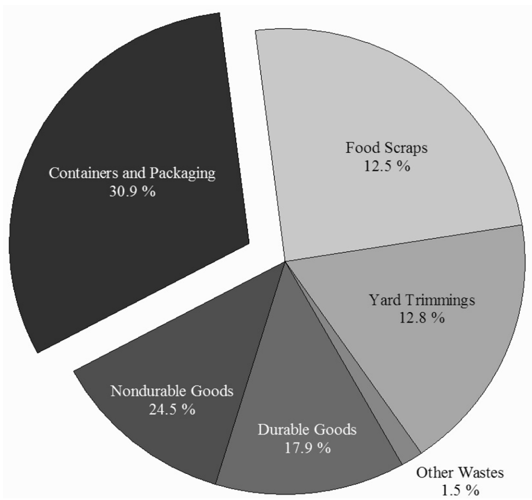

Fig. 3. Total MSW generation by category, 2007[2].

packaging has relatively small recovery rate. One reason is that the recovery process requires that plastic materials undergo decontamination[3]. Another reason is that present recycling, sorting and cleaning techniques cannot handle all kinds of plastic packaging because many common packages do not consist of a single-type polymer but rather of polymer mixtures or copolymers.

With increasing environmental demands, post-consumer plastics packaging materials have also been considered more and more for recycling into new packaging. Several approaches for re-use of recycled material in packaging are driven by the recent strong increase in PET bottle for soft drinks, water and other products in Europe[4]. Another approach is use for other container such as thermoformed applications in U.S. and other Asian countries.

Biodegradable Plastics

For environmental concerns, biodegradable polymer, such as poly lactic acid (PLA), have gained enormous attention as a replacement for conventional synthetic packaging materials. Biodegradable polymer, especially PLA, has numerous advantages; (1) it can be obtained from a renewable agricultural source (corn), (2) its production consumes quantities of carbon dioxide, (3) it provides significant energy savings, (4) it is recyclable and compostable[5]. However, demand for PLA has been shifting to postconsumer recycled (PCR) resins due to several disadvantages of PLA. PLA has a relatively high moisture vapor transmission rate which means that water-based products are not especially well suited to long-term storage in PLA packaging. Based on our experiment, it was found that water vapor permeability coefficient for PLA films has relatively higher than water vapor permeability coefficient for both 100% virgin and 100% recycled PET films (Table 1). Moreover, according to Auras et al[5], solubility parameter predictions indicate that PLA will interact with nitrogen compounds, anhydrides and some alcohols. It implies that PLA will not be suitable for some food packaging. All bioresins and biodegradable plastics are currently not pulled into recycling center because recycling code of biodegradable plastics is ‘other’. These situations described above drive another several approaches to achieve greener packaging. One of approaches is using postconsumer recycled resins. When recycling process is done correctly, recycled PET shares the same chemical properties as virgin resin. PET can even be ‘solid-stated’ to bring it back to virtually the same intrinsic

Table 1. Water vapor permeability coefficient for PLA, 100% virgin and 100% recycled PET film at 99 %RH and 37.8°C

Film sample	Water vapor permeability coefficient ($kg{\cdot}m/m^2{\cdot}s{\cdot}Pa$)
PLA	$1.80 \pm 0.01 \times 10^{-14a}$
100% virgin PET film	$2.73 \pm 0.08 \times 10^{-15b}$
100% recycled PET film	$2.76 \pm 0.02 \times 10^{-15b}$

*Values in the same column with different superscripts are significantly different at $\alpha = 0.05$

viscosity as virgin PET. Moreover, PET PCR can be used for all PET blow molds so that it is easy to convert current packaging from virgin PET to recycled PET with minimal tests and no new mold costs. Namely, PET PCR has more economically feasible than biodegradable plastics. Reuse, refill and reduction of packaging material can be other approaches to reduce environmental footprint. Therefore, this study is aimed for studying source reduction, such as reuse and refill and the recovery of recycling through the various treatment methods and historical studies for MSW disposal in order to search for sustainability in PET.

Sustainability in PET

Sustainable development, which is defined by the former Norwegian Prime Minster Gro Harlem Brundtland, is the development that "meets the needs of the present without compromising the ability of future generations to meet their own needs."[6] Sustainable development is concerted action to protect the earth's life support systems while promoting both economic and social justice goals. Therefore, sustainable development is created with the interaction of three fundamental criteria: ecology/environment, economy/employment and equity/equality, known today as the Three Es[7]. EPA has ranked the most environmentally sound strategies for MSW. The most preferred method is a source reduction such as reuse and refill, followed by recovery of recycling including composting, and finally, disposal in combustion facilities and landfills (Fig. 4)[2]. Among these methods, composting is the controlled biological decomposition of organic matter, such as food and yard waste, into humus, a soil-like material. Biodegradable polymers are regarded as the renewable packaging material as alternatives to traditional oil-derived plastics, and currently entering the marketplace, such as polylactic acid (PLA) and starch based polymers. However, these polymers have disadvantages that they are still higher price than conventional commodity polymers and biodegradable only when their products are disposed of properly in a compositing site. Therefore, the most useful methods in pursuit of sustainability in packaging are the source reduction and the recovery of recycling.

1. Source reduction of PET

Source reduction, called "waste prevention," is defined by the Environmental Protection Agency (EPA) as "any change in the design, manufacturing, purchase, or use of materials or products (including packaging) to reduce their amount or toxicity before they become MSW. Prevention also refers to the reuse of products or materials"[2]. Source reduction can be achieved by a broad range of activities by private citizens, communities, commercial establishment, institutional agencies, manufacturers and distributors[2]. Redesigning products or packages to reduce the amount of materials by replacing lighter materials for heavier ones is one of the examples of source reduction actions. Reusing products or packages is another action. Redesigning and reusing are considered better, according to the EPA, than recycling because the product does not need to be reprocessed before it can be used again. The efforts on refilling and light weighting of PET bottles are good examples.

2. Light weight

The light weighting of PET bottles started in the mid 90s with developments in PET resin technology and conversion equipment. At this time, the weight of 2-liter, 1.5-liter and 500 ml PET water bottles were 58 g, 40 g and 22 g, respectively. By 2006, the lightest 1.5-liter PET water bottles weighed 30 g, and 2-liter PET water bottles were 47g, while 500 ml bottles had slimmed down to 12.5 g[8, 9]. In the last few years, the concern of light weighting has continually increased as one of the source reduction actions. According to the report of Easterform Packaging[10], they designed 20 g of 500 ml and 40 g of 2 liter lightweight PET bottles, compared to 25 g of

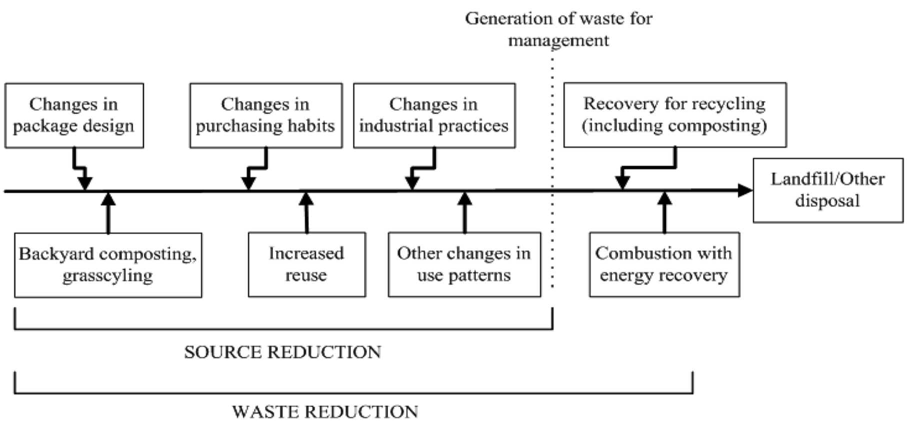

Fig. 4. Diagram of solid waste management[2].

500 ml and 42 g of 2 liter PET bottles. After they produced lightweight PET bottles, they analyzed whether lightweight PET bottles meet bottle specifications, and compared energy, economic efficiency and energy, carbon emission saving with traditional PET bottles. In consequence, lightweight PET bottles satisfied bottle specifications without losing their performance. Table 2 shows energy and material saving of lightweight PET bottles compared to traditional PET bottles.

In theory, lightweighting involves removing weight from the neck finish area and the body. However, in practice, there are several issues, especially for lightweight PET bottles[8]. One of the problems is that product rigidity and top load resistance are decreased with decreasing wall thickness. Another possible problem is nesting of preforms (body of preform is less than opening of the neck) in the blow stage. Moreover, decreasing bottle weights affects not only bottle production and product filling speed but also shelf life of bottles. In order to solve these issues, three major technologies can be applied in practice. Redesigning preform shape, moulds and injection-stretch blow machine can be one of the technologies. Another technology is to develop a new PET material that is able to achieve light weighting along with improved processing and barrier performance. Eastman chemical introduced a new PET resin series named "Vorcalor PET CB11E, 9921W, and AQUALOR PET 18696," which can get up to 30% energy saving and is very compatible with recycling processes[11]. The third developing technology is preform re-heat profile in an IR oven that obtains a perfect heat distribution between the inside and outside temperature of the preform, and the PET bottle can achieve the same stiffness at reduced material thickness. Table 3 show commercialized lightweight PET bottles by company.

3. Reuse/refill

In the U.S. today, most consumer packages are not designed to be returned for reuse because the design and implementation of the collection, return and cleaning are not considered. Two-thirds of consumer packages are landfilled, and the remaining one-third are reprocessed and recycled into new products. Not too long ago, refilling systems gained popularity as a more efficient way of handling used containers, especially beverage containers, than recycling systems. In some European countries, refillable PET bottles are common for soft drinks, water and beer. One of the most general refillable PET bottles is the 1.5 liter soft drink bottle, which has enabled refilling system to package beverages in plastic that is more light-weight than glass or metal, shatterproof for handling, and multi-serve containers in distribution level. Table 4 indicates costs of 500 ml refillable and one-way glass and PET beverage containers in Europe.

However, even though refilling system have many advantages, such as increasing cost benefit and decreasing environmental burden, the beer and soft drink industries in the U.S. have dismantled their refilling systems. While American soft drink companies have replaced refillable glass bottles with single-use plastic bottles and aluminum cans in the U.S., they have been using state-of-the-art refillable containers in many European and Latin-American countries.[15] In many European countries and some Canadian provinces, policies to promote or require the use of refillable beverage containers

Table 2. Energy and material saving of lightweight PET bottles compared to traditional PET bottles[10]

	Per million 500 ml PET bottles (Using 20 g rather than 25 g preforms)	Per million 2 liter PET bottles (Using 40 g rather than 42 g preforms)
PET weight savings	5 tonnes	2 tonnes
PET material cost savings at $1,300/t	$6,503	$2,601
Carbon emission savings	0.41 tonnes	0.10 tonnes
Energy savings	4,133 kWh	1,653 kWh

Table 3. Examples of lightweight bottle productions with producer[12-14]

Company	Product	Description
Colgate-Palmolive	Softsoap® hand soap pouch refill	50% weight reduction compared to like-sized PET bottle
Easterform Packaging	CSD(carbonated softdrinks) bottles	500 ml CSD bottle (25 g to 20 g) 2L CSD bottle (42 g to 40 g)
Kraft	Salad dressing PET bottle	19% weight reduction by process refinement
Coca-Cola	CSD bottles	23% less PET in 600 ml CSD bottles in Mexico
	Dasani water bottle	35% less PET in 500 ml Dasani bottle
	Cap for PET bottle	38% smaller cap for PET bottles
Sidel	NoBottle	9.9 g per 500 ml bottle
Krones	PET lite 6.6	6.6 g per 500 ml bottle (lightest bottle on the market)
Filmatic	-	16 g per 500 ml bottle compared to traditional 26 g

Table 5. Refillables as a portion of total beverage sales and policies in some countries[15]

	Soda	Beer	Policies
Prince Edward Island (Canada)	100%	100%	Bans non refillables
Ontario (Canada)	NA	81%	~9¢ tax on one-way beer container
Quebec (Canada)	NA	80%	No more than 37.5% of beer can be in one-ways
Finland	98%	73%	Levy on one-way containers
Denmark	90%	100%	Banned cans and required refillables for domestic soda/beer
The Netherlands	75~80%	100%	Cannot substitute one-way for refillables unless environmental impact is same or less
Germany	75%	75%	72% most be packaged in refillables or be subject to mandatory deposits
U.S.	<3%	<5%	

have been enacted since the 1970s. Table 5 shows refilling rates and legislations for refilling system in some of European countries, and some Canadian provinces.

4. Recycling of PET

There are several key factors to affect market dynamics of PET recycling. First reason is the price of PET resin. The price of virgin PET has remained high due to the high price of petroleum. Both virgin PET and gasoline production compete for the same petroleum precursor, paraxylene. Therefore, as long as gasoline prices remain high, virgin PET prices will remain high. In general, high virgin PET prices also allow PET reclaimers to charge higher prices for recycled PET flakes. As shown in Figure 5, the price of both crude oil and gasoline has been increasing until September, 2008. Following the trend for gasoline pricing, virgin PET prices are expected to remain high, even in the presence of excess supply. Moreover, another PET precursor, isothalic acid, was in short supply in the spring of 2007 which further increased virgin PET pricing.

Second reason is demand for PET resin. According to the report of The National Association for PET Container Resources (NAPCOR) illustrated in Figure 6, 5683 million pounds of PET bottles were on U.S. store shelves in 2007 compared to 1950 million pounds in 1995, representing a 191% increase[16]. However, market growth of about 4.8% for

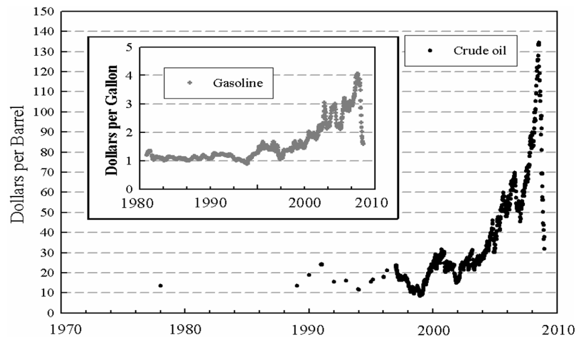

Fig. 5. U.S. price trends of gasoline and crude oil. Source: Energy Information Administration.

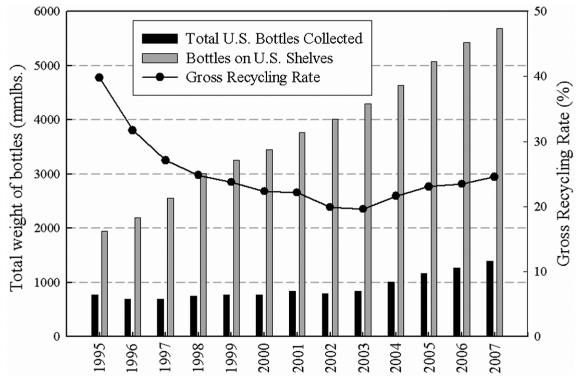

Fig. 6. Total weight of bottles on U.S. shelves and collected with gross recycling rate[16].

PET bottles and jars sold in the U.S. during 2007 slowed down from 6.9% in 2006[16]. The staggering sale of bottled water in the past decade is predicted to slow down as the market is saturated. In 2006, isotonic drinks, tea, and the energy drink segments leaded the market growth of PET bottles and jars. In 2007, not only did those segments continue to perform well, but first "upscale" wine was offered in PET bottles. Not only were 375 ml bottles used to access away-from-home markets, but 750 ml bottles were introduced at retail, primarily by Australian vineyards selling in North America. For some reasons, the overall global PET demand is expected to grow at a rate of 7% per year between 2006 and 2011, with most of the new virgin PET production capacity in Asia and the Middle East.

Third reason is demand for recycled PET (RPET) resin. Demand for RPET is at a record high due to increasing demand for all end-use applications such as carpets, filters, fabrics, roofing, paintbrushes and brooms, and packaging. It is expected that demand will grow from the current 1 billion pounds per year to between 2 and 2.5 billion pounds per year [16]. Given in Figure 7, cost advantage of recycling PET over than 40 cents compared to virgin PET resin also encourages manufacturers of PET products to use recycled PET contents. In addition, environmental concerns, as evidenced by the Wal-Mart (Bentonville, AR) packaging sustainability initiative, are

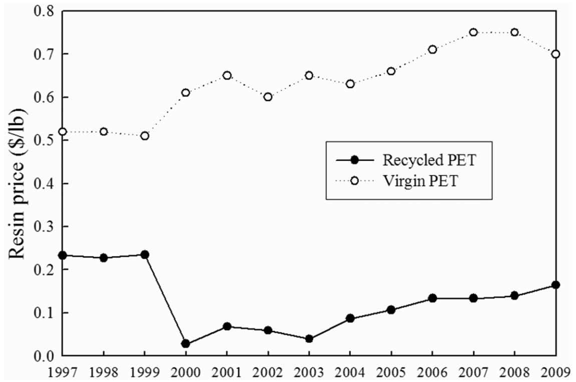

Fig. 7. Price of virgin and recycled PET resin, 1997 to 2009, according to report of the Innovation Group "Chemical profile-PET" and "Plasticsnews.com PET resin price".

motivating some packaging manufacturers to shift substrates from polystyrene (PS) and polyvinylchloride (PVC) towards recycled content PET. Earlier in 2009, Coca-Cola Company opened the world's largest plastic bottle-to-bottle recycling plant in Spartanburg, S.C. The plant will produce approximately 100 million pounds of recycled PET plastic for reuse each year. Moreover, California has passed a Rigid Plastic Packaging Container (RPPC) law (amended 2005), which requires that non-food plastic packaging be source-reduced (light-weighted) by at least 10%, reused a minimum of 5 times, or contain a minimum of 25% recycled content[17]. Therefore, increased enforcement of the RPPC by the California Integrated Waste Management Board (CIWMB) would further increase RPET demand.

5. Improvement the recyclability in PET packaging

In comparison to other packaging plastics, such as polyolefin or polystyrene, PET has a much more inertness due to low diffusivity. Therefore, recycling of PET does not have significant problems in its properties if it is on close-loop recycling process. However, contamination levels and frequency of misuse of recycled plastics, such as residual adhesives from attachment of label and mismatch of other plastics, can affect it. Especially, as both densities of PET and PVC are similar, mixing between two plastics can be produced, the contamination that has only 4 to 10 ppm could cause serious problem[18]. Recently, these kinds of problems were solved and increased recycling efficiency by new technologies to separate and sort other materials, and introduction to so-called super-cleaning recycling processes which generally use high-temperature by heat, vacuum or surface treatment with chemicals for a proper time in solid-stating steps to decrease the concentration of contaminated materials in RPET. This super-cleaning recyclates can be reused safely in direct food contact even if the material was previously used for other applications such as shampoo or detergent. FDA has published several no-objection letters[19] for recycled food grade PET previously used for non-food products. Another contamination issue was RPET contained aluminum; this problem could also be improved by combining re-roll systems with electronic control system (ECS) which had an efficiency of 99.1 to 99.5 %[1]. Another way as a source control is to avoid PVC and aluminum closure at the packaging design stage as the concept of cradle-to-cradle for a sustainable PET packaging. Therefore, the source control is the first and most important step for recycling in PET packaging.

Entering this century, a new and huge market was opened in beer market as a PET bottle in the worldwide. For 20 oz and 1 liter PET bottles in USA there has been used a new five-layer plastic of which two layers in three layers are virgin PET and core layer is RPET, and the remained two layers, which are incorporated between each PET, are made of a new polyamide barrier named MXD6. This structure is very effective to prevent migration from recycled PET, such as three layer PET bottles which have been used in soft drink in Europe[20]. SurShot system also has five layers (PET/SurBond/PET/SurBond/PET), and SurBond is based on ethylene vinyl alcohol (EVOH), which can be effectively separated from PET during recycling. The recycling rate is increased up to 40%. This system was shipped in January 2007 in the U.S.[21]. On the other hand, the technology for plasma coating systems has been improved continuously in Europe and Japan, which is the method to coat in plasma state on inside or outside of PET. By the success in beer market worldwide, recycling of multilayer and barrier coated PET container is gathering strength, and packing industries in many countries are improving their conventional cleaning system, processing conditions and wash chemistries to remove the residual materials in RPET flakes. Table 6 shows removal efficiency in various PET barrier bottles by using various wash treatment[22].

Table 6. PET recycling of barrier coated bottles and multilayer bottles[22]

Material	Wash treatment	Residual barrier layer (ppm)	Removal efficiency (%)
PPG Bairocade Functional Coating	2.5% NaOH, 1.5% Butyl Carbitol, 0.1% Teric	4.8	99.96
Multilayer Nylon & Scavenger	2% NaOH, 0.02% Oakite RC-7A	700	86
Nylon	2% NaOH, 0.02% Oakite RC-7A	546	94.54
Krones SiO_x Surface Deposition	2% NaOH, 0.02% Oakite RC-7A	None detected	Unknown
Sidel Internal Carbon Deposition	2% NaOH, 0.02% Oakite RC-7A	None detected	Unknown

Conclusion

This review focused on the source reduction, reuse/refill and the recovery of recycling through the various treatment methods in order to search for sustainability in PET, which is obviously the most sustainable packaging material because it has excellent inertness for recycling, mechanical strength for reduction and light weight, optical proprieties for refill or reuse, and reasonable price and well systemized infrastructure than any other commodity plastics. However, in 2007, the rate of recovery in plastics containers and packaging that is major target of environmental issue was only 11.7% in the U.S., even the recovery rate of PET soft drink bottles was 37%, comparing with that of steel packaging was 65% and commercial printing papers was 57%[1)]. Furthermore, entering this century, we are facing much more critical situations than ever by rapid increasing of oil price as still a major fuel, global climate change by greenhouse gas emission, pollution of air and water by waste and energy treatments. Therefore, decision makers should consider thoroughly the sustainable packaging that contains technical and economic information to solve municipal solid waste disposal from the initial step of planning and designing for a new product. Specifically, in case of PET PCR, not only advanced recycling system for recovering properties of PET PCR as high as virgin PET but also cleaning and sorting system to remove residual contaminant more efficiently must be developed. In case of reuse and refill, not only policies or laws supporting reuse and refill but also public perception for reusing and refilling of PET packaging must be cooperated in each other. For reducing weight of PET packaging, further research and development are needed. To sum up, in order to achieve sustainability in PET packaging, development of new technologies and concerns in marketplace and public for PET packaging must be cooperated.

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