News

PET Recycling: High Quality And Sustainability Combined

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Each minute, more 1 million plastic bottles are purchased around the world. Plastics have undoubtedly transformed modern life, delivering convenience, durability, and cost-efficiency, but their environmental impact has become an urgent global concern. Simply put, they do not degrade quickly and have accumulated in many places. Just think of the countless plastic bottles lining roadsides.

Due to its toughness, clarity, and stability, polyethylene terephthalate (PET) is an ideal material for food and beverage packaging, effectively protecting, preserving, and showcasing contents. This toughness means PET can fulfill its role while being remarkably thin (typically 0.010 to 0.020 inches). These qualities reduce transportation costs and lower the carbon footprint by allowing more of a beverage shipment to be the beverage itself, and less of the container. The massive number of beverages consumed worldwide results in a corresponding volume of discarded bottles. Around 500 billion PET bottles are used globally each year, with 35 billion empty bottles discarded annually in the U.S. alone. This is where PET’s durability becomes a challenge. Fortunately, PET is highly recyclable, and when properly cleaned, it can be re-extruded into new bottles that closely match the quality of the original ‘virgin’ material. However, there are three fundamental obstacles to large-scale PET recycling: logistics, economics, and technical constraints. Let’s take a closer look at each challenge and the solutions being applied.

#1: Operational Challenges

The initial logistical challenge lies in accumulating a sufficient quantity of bottles for cost-effective processing. It is far easier to manufacture a million PET bottles and distribute them to consumers than it is to retrieve those million bottles post-use, making collection a major hurdle.

One of the best solutions to this problem is an economic one, specifically motivating the end user. Consider the bottled drink: most consumers are not interested in the bottle itself. It is merely a container for the product. Once empty, the bottle has no value to them, and most see it as trash and to be disposed of quickly, sometimes leading to litter.

To counter this, an effective approach is to create tangible consumer value out of that empty bottle, and cash has proven to work well. This is the idea behind deposit schemes: add a small deposit to the purchase price and refund that amount when the bottle is returned. The amount is small, so it will not affect purchasing decisions, but it will make consumers feel compensated when they return the bottle.

The success of these systems is dependent on the size of the deposit and the ease of receiving a refund. In Germany, where beverage containers carry a significant deposit (often €0.25 per bottle), bottles are rarely discarded. In addition, nearly all grocery stores are equipped with reverse vending machines, making bottle return quick and convenient. Deposit schemes require infrastructure, but they are undeniably effective in reducing litter and increasing recycling rates.

#2: Economic Challenges

Collecting and transporting bottles is an expensive task, creating an economic obstacle for large-scale PET recycling. Even with a robust return system in place, recyclers are responsible for the transport and processing costs of feedstocks that are often dirty and mixed with other plastics. Along with the cost of transport, approximately 70 percent of a typical plastic recycling process yields usable material, creating additional economic barriers for recyclers. Few will take this on at an industrial scale without adequate incentives.
Three economic mechanisms can make PET recycling viable:

1. Intrinsic cost of the material
2. Penalty avoidance through regulation
3. Perceived value of the recycled material

Intrinsic Cost
Intrinsic cost lies in one fundamental question: can recycled PET (rPET) be sold for more than it costs recyclers to produce? For beverage manufacturers using PET, the decision lies in the choice between rPET and virgin PET (vPET). If the cost ratio of vPET to rPET is less than 1.0, vPET is cheaper. If greater than 1.0, rPET is the lower-cost option.

$$\frac{Cost_i(vPET)}{Cost_i(rPET)} = X$$

Equation 1: PET source-cost ratio

A primary expense in the production of vPET is petroleum feedstock. When oil prices rise, vPET becomes more expensive and rPET gains competitiveness. Conversely, falling oil prices make vPET more attractive. This price volatility has made long-term investment in rPET challenging, as profitability is entirely dependent on unpredictable oil markets.

Penalty Avoidance

An effective mechanism to improve the adoption of PET recycling is governmental regulation. Regulations aim to ‘rebalance’ incentives so that a greater societal benefit is achieved. A familiar example is seat belt laws. Seat belts significantly reduce injuries and fatalities in car crashes, and while wearing a seat belt is easy for individuals and beneficial for society, widespread adoption requires penalties for non-compliance. This concept gave rise to campaigns like “Click It or Ticket.”

Similarly, many countries have implemented minimum recycled content requirements to encourage the use of rPET. If manufacturers fail to meet these minimums, they face fines, increasing the cost of virgin PET, and making rPET comparatively more attractive. While penalties may not be as favorable as positive incentives, they can help emerging recycling industries grow as they become self-sustaining.

We can represent this in an equation by reducing the total cost of rPET to reflect the penalty avoidance:

$$Cost(rPET) = Cost_i(rPET) - Penalty\,Avoided$$

Equation 2: The effect of avoided penalties on the total cost of recycled PET

Perceived Value

rPET becomes more attractive if it carries additional value beyond the basic cost of materials, energy, and labor, often referred to as “perceived value.” This concept goes beyond intrinsic value, is difficult to quantify, and is usually subjective. While it may seem abstract, perceived value explains why someone might pay thousands of times more for a Birken bag than a simple grocery bag, when both serve the same basic function.

In recent years, recycled PET has benefited enormously from increased perceived value. As beverage manufacturers became more aware of the environmental impact of their packaging, they recognized the advantages of promoting bottle recycling.

This not only reduced their carbon and water footprint and water consumption, but also enhanced customers' perception of their brand and products. In many cases, the decision to use rPET shifted from purchasing departments to marketing teams, adding a new dimension to rPET's overall value proposition.

$$Cost(rPET) = Cost_i(rPET) - Penalty\ Avoided - Perceived\ Value$$

Equation 3: The effect of Perceived Value on the total cost of recycled PET

Together, these factors have significantly improved rPET's position relative to virgin PET, investing rPET as a more attractive and stable opportunity, while also driving innovation in the field.

Technical Challenges

Recyclers remain focused on reducing the intrinsic cost of rPET by increasing purity and yield, even amid improving economic conditions. Unlike the highly consistent quality of vPET, rPET faces challenges related to feedstock variability and contamination. To address this, recyclers are optimizing various processing steps to enhance the quality of rPET.

Sorting Technology

PET containers typically arrive compressed into bales, often contaminated with labels, caps, and other plastic and non-plastic materials. Optical sorting uses high-speed cameras and near-infrared (NIR) sensors to identify material types, and mechanical methods separate them by material type and color.
Once sorted, containers are shredded into flakes, usually 4 to 10 mm wide, increasing surface area and improving downstream processing by allowing for more uniform flow in wash systems. These flakes are the input for further cleaning and separation.

PET Flotation Separation

The recycling process includes multiple washing stages, with at least one flotation step to remove non-PET material. To separate polyolefin material (caps and labels) from the rest of the PET in recycling lines, their different densities are exploited. PET's density ranges from 1.2 to 1.4 g/cm^3, making it heavier than water (1.0 g/cm^3) and causing it to sink. In contrast, common contaminants like HDPE (0.93–0.97) and LDPE (0.91–0.94) are lighter and tend to float.

When flakes are stirred in water and given time to settle, a polyolefin-rich layer forms on top pf the wash, while PET sinks. This simple flotation works well with large volumes and can be modeled as:

$$R(t) = R_{\infty} \left[1 - e^{-kt}\right]$$

Equation 4: Flotation modeled as a first-order process

In this model, the recovery of PET at time t is dependent on the maximum recovery at infinite time (R_{∞}), multiplied by a factor that incorporates the actual time t and k, which is the first-order rate constant for separation, n. Time is the limiting factor in most chemical production processes, so it is always desirable to minimize the time needed to get the maximum separation. This can best be done by improving k, the rate constant for the separation process.

To enhance material separation, recyclers have improved wettability using additives, optimized particle size, and adjusted ionic strength, resulting in better flotation performance, increased yield, and higher purity.

PET Washing

Washing is an essential step in the production of high purity rPET. In some countries, like Japan, returned bottles are incredibly clean, while in other areas of the world, post-consumer PET is far dirtier. Washing can involve heat, agitation, and caustic soda, but aggressive conditions have trade-offs.

Excessive heat and caustic soda can degrade PET through hydrolysis, reducing clarity and making the flakes brittle. This leads to fines (tiny PET fragments) that lower yield and clog filters. High foaming during saponification also limits efficiency and wastes water and chemicals through excess chemical and water use.

Specialty detergents provide a balanced solution, reducing the need for heat and caustic agents while minimizing foam and fines. These detergents result in higher throughput, lower maintenance, and improved rPET quality, lowering the cost per ton of flakes, benefiting both recyclers and bottle manufacturers, and reducing the overall cost per ton of flakes.

Sustaining Momentum

PET is a highly versatile packaging material, valued for its excellent physical properties and recyclability, making it a preferred choice across industries. The environmental and economic advantages of using rPET are clear, but achieving profitability has long relied on technical innovation and regulatory support.

As demand for rPET continues to grow, so does its market appeal and competitiveness. Sustaining this momentum will require continued process improvements to boost efficiency and sustainability, delivering long-term benefits for consumers, manufacturers, and the broader recycling ecosystem.

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