1 Flexible Plastic Packaging and Recycling

1.1 Definition of Flexible Packaging

The expression “flexible packaging” refers to packaging structures that are capable of being flexed or bent, such that they are pliant and yieldable in response to externally applied forces. Accordingly, the term “flexible” is substantially opposite in meaning to the terms inflexible, rigid, or unyielding. A packaging structure that is flexible, therefore, may be altered in shape to accommodate external forces and to conform to the shape of objects brought into contact with them without losing their integrity. As one of the fastest growing segments of the packaging industry, flexible packaging delivers a broad range of protective properties while employing a minimum amount of material. It typically takes the shape of a bag, pouch, liner, or overwrap.

1.2 Flexible Packaging Categories

Flexible packaging is typically described in relation to the type of product being packaged, for example, retail food, medical devices, pharmaceuticals, etc. It can also be categorized by layer/function. It is convenient to categorize packaging by layer or function:

- primary packaging—the material that first envelops the product and is in direct contact with the contents;
- secondary packaging—the material that is outside the primary packaging, often used to group primary packages together. Film wrappers around the primary packaging are examples of secondary packaging; and
- tertiary packaging—the material that is used for bulk handling, warehouse storage, and transport shipping. The most common form is a palletized unit that packs into containers.

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These broad categories are arbitrary. For example, depending on the use, a shrink wrap can be primary packaging when applied directly to the product, secondary packaging when bundling smaller packages, and tertiary packaging on some palletized distribution packs.

1.3 Selection Criteria of Flexible Packaging

The main selection criteria for an optimum flexible packaging could be summarized as follows:

- product protection (performance)
- packaging cost
- usage benefits and
- environmental impact

Flexible packaging protects the enclosed product from damages (breakages, spoilages, contamination), extends shelf/usage life, safeguards hygiene, and provides an attractive appearance. Most flexible packaging has been optimized for minimum material usage for a given functionality. Flexible packaging reduces overall package size and weight, reduces shipping costs, and promotes fitting more products on a delivery truck. In most cases, flexible packaging materials are intended for single use.

Flexible packaging can be monolayer, coated monolayer, or multilayer. The layers are different material with specific functions in the structure and can include outer bulk layers, barrier layers, tie layers, and seal layers.

Polyethylene, including low density polyethylene (LDPE), linear low density polyethylene (LLDPE), and high density polyethylene (HDPE), is by far the most used polymer in the flexible packaging industry. Other polymers are polypropylene, including cast polypropylene and biaxially oriented polypropylene (BOPP), poly(ethylene terephthalate) (PET), and poly(vinyl chloride) (PVC).

Polyethylene gives the packaging its bulk and structural integrity. For tougher packaging, a packaging company might opt for PET. Polyethylene can also be used to seal the package. But often lower melting point ethylene-vinyl acetate (EVA) is the better choice for that. And if the food inside the packaging is greasy, a food company might opt for a higher-end sealant ionomer, such as Surlyn® (DuPont, ex-Dow). Most food packaging needs a barrier layer to protect against oxygen. Ethylene-vinyl alcohol (EVOH) and poly(vinylidene chloride) (PVDC) are effective in blocking oxygen. If even more barrier is needed, a package might incorporate a metallized film [1]. Metalized films provide optimal protection for high oxygen, gas and water vapor barrier levels, aroma, and flavor retention. Metalized films can also provide special optical properties or a metal look for decorative applications.

There is demand to replace part of these films, especially those used for packaging goods with a short shelf life (e.g., food packaging, waste bags) with films made of biodegradable polymers. The most commonly used polymers in plastic packaging are made of fossil fuel−based resources and degrade very slowly in the environment. Packaging materials made of bio-based polymers address the concerns about depletion of natural resources and greenhouse gas (GHG) generation effects. Bio-based polymers are expected—once fully scaled-up—to help reduce reliance on fossil fuels, reduce production of GHGs, and be biodegradable or compostable as well. Packaging is the biggest application for bio-based and biodegradable polymers nowadays [2].

1.4 Benefits of Flexible Plastic Packaging

The food and beverage market is flexible packaging's largest end user segment, although healthcare has become the fastest growing. Flexible packaging is used in almost every consumer goods section. The benefits of flexible plastic packaging can be summarized as follows [3]:

- Less material needed for production.
- Uses less energy to produce and less plastic than rigid containers.
- Lighter weight allowing transport of higher volumes of product.
- Generates less CO_2 during transportation.
- Creates less waste and takes up less space in the landfill.
- Extends the shelf life of many products, especially food.
- Maintains freshness.
- Provides efficient product-to-package ratios.
- Reduces food waste.
- Creates self-appeal.
- Enables visibility of the contents.
- Easy to open, carry, store, and reseal (convenience).
- Extensible into diverse product categories.

1.5 Flexible Packaging versus Rigid Packaging

Consumer, retail, and technology trends have contributed to a gradual replacement of rigid formats by flexible packaging types, mainly pouches, during the last decade. Flexible plastic packaging is widely used instead of (semi-)rigid plastic packaging because of its flexible convenient format, low weight, durability, cost effectiveness, attractiveness, and its easiness to be shaped. In particular, flexible packaging uses less energy and fewer resources, helps extend food shelf life, minimizes spoilage, brings savings in transportation costs and gas emissions, and reduces food waste. To the consumer it takes up less space when empty than rigid packaging [4]. According to the Flexible Packaging Association (FPA), the flexible packaging uses 50% less energy to produce and 60% less plastic than rigid bottles [5] (see Fig. 1.1).

With flexible packaging such as pouches, the converting of the pouch generally includes full printing features along with the lamination of the films, if necessary. This printing only marginally increases the cost of the pouch and has no effect on the filling process itself. Printing options for flexible packaging are numerous and can be changed if required. On the other hand, part of the total cost of rigid packaging is the labels, which are applied as part of the filling process. Labels are supplied from a different supplier than the bottles, meaning that they often become a bottleneck in the filling process [7].

Further, flexible packaging can be printed with security or brand identity graphics. This technology includes pigment additives that only appear under certain lighting and inks that disappear and reappear depending on environmental conditions. Such technology is not possible with rigid packaging [7].

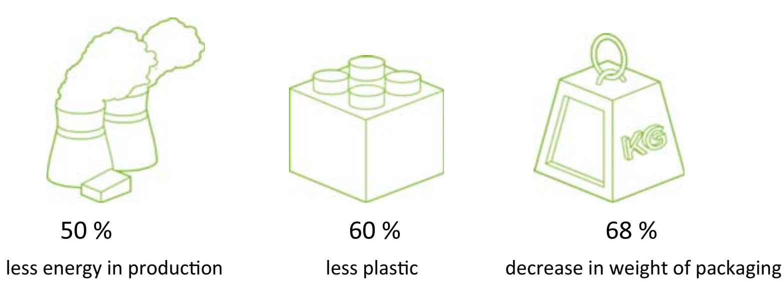

Figure 1.1 Flexible plastic packaging versus rigid packaging. *Courtesy of Enval Ltd., 2019. The Enval process [6].*

One of the main advantages of flexible packaging over rigid packaging is the ability to fine-tune the appropriate barrier level for the product and end use. Bottles made from PET, glass, or multilayer paperboard laminates provide a barrier for all products whether it is required or not. A flexible package can be supplied with barrier properties that can provide anything from moisture and aroma protection to essentially the same barriers as glass [7].

As far as recycling is concerned, the main differences between flexible plastic packaging and rigid plastic packaging can be summarized as follows:

- Most households have access to a rigid plastics packaging recovery system (e.g., PET bottles), while similar services for domestic consumers of flexible plastic packaging are still in their infancy [8].
- Many municipalities do not accept flexible packaging in curbside recycling bins. Plastic films and bags must be taken to a drop-off location, such as a grocery or other retail store, to be collected for recycling (see also Chapter 5; Section 5.2.2).
- Multilayer flexible packaging structures, such as pouches, are not recyclable.
- The recycling rate of flexible packaging is less than 1%, while the rigid packaging is around 40% [8].

1.6 Limitations of Flexible Plastic Packaging

The most commonly used polymers in plastic packaging are made of fossil fuel—based resources and degrade very slowly in the environment. Unlike rigid plastic packaging (e.g., PET bottles), there is no established recovery facilities for flexible packaging. The lack of recycling infrastructure, largely because of problems of collection, sorting, and recycling of films and multilayer structures, particularly arising from postconsumer waste, is the main limitation of flexible plastic packaging. Actually, lack of recycling is the Achilles' heel of flexible plastic packaging. The problem of disposal is especially acute with the flexible multilayer packaging waste.

Up to date, packaging films can be recovered from plastic waste streams by recycling technologies requiring sorting of the commingled plastic materials. Sorting can require use of costly techniques, such as video cameras, electronic devices, infrared detectors, and organic" markers", to provide effective segregation of like plastics. However, even sorted scrap film can present problems in processing as a result of density and chemical differences among polymers falling in the same general class and made by different plastics manufacturers.

Further, sorted scrap film must be subjected to shredding and/or grinding to produce flake scrap material that, then, must be pelletized and ground again to provide powder feedstock for blow molding, rotational molding, extruding, spray coating, and other melt processing techniques that require powder feedstock.

The high cost of sorting has greatly limited widespread use of recycling approaches that require a sorting step. In particular, collected and sorted postconsumer plastic materials are usually more expensive than the corresponding virgin plastic materials. Thus, users of plastic materials are discouraged from using sorted, recycled plastic materials.

While flexible packaging films are favored by brands for their ability to efficiently transport products with minimal packaging waste, they are rejected by recyclers because of their sorting difficulties at material recovery facilities (MRFs) [9]. Recyclers do not accept postconsumer flexible packaging, due to the fact that 80% of the flexibles are food contaminated—food waste contamination levels are often 10%–20% of package weight—and as such unsuitable to go into their existing recycling stream as it will contaminate the final recyclate. This contamination makes the recyclate unacceptable for first-grade applications [10]. Further, packaging films have the tendency to get tangled and clogged in the sortation equipment at MRFs (see Chapter 6, Section 6.1).

1.6.1 The Problem of Flexible Multilayer Plastic Packaging

Up to today, there is no proper system or technology available for the economical recycling of disposed multilayer flexible packaging [10]. There are several reasons for this:

- large variety of materials used for each layer;
- large differences in the processing properties of the polymers used for multilayer films;

- lack of systems for identification of multilayer film;
- lack of system solutions for the collection of these materials;
- lack of economically viable systems of separation of the various materials; and
- lack of standard research of the properties, processing, and applications of composites based on recycled multicomponent materials.

In principle, it is not the technology that makes it difficult to recycle flexible multilayer packaging, but the selection process. In other words, every single flexible packaging layer has to be analyzed and categorized, separated, and recycled individually to recover a maximum of every component to further convert into a recyclate, which increases the overall recycling cost; especially, the different material components used in flexible pouches makes their recycling practically impossible to implement, too complicated, and too risky in terms of investment [10].

There is as yet no commercial facility in the world that can recycle flexible multilayer packaging or metalized films. For example, while PET recycling industry has been established for several decades and accepted as the most leading recycled material, metalized PET films are discarded as waste and end up in the landfill.

Multilayer packaging is composed of a mixture of incompatible polymers and cannot be recompounded without the use of expensive modifiers. In addition to that, the products obtained by recompounding such materials exhibit worse mechanical properties than pure polymers and their compatible polymer blends.

The bulk of flexible plastic packaging are printed, labeled, or decorated for providing usage instructions to meeting statutory requirements (labeling, price details, manufacture details, ingredients, trademarks, and safety information among others) or for esthetic, branding, and differentiation reasons. The removal of the inks, adhesives, coatings, or labels used is not an easy task.

1.7 Recycling

Recycling refers to the recovery of several components from a waste flexible plastic packaging by mechanical, physical, chemical, and biological processes or their combination to convert them into monomers, oligomers, and polymers, which can be used, optionally in combination with virgin polymers, for the making of new products. This process is often, although not quite correctly, called a "cradle-to-cradle" recycling.

The EU's waste management hierarchy [11] (Fig. 1.2) places prevention, reuse, and recycling (including composting) clearly above recovery options (e.g. waste to energy and incineration), while waste disposal (e.g. landfilling) is the very last resort.

The US EPA waste management hierarchy [12] (Fig. 1.3) places source reduction first and recycling/composting second on its list of preferable waste management strategies.

Dumping the flexible plastic packaging waste in landfills is impractical. Plastic waste degrades very slowly and takes up a significant amount of landfill space. Further, the land available for waste disposal is quickly disappearing. Therefore, burying such waste does not significantly contribute to the elimination of disposed plastic packaging products. Incineration is also impractical. It is expensive, and not all of the toxic or near toxic emissions can be captured or scrubbed out of the resulting fumes. This is especially true of packaging materials composed of a variety of different plastics.

Beyond the obvious environmental benefits, there are practical gains to companies that recycle flexible packaging films. The removal and recycling of flexible packaging films from the waste stream reduces the volume needed to be taken away from their facility and their waste bill.

Figure 1.2 Waste management hierarchy of the European Union (EU) [11].

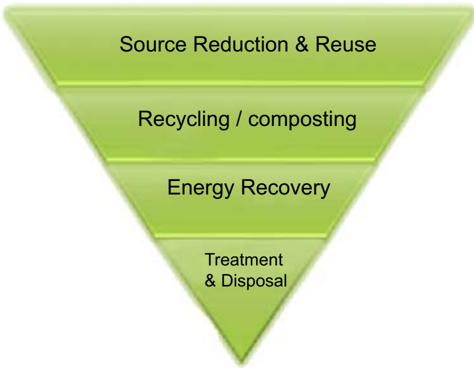

Figure 1.3 Waste management hierarchy of US Environmental Protection Agency (EPA). *Courtesy of United States Environmental Protection Agency (EPA) [13].*

Many recycling companies pay for the used packaging film. Flexible packaging film waste takes up less space than other types of packaging such as corrugate paper waste, meaning less frequent deliveries and recycling pickups and, therefore, less transport costs. Because the bulk of plastic packaging is made of polyethylene, which is derived from natural gas, it uses less energy to produce and recycle compared, for example, with corrugate paper [14].

According to the Association of Plastic Recyclers (APR), an item is "recyclable per APR definition" when the following three conditions are met [15]:

- at least 60% of consumers or communities have access to a collection system that accepts the item;
- the item is most likely sorted correctly into a market-ready bale of a particular plastic meeting industry standard specifications, through commonly used MRFs and plastic recovery facilities (PRFs), including single-stream and dual-stream MRFs' and PRFs', systems that handle deposit system containers, grocery store rigid plastic, and film collection systems; and
- the item can be further processed through a typical recycling process cost effectively into a postconsumer plastic feedstock suitable for use in identifiable new products.

According to the Global Plastics Outreach Alliance definition [16], an item is considered recyclable if it meets the following conditions:

- the item must be made with a plastic that is collected for recycling, has market value, and/or is supported by a legislatively mandated program;
- the item must be sorted and aggregated into defined streams for recycling processes;
- the item can be processed and reclaimed/recycled with commercial recycling processes; and
- the recycled plastic becomes a raw material that is used in the production of new products.

The properties of the discarded plastics are varied widely due to numerous suppliers, each of which uses proprietary additive packages, fillers, etc. It has been established that it is not possible to control the consistency of the discarded feedstocks before recycling. Because mixed (commingled) plastics are incompatible with one another, their reprocessing presents numerous challenges, including phase separation in the melt, delamination of molded parts, and inconsistent color, among others.

1.7.1 Types of Recycling

Recycling processes for plastics can be classified in a variety of ways. Depending on the final product (polymer, monomer/oligomer), the recycling processes of plastic waste can be classified into four categories (see Table 1.1).

Primary recycling involves the recycling of preconsumer industrial (in-plant) plastic scrap (see Chapter 5, Section 5.2.3.1). The recycled scrap or waste is either mixed with virgin plastic or used as second-grade material with less demanding specifications. Secondary recycling involves the recycling of postconsumer and postcommercial plastic waste. Tertiary recycling involves the chemical treatment of plastic waste, whereby the recovered chemical compounds are used for making new polymers (see Chapter 9). Biological recycling involves the depolymerization by enzymes or microorganisms of plastic waste and use of the recovered chemical compounds for making new polymers.

Quaternary recycling or energy recovery or valorization is not considered to be true recycling and is outside the scope of the book.

Table 1.1 Categories of Plastic Waste Recycling

Types of Plastic Recycling	**Synonyms**	
Primary recycling	Mechanical recycling Physical reprocessing	Closed-loop recycling
Secondary recycling	Mechanical recycling Physical reprocessing	Downgrading
Tertiary recycling	Chemical recycling – Chemical modification – Chemical depolymerization	Feedstock recycling
Biological recycling	Enzymatic depolymerization	
Quaternary recycling	Energy recovery	Valorization

An alternative categorization is mechanical and chemical or feedstock recycling [18]. Mechanical recycling uses mechanical processes to convert the plastic to a useable form, thus encompassing the primary and secondary processes outlined above. In mechanical recycling, plastics stay intact, and this permits, in theory, for multiple reuse of plastics in the same or similar product—effectively creating a closed-loop.

To mechanically recycle postconsumer flexible plastic packaging, the waste has to be collected, separated/sorted, baled, shipped, washed, shredded/ground, and reprocessed before it can be mixed with virgin plastics of the same type for molding new products or used on its own for alternative (usually lower value) products (see Chapters 5, 6, and 8). In practice, the mechanical recycling of the recycled product over repeated cycles downgrades its physical and mechanical properties. When plastic material that has been recycled only once is mixed with virgin plastic, only minor impairments are caused in the film properties. The slight impairments of the film may be compensated by reducing the proportion of plastic material that has been recycled once. Further, there are limitations in the use of recycled polymers in the food contact compliance area where certain end use applications are temperature restricted [19] (see Chapter 10, Section 10.2). When processing biodegradable plastics, special attention must be paid to low and uniform processing temperatures (avoiding temperature peaks), increased sensitivity to shearing, and oxidation [20].

Chemical or feedstock recycling is essentially equivalent to tertiary recycling, using the recycled plastic as a chemical raw material, generally for the production of new polymers [18] (see Chapter 9). A special subcategory of chemical recycling can be considered the chemical modification of the polymers of a plastic waste. It can include modification of incompatible polymers with reactive compatibilizers (see Chapter 8, Section 8.7.1.1).

1.8 Life Cycle Analysis

The packaging sector is using life cycle assessment (LCA) to evaluate the potential environmental impacts of flexible plastic packaging throughout its life cycle from the production of raw materials to the disposal of finished products. The rules for conducting an LCA analysis are defined by ISO (International Standard Organization) standards 14040 and 14044.

From a general LCA perspective, flexible film packaging is a highly efficient form of packaging—even when it is not able to be recycled, it typically results in less global warming potential, energy use, and quantity landfilled than recyclable rigid package alternatives [21].

Six different LCA case studies, commissioned by the FPA, were developed by PTIS using the EcoImpact-COMPASS® LCA software, comparing flexible packaging to other formats across a range of products (see Table 1.2). The case studies included coffee, motor oil, baby food, laundry detergent pods, cat litter, and beverages (single-serve juice-flavored beverages). The results from the case studies showed that flexible plastic packaging has more preferable environmental attributes for carbon impact, fossil fuel usage, water usage, product-to-package ratio, and material to landfill, when compared with other package formats. This is due to the efficient use of resources enabled by flexible packaging. This further supports the close alignment of flexible packaging with Sustainable Materials Management (SMM), which focus on the efficient use of resources, and minimizing associated environmental impacts [13,17,22].

Flexible Packaging Europe (FPE) had a number of full LCA studies carried out by independent third party LCA specialist institutes to evaluate the environmental impacts of flexible packaging in different packed food products [23]. The three main objectives of these studies were to

Table 1.2 Six Life Cycle Assessment (LCA) Case Studies of Flexible Plastic Packaging Versus Other Packaging Formats [17]

Case Study	Formats	Results
Ground coffee	Stand-up flexible pouch Steel can HDPE canister	Stand-up flexible pouch has a number of significant benefits than steel can and HDPE canister. This is attributed mainly to the reduced amount of material being used and the favorable product-to-package ratio. Other general benefits include product protection, brand message, and ease of use
Motor oil	Stand-up pouch with fitment DPE bottle	Large benefit across all SMM attributes for flexible packaging option—in a new product category.
Baby food	Pouch with fitment Thermoformed tub Glass jar	Flexible packaging offers better environmental attributes than glass and thermoform tub and overall less material to landfill.
Laundry detergent pods	Stand-up pouch with zipper Rigid PET container	Stand-up pouch has a number of significant benefits (fossil fuel usage, carbon impact, water consumption, and municipal solid waste) over the PET rigid container, even when taking the current

(*Continued*)

Table 1.2 Six Life Cycle Assessment (LCA) Case Studies of Flexible Plastic Packaging Versus Other Packaging Formats [17] (*Continued*)

Case Study	Formats	Results
		recycling rate of the rigid container into consideration.
Cat litter	Stand-up bag Barrier carton Rigid pail	Stand-up bag has a number of significant benefits (fossil fuel usage, carbon impact, water consumption, and municipal solid waste) over the rigid pail and barrier carton, even when taking the current recycling rate of the rigid container into consideration.
Single-serve juice-flavored beverages	Drink pouch Composite carton PET bottle Aluminum can Glass bottle	Drink pouch has a number of significant benefits (fossil fuel usage, carbon impact, water consumption) over the other formats when considering these environmental indicators. The drink pouch also results in much less municipal solid waste than all of the package formats, except for the aluminum can, which has a slight advantage based on its relatively high recycling rate.

- understand the environmental impact of flexible packaging with respect to its function within the life cycle of the product;
- quantify the contribution of flexible packaging to increasing the use of that resource efficiently, e.g., through the prevention of spoilage of the product and efficient pack design; and
- show how flexible packaging adds value by helping consumers to consume more sustainably, e.g., by considering aspects such as consumption occasions and portion sizes and contrasting these benefits with the increase in environmental impact due to the packaging.

The packed food products included butter [24], coffee [25], goulash [26], and spinach [27]. The different LCA studies showed that flexible packaging actively contributes to minimizing the overall environmental impact of the product by reducing spoilage, over consumption, and/or by facilitating more sustainable lifestyles [23].

An LCA study compared retort pouches (made from a laminate of flexible plastic and metal foil) and cups to metal cans for the packaging of tuna products. Retort cup system possessed a significant advantage over metal cans and retort pouch systems in terms of overall GHG emissions [28].

In another study, two series of five LCAs corresponding to five EU countries were conducted on three olive packaging solutions: doypacks (sealed plastic bags that are designed to stand upright), glass jars, and steel cans. The environmental performance of each packaging type differs from one country to another. The plastic packaging (nonrenewable and nonrecyclable) has the lowest environmental impact, while glass has the greatest [29].

The evaluation of flexible packaging's environmental performance usually concentrates on a comparison of different packaging materials or designs. Another important aspect in LCA studies on packaging is the recycling or treatment of packaging waste. LCA studies of packed food include the packaging with specific focus on the contribution of the packaging to the total results. The consumption behavior is often assessed only roughly. Broader approaches, which focus on the life cycle of packed goods, including the entire supply system and the consumption of goods, are necessary to get an environmental footprint of the system with respect to sustainable production and consumption [30].

There is also too much emphasis of LCA on GHG emissions and too little on end-of-life impacts. The result is complex packaging design, such as pouches, which cannot be recycled, and end up either in landfills or destined for incineration or disposed in the environment [31]. Existing LCAs often ignore disposal of flexible packaging in the environment. LCAs should consider the waste treatment in the field to develop measures to reduce marine litter and other forms of pollution [31].

LCA should take into account the gained expertise on food waste drivers, as many food waste drivers (e.g., overpurchasing and preparation techniques) are not linked to packaging, and some packaging practices (e.g., trimming and multipacks) can actually increase food waste [32].

The environmental performance of flexible plastic packaging is difficult to ascertain, given the complex trade-offs and competing interests [32].

According to the Australian Packaging Covenant [8], the LCA-related considerations in favor of flexible plastic packaging can be summarized as follows:

- Plastic packaging has high strength-to-weight ratio and can provide excellent packaging-to-product weight ratio.
- Plastic packaging manufacturing usually generates little solid or liquid waste.
- Life cycle studies comparing the use of flexible plastic containers with rigid plastic, fiber, glass, or metal alternatives have found that the flexible packs perform as well or better across most areas of environmental impact.
- Bags and pouches use a lot less material than rigid alternatives, resulting in significant energy and water savings in production (often up to 75%).
- Flexible plastic packaging is lightweight and saves energy in transport.
- Flexible plastic packaging is versatile and inexpensive and provides reasonable product protection.
- There is a low risk of food contamination from the packaging. However, the use of recycled plastic is avoided for some food contact applications out of caution.
- Plastic packaging, if disposed to landfill, will not decompose. This results in the continuing long-term sequestration (storage) of the fossil carbon in the plastic, rather than this being released to the atmosphere as a GHG.

The corresponding LCA-related considerations against flexible plastic packaging are as follows [8]:

- Plastic packaging is generally made from nonrenewable fossil fuel resources.
- The extraction of nonrenewable hydrocarbons results in the direct emission of GHG and is a significant source of risk for pollution of the local environment.
- Flexible plastic packaging is not collected by most curbside collection systems.
- Plastics films and bags are generally more difficult to sort from commingled curbside recycling streams at MRFs.
- Flexible plastic packaging is more challenging to recover because it often involves multiple polymer layers and/or a layer of aluminum, which are difficult to separate.
- Being lightweight and more likely to be blown away by wind, flexible packaging films and bags have a higher tendency to become part of the litter stream, particularly when disposed in the environment [33].
- Most plastic packaging can take hundreds of years to fully degrade and bring damage to the ecosystem.
- Virgin polymer production is energy- and chemical-intensive.
- Flexible plastics containing recycled content are uncommon and difficult to source.
- If plastic reprocessing is undertaken, it can be water-intensive (due to the washing and separation process steps).

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