11 Economic Evaluation and Trends

11.1 Market of Flexible Plastic Packaging

Flexible packaging has the largest market share (39%) compared with other packaging types [1]. A report from Smithers Pira forecasts that the global market for flexible packaging will reach $228 billion in 2019 and grow at an annual average rate of 3.3% reaching $269 billion in 2024. The total volume of consumer flexible packaging will rise at a greater rate of 4.0% from 29.9 million metric tons (MMT) to 36.4 MMT across the same period [2]. Asia-Pacific accounts for the largest market share of the global flexible packaging market [3]. In the European Union, the total consumer flexible packaging market was 4 MMT (including exports) in 2016. About 3 MMT of consumer flexible packaging is monopolyethylene or polypropylene or their mixture, and it is technically "recycling ready" if it can be sorted into polyethylene or polypropylene film fractions or a mixed fraction [4].

Globally, pouches account for the majority of the flexible packaging used. Pouches are the fastest growing category, and the lay flat pillow pouch is the predominant format (39%). However, stand-up pouches (SUPs) are anticipated to dominate the global market in terms of revenue over the period 2018 to 2025 [5]. According to Schönwald, by 2017, 45.7 billion SUPs were used Europe-wide [6].

Food is the largest end-use industry for flexible packaging accounting for nearly half of the flexible packaging used [1].

11.2 Economic Evaluations of Recycling

Plastic film recycling represents, together with PET bottles, one of the most important sections and sources of income of the recycling market. This is due to the huge amount of plastic film waste available on recycling market [7].

Recycling of Flexible Plastic Packaging
https://doi.org/10.1016/B978-0-12-816335-1.00011-6

According to More Recycling,[1] in 2016, the amount of plastic bags and film reported as recovered in the United States for recycling was 1.3 billion lb (0.59 MMT) [8], an increase of 123 million lb (55.8 million kg) over 2015 values [9]. About 47% of the total quantity recovered (617.7 million lb or 0.28 MMT) was reclaimed in the United States or Canada, and the rest was exported. The amount of material reported as recycled by US or Canadian processors increased by 7% from 2015 [8].

In 2018, the European total capacity of polyethylene film (low-density polyethylene [LDPE], linear low-density polyethylene [LLDPE]) was 2.5 MT. The EU recycling rate for polyethylene film (LDPE, LLDPE) is about 31% and the biggest streams are commercial and retailer waste (43%) followed by production waste (23%), agricultural waste[2] (17%), and household packaging (13%). The EU Members States with the highest recycling rates of polyethylene flexible packaging are Spain (18%), Germany (17%), Italy (13%), Poland (10%), and France (6%), with nearly two-thirds of Europe's installed recycling capacity [10].

11.3 Markets of Recycled Flexible Plastic Packaging

The recycled packaging film enters the global recycling market in different types that have widely varying prices depending on the quality. The main types of recycled film found in the market are [8]

- PE clear film, also known as postcommercial clear film. It is a clean polyethylene film from commercial sources, including stretch wrap and poly bags (no postconsumer bags).
- PE mixed color film, also known as postcommercial mixed color film. It is a clean colored polyethylene film from commercial sources, including stretch wrap and poly bags (no postconsumer bags).
- polyethylene retail bag and film, also known as mixed film. It is a mixed clean and color polyethylene film, including stretch wrap and retail collected postconsumer bags, sacks, and wraps.
- polyethylene MRF (Material Recovery Facility) curbside film, also known as curbside film. It is a postconsumer mixed polyethylene film collected curbside.

[1] Formerly known as Moore Recycling Associates.
[2] Recycling of agricultural film is outside the scope of the book.

- Other film. It refers to non-PE films such as PVC and polypropylene.

The polyethylene clear film, often labeled Grade A, has the highest market value. It is generated in high volume and has very high market demand because it provides a fairly easy substitute for virgin feedstock in a wide variety of end products. Currently, demand exceeds supply. Moore Recycling Associates estimates that the quantity of postcommercial film collected for recycling in North America exceeds the amount of post-consumer film collected for recycling [11].

Clean return center-collected mixed polyethylene film has a moderate value. Combining high-density polyethylene (HDPE) and LDPE of various colors usually lowers the scrap value but may create the volume needed to enable collection. Recyclers that are capable of handling fairly "dirty" film most often can only use one polyethylene type (i.e., LDPE), while recyclers that are capable of handling a mixture of polyethylene types (i.e., LDPE, LLDPE, and HDPE) cannot handle "dirty" film. According to Reclay StewardEdge, the reason is that because profit margins for reclamation are very tight, recyclers must be selective to contain their processing costs (e.g., choosing either washing or sortation, but not both), and often they seek very specific grades of film material [11].

Curbside collected mixed polyethylene film has a far lower value. Bales of curbside film have about one sixth of the value of mixed film that comes from retail collection programs, due to the contamination that curbside film collects during collection and processing in MRFs.

Film quantity is also important to the cost-effectiveness of film recycling programs. For this reason, many commercial return center recycling programs for post consumer film combine postcommercial polyethylene film (e.g., pallet wrap) that is generated on-site to achieve the volume necessary to warrant a film collection program or investment in a baler. Currently, there is strong demand for bales containing a combination of polyethylene films provided the material is clean and dry.

Increasing the amount of collected packaging film requires an increase in end-use demand. Film recyclers face continued challenges to find buyers for the recycled packaging film. Stronger end-use demand from brand companies, retailers, and resin companies is necessary for continued growth in flexible film packaging recycling [9]. At the same time, film recyclers are struggling to compete with virgin resin, including off-spec, which is dampening the market demand for postconsumer recycled film, which in turn provides disincentive for improving collection the infrastructure [8].

11.4 Trends and Proposals

Current flexible packaging materials are neither sustainable, because they are derived from fossil fuel–based resources, nor recyclable, because most of them are made of multilayer structures. As sustainable and recyclable packaging is becoming an increasingly important topic in the market for flexible packaging for both brand owners and end users, the plastics and packaging industries are looking for new structures and alternative materials to reduce pollution and facilitate recycling; this applies especially to e-commerce, the fast growing of which influences trends for flexible plastic packaging that is more durable and at the same time sustainable (see Chapter 4, Section 4.3.5). The main trends toward a sustainable and recyclable flexible packaging are the following:

- redesign;
- increase collection;
- improve sorting;
- new recycling technologies;
- alternative materials; and
- more end uses.

11.4.1 Redesign

Nowadays, the current trend in flexible packaging design is the inclusion of the recyclability aspect as an essential criterion on top of other performance criteria: product safety, shelf life, marketing and branding, etc. The various objectives of a plastic packaging should be balanced, without ignoring its recyclability [12]. Redesign aims to make flexible packaging easily recyclable.

Various associations, such as APR, encourage package designers to utilize the APR Critical Guidance and Responsible Innovation programs, as well the APR Design Guide to create the most recyclable packaging [13].

The CEFLEX project aims to develop a robust set of design guidelines for flexible packaging to both maximize the overall resource efficiency and optimize the recyclability [4,14].

11.4.1.1 Reduction of Food Waste

Food waste represents an economic and social loss with far-reaching environmental consequences. The financial costs of food waste are substantial and amount to about $1 trillion each year [15], which is largely borne by manufacturers and retailers. It is asserted that the global food waste is just behind the United States and China in terms of annual greenhouse gas (GHG) emissions [16].

A study from Friends of the Earth Europe and Zero Waste Europe [17] claims that single-use plastic packaging has actually led to an increase in the amount of food thrown away by encouraging a culture of disposability [18]. According to the study, many packaging practices used by the food industry and retailers (e.g., multipacks) are implemented to support economic efficiencies and marketing and brand objectives rather than to preserve food.[3] These practices increase wastefulness of both food and packaging [17].

On the other hand, representatives of the flexible plastic packaging industry argue that without plastic packaging, the cost of food waste could rise [19]. The reduction of food waste is a key design consideration in the flexible packaging industry [20]. There are opportunities, however, to reduce further both food waste and the use of packaging by changing retail and packaging practices and by using shorter supply chains. Smaller packaging can also help to reduce food waste. By offering smaller packages, the consumer can buy a more specific portion, reducing the chance for food waste. It is imperative that the food packaging is made of sustainable material [16].

11.4.1.2 Reduction of Material Used

Most food packaging remains at odds with the objectives of the circular economy (CE). The majority of flexible plastic packaging is used only once, with 95% of its value lost to the global economy after this first use (worth an estimated €100 billion annually). This necessitates the reduction of single-use plastic packaging targets, scaling up reusable packaging and reviewing ecodesign criteria [17].

Another strategy for minimizing the environmental impact of flexible packaging involves reduction in the amount of material used (thinner

[3] For example, cutting green beans to fit plastic packaging has been found to result in 30%−40% of the beans being wasted.

packaging), rather than emphasizing end-of-life issues [21] (see also Chapter 2, Section 2.1). Currently, with polymer recycling not at a high level, evidence suggests that this strategy is justifiable. The trend to thinner films is on the rise, although many of the traditional films are reaching the limits.

Thin barrier multiple coatings can also replace the previously used barrier layers in multilayer packaging.

3D printing can also contribute to the reduction of industrial plastic waste. The process itself hardly produces any waste as there is never excess material that requires cutting [22]. Further, 3D printing decreases cost through significantly cheaper molds [1].

DuPont (presently Dow) came up with an alternative solution in achieving sustainability goals by reducing food packaging waste and lowering costs, while at the same time meeting customer expectations for tough yet attractive flexible packaging. In a typical paper-based pouch for a dry mix or salty snack, for example, Surlyn® ionomer resin [23] can be used to create a layer one-third the size of other polyethylene layers, while maintaining package stiffness. This translates into less waste and lower food packaging costs by reducing material costs by 13%, all while improving puncture resistance. These benefits can be extended to a variety of uses including packaging for snacks, dairy products, processed meats, personal care products cosmetic, and medical device packaging [24].

11.4.1.3 Reduction of the Number of Layers

One of the approaches addressing the issue of complex packaging materials is to reduce the number and type of layers used in multilayer plastic packaging. Avantium's business unit Synvina produced pouches of reduced complexity consisting of a two-layer laminate of a biaxially oriented poly(ethylene furanoate) layer and commercial 55% biobased polyethylene sealing layer [25] (see also Chapter 4, Section 4.2.3).

11.4.1.4 Monomaterials

Another trend is the development of monomaterials, especially of polyethylene, for flexible multilayer packaging structures. This can be achieved by laminating a polyethylene film to a further polyethylene film structure. Because such laminates are based on one single class of polymer, they can be more easily recycled. To deliver a full polyethylene barrier laminate is not an easy task as the mechanical properties of polyethylene are not optimized for web transportation, stability, and conversion, and the heat sensitivity of the film also creates additional challenges when using vacuum deposited barrier layers. For a "100% polyethylene" laminate solution, there is an increasing need to provide polyethylene materials and films, which have enhanced stiffness, good impact behavior, good optical properties, and isotropic mechanical properties without the use of polypropylene, PET, polyamide, or aluminum. Further, it is necessary to provide such polyethylene materials that can be converted on existing film lines applying commonly known conversion technologies, such as biaxial orientation via tenter frame technology, with good or improved output (2018, **EP3335874** A1, BOREALIS AG).

Borealis (2018, **EP3335874** A1, BOREALIS AG) and Borouge, in cooperation with leading partners along the value chain (Hosokawa Alpine, BOBST, GEA, and Erema), presented in 2016 the Full PE Laminate Solution: a monomaterial polyethylene for flexible packaging based on the proprietary Borstar® bimodal technology in combination with machine direction−oriented processing technology. Packaging solutions of the Full PE Laminate are as efficient in terms of performance

Figure 11.1 Full Polyethylene (PE) laminate pouch *Courtesy of Borealis AG. Borstar®-based Full PE Laminate solution improves recyclability of flexible packaging materials; 19-10-2016. https://www.borealisgroup.com/news/borstar-based-full-pe-laminate-solution-improves-recyclability-of-flexible-packaging-materials.*

Figure 11.2 Pouch made of polyethylene monomaterial for Frosch products *Courtesy of Mondi Newsroom. Mondi flexible packaging "leapfrogs" ahead in the recycling game; 10-09-2010. https://www.mondigroup.com/en/newsroom/mondi-flexible-packaging-leapfrogs-ahead-in-the-recycling-game/.*

as other flexible packaging structures and serve as 100% substitutes for multimaterial film solutions in pouches and packs. The recyclate gained from the full PE Laminate packs can be used for valuable end products, without compromising on product efficiency or integrity, and can even be used to produce polyethylene film products [26] (Fig. 11.1).

Mondi and Werner & Mertz developed a recyclable pouch made of polyethylene monomaterial, with detachable decorative panels, which can be placed into appropriate recycling streams [27] (see also Chapter 4, Section 4.2.3). The pouch is free of glue or adhesive. Spout and cap are also made of polyethylene. The pouch replaces conventional flexible packaging for Frosch products (see Fig. 11.2).

Multilayer pouches made from an all polyethylene structure can be included in the store drop-off program for recycling within the polyethylene film stream [28].

Nestlé India has recently renovated its *Munch* chocolate bar packaging using a monomaterial polypropylene film instead of a complex laminate structure [29].

11.4.1.5 Removable Parts (Layers, Adhesives, and Labels)

Another approach is the design of flexible pouches, whose constituent parts can be easily deconstructed or disassembled and placed into appropriate recycling streams (see Chapter 4, Section 4.2.3).

The use of adhesives for attaching labels and for closure systems in flexible plastic packaging that can be removed in normal washing processes to avoid a reduction in the quality of the recycled material has been proposed. It is important that the adhesives do not leave glue residues on the attached label or component after the washing process. For this purpose, the use of adhesives that are water soluble at a temperature range of 40–60 °C is recommended [10,30].

There are different opinions on the type of material to be used for labels or sleeves. In the sorting process, it is easier if the same material is used for the main packaging body and the label or sleeve, as it is more likely to be sorted into the right material fraction. On the other hand, in the washing process, it is easier to separate the two from each other if they are made of different materials [30]. Another alternative is the use of floatable labels that easily separate and remain buoyant in the wash-out process.

The labels and sleeves shall not affect the sorting and recycling process. The labels and sleeves shall not cover more than 60% of the surface of the packaging product to avoid issues with the identification of the packaging material by the NIR (Near-Infrared) detector.

11.4.1.6 Effect of Additives and Inks

The amount and type of additives compounded with the film material could alter the overall density of the packaging film and cause the film to sink during the density separation hampering the material's recyclability [12] (see also Chapter 8, Sections 8.1.1 and 8.4.1). The use of fillers such as silica, chalk, and talc powder should be avoided, but if used, their concentration should not exceed 0.97 g/cm^3 [10].

The use of inks, other than bar code and expiry date, is discouraged because they cause discoloration of the recycled film, and wherever used, they must be nontoxic, nonhazardous, and nonbleeding [10]. A study showed that flexible plastic packaging materials with no color pigment and no printing ink were suitable for secondary recycling to produce high quality of recycled plastic pellets and leverage the selling price [31].

11.4.2 Increase Collection

Low collection rates and low quality of input materials are the main. Challenges of waste collection destined for recycling increased collection will put more packaging materials back into the recycling system.

Typically, postconsumer packaging film waste (e.g., films, carrier bags, stretch films, wrappers, etc.) is collected from households together with other packaging materials via curbside or comingled systems. It is estimated that around 62% of household and commercial polyethylene flexible film is collected in the European Union, 21% from households and 41% from the commercial stream [10].

According to More Recycling [8], two primary issues must be addressed to increase collection of packaging film:

- widespread lack of awareness of how to recycle film; and
- recyclers' struggle to compete with virgin resin, including off-spec, which is dampening the market demand for recycled postconsumer film, which in turn provides disincentive for improving the collection infrastructure.

The first issue can be tackled through continuing education schemes, public campaigns, social media, handy electronic tools, and apps. According to Flexible Packaging Association (FPA), smart technology, mobile devices, and the growth of the Internet of Things will enable printed electronics to be included on packaging to communicate with consumers and educate them on where and how they can recycle flexible packaging [32]. Businesses can improve brand loyalty by establishing schemes to incentivize the return of the packaging through deposit and reward schemes [33].

Regarding the second issue, fully implemented separate collection schemes for postconsumer waste will increase the quality of the material destined for recycling and subsequently its yield. This will need to involve establishing harmonized schemes across the European Union. The collection of all plastic packaging in a unique postconsumer-separated stream is preferred as it decreases contamination and optimizes the efficiency of the process [10]. Presently, most curbside systems are not equipped to handle packaging film.

The separate collection of postconsumer films will improve the quality of bales. Plastics Recyclers Europe released a set of bales quality guidelines aiming at improving the quality of the collected and sorted polyethylene [34] and polypropylene films [35] and increasing the quality of input that reaches the recycling plants.

Further, the collection of non-polyethylene film for recycling shall be promoted. A valuable polymer that can be collected and recycled is polypropylene, large amounts of which are used in flexible packaging. Actually, the packaging industry occupied the largest share of polypropylene in 2016 [36]; 100,00 tons of this packaging material are marketed every year in the United Kingdom alone. So far, polypropylene film is not collected and ends up in landfills and incinerators. According to Axion Group, polypropylene films can be collected in significant volumes through curbside collection systems and reprocessed and used in nonflexible applications [37].

The Ellen MacArthur Foundation proposes a number of strategies for improving collection of packaging [33]:

- The “return from home” reuse model is suitable for e-commerce as the pickup of empty packaging can be combined with the delivery of new products (see Section 12.4.6.2).
- Establish schemes to incentivize the return of the packaging through deposit and reward schemes.
- Increase the number and density of drop-offs points to ensure easy return for users.

11.4.3 Improve Sorting

Educating consumers on what to do with their flexible recyclables is only half of the story. The other half is to make sure that the films are properly sorted and recycled.

There is a variety of existing and emerging technologies that offer significant promise for sorting multimaterial flexible packaging along the MRF sortation line. MRFs have been retrofitting with advanced sorting equipment that can identify and properly handle a wider range of packaging forms, including flexible film and smaller items made of otherwise recyclable material [38]. Promising technologies include the use of

- Advanced NIR optical sorters to detect multimaterial films combined with the use of airflow to eject films toward an independent collection point is likely the best solution for sortation (see Chapter 6, Section 6.1.6.1).

- Robotic sorters combining artificial intelligence with optical/visual capabilities and robotics to analyze a waste stream and robotically sort it (see Chapter 6, Section 6.1.7).
- Digital watermark on packaging, which would be undetectable to the human eye but readable by optical sorters, could allow much better sorting and traceability of materials, with few retrofitting costs [39] (see Chapter 6, Section 6.1.5.3).
- Active and intelligent packaging through the use of radio-frequency identification tags and smart labels [40].

Although these technologies offer potential promise for sortation, the economics of end market sales will dictate their long-term adoption. Finding a solution for sorting different types of flexible plastic packaging, a segment representing approximately one-third of postconsumer packaging (by weight) and a production of around 1 trillion units a year, could significantly increase the volume of packaging available for recycling [41,42].

11.4.4 New Recycling Technologies

Some of the relatively new recycling technologies with high prospects are the following:

11.4.4.1 Compatibilizers

Compatibilizers can be used with PE-based multilayer films. This technology is now available directly within the film. This simplifies the recycling process as it prevents processors from needing to know film compositions to estimate compatibilizer amounts and permits for recycling directly with existing polyethylene streams [43] (see also Chapter 8; Section 8.7.1.1).

Dow's innovative recycle compatibilizer technology is based on a reactive, ultralow viscosity compatibilizer. Reactive groups "coat" the polar components, encapsulating them into microdomains to enable excellent dispersion. When blended at specified ratios with pelletized barrier film recycle streams, the Retain polymers allow converters to recycle barrier film trim back into film production without sacrificing optical or physical properties [44].

11.4.4.2 Solvent Separation

Solvent separation is a promising approach for the separation of multilayer packaging films. The Fraunhofer IVV in collaboration with CreaCycle GmbH developed an innovative recycling technology called CreaSolv® Process, which allows the recovery of high-quality plastic recyclates from plastic waste by using a selective and technically safe solvent with a specific Hansen parameter [45]. Customized solvent formulations were developed for a wide range of plastic wastes and target polymers, and used solvents can be recycled. Purified polymer recyclates have properties akin to virgin polymers. Unilever is testing the long-term commercial viability of the CreaSolv® technology for the recycling of plastic sachets at a pilot plant in East Java, Indonesia. Indonesia is one of the most critical markets in terms of sachets infiltrating ocean waste [46] (see also Chapter 7, Section 7.3).

APK cooperates with DSM for the recycling of multilayer PE/polyamide 6 packaging waste using APK'S solvent-based core technology, called Newcycling® technology (see Chapter 7, Section 7.3) [47]. APK AG has also formed a group with Henkel, Mondi, and Borealis with the goal to improve the sustainability of plastic multilayer flexible packaging through the Newcycling® process developed by APK AG [48].

Procter & Gamble developed a process for the purification of recycled polyethylene and polypropylene through the use of a pressurized solvent and solid media (2018 **US2018171095** (A1; 2018, **US2018171094** A1, PROCTER & GAMBLE). The process removes color, odor, and other contaminants from recycled feedstock resulting in virgin-like polyethylene or polypropylene suitable for any market. The process can be applied for the purification of polyethylene and polypropylene packaging waste.

PureCycle Technologies licensed the technology from Procter & Gamble and partnered with Milliken & Company and Nestlé S.A. with plans to open its first plant to reclaim polypropylene waste. Milliken, whose additives will play a critical role in reinvigorating recycled polypropylene, has formed an exclusive supply relationship with PureCycle to help solve the plastics end-of-life challenge. Nestlé is working with PureCycle to develop new packaging materials that help avoid plastic waste, in line with the company's commitment to make 100% of its packaging recyclable or reusable by 2025 [49].

11.4.4.3 Chemical Recycling

Recent research points to the way toward chemical recycling (depolymerization to yield repolymerizable monomers and/or oligomers), methods with lower energy requirements, compatibilization of mixed plastic wastes to avoid the need for sorting, and expanding recycling technologies to traditionally nonrecyclable polymers [50]. Chemical recycling—not a new concept in itself—gains momentum in the context of the challenges of dealing with plastic waste. The chemical recycling is still at early stages of development and is not expected to be fully operational before 2025 [51]. A forerunner in the chemical recycling of plastics is BASF, which developed the so-called ChemCycling technology to convert mixed plastic waste through thermochemical processes into repolymerizable monomers and/or oligomers and eventually new polymers [52]. The technology can be applied to the recycling of multilayered plastics structures, which are difficult to handle by existing recycling processes because they combine various types of plastic [53] (see also Chapter 9, Section 9.4).

11.4.5 Bioplastics

Disposal of flexible packaging materials has become a serious environmental problem. In view of the rising tide of disposable packaging materials, many countries, particularly those in Europe, have put restrictions either on the use and disposal of packaging materials by mandating their recycling or promoting the use of renewable packaging materials. Recycling systems are being developed only very slowly, have questionable effectiveness, and are often only implemented regionally. In addition, fossil fuel resources for most synthetic polymers are limited. These circumstances were the motivating force for the development of bioplastics. Bioplastics are alternative materials to conventional plastics (e.g., polyolefins) in the flexible packaging industry, can be fully or partially biobased, and/or biodegradable in nature.[4] Packaging is one of the largest fields of application for bioplastics with a share of almost 60% of the total bioplastics market [54].

The global production of biopolymers in 2017 was about 2.05 MMT and is predicted to reach 2.44 MMT in 2022. Despite the dynamic market growth, biopolymers represent less than 1% of the total plastics

[4] There is confusion in the public about the terms biobased and biodegradable plastics and their differences.

production (about 320 MMT in 2017) [55]. The pattern of production is shifting from biodegradable to biobased nonbiodegradable polymers. Biobased nonbiodegradable polymers represent about 57% and biodegradable polymers almost 43% of the whole production [54,55]. This is in contradiction to the public perception that most biopolymers are biodegradable.

Biodegradable polymers can be either bio- or fossil fuel−based. Biodegradable biobased polymers used in flexible packaging include cellulose, starch, poly(lactic acid) (PLA), polyhydroxyalkanoates (PHAs), poly(butylene succinate) (PBS), poly(butylene succinate-*co*-terephthalate) (PBAT), and their blends. Typical biodegradable fossil fuel−based polymers include polycaprolactone (PCL) and poly(vinyl alcohol) (PVOH).

Biobased nonbiodegradable polymers used in flexible packaging include bio-polyethylene (bio-PE), (bio-LDPE, bio-HDPE), bio-PET, and potentially poly(ethylene furanoate) (PEF). Typical applications of selected bioplastics are listed in Table 11.1 [56].

11.4.5.1 Commercial Products

Representative bioplastic-based packaging products brought recently to the flexible packaging market are listed in Table 11.2.

Some recent developments include the use of PHAs and alginate hydrogels in flexible packaging applications:

Danimer Scientific and Pepsico developed a biobased and compostable packaging[5] using Danimer 24365B & Danimer 01112 resins. The industrial compostable snack bag is comparable in feel, noise, and performance to PepsiCo's current bags and certified to be industrially compostable by TÜV. The new Danimer resins are blends of PHA and mineral filler and give the bag its white exterior. Danimer and PepsiCo are collaborating on a third-generation chip bag that is based on Danimer's PHA technology that is fully biodegradable in home composting environments [82]. PHAs are also used for making carrier bags, produce bags, waste and compost bags, odor-barrier packaging films, and liquid water barrier requiring breathable films [83].

[5] Danimer Scientific and Pepsico were the joint winners of the 2018 Innovation in Bioplastics Award from the Plastics Industry Association

Table 11.1 Typical Applications of Bioplastics in Flexible Packaging [56]

				Blends from							
Flexible Packaging	**PLA**	**PHA**	**PBS**	**Cellulosic Materials**	**Starch**	**PBS**	**PHA**	**PLA**	**PBAT**	**Bio-PE**	**Bio-PET**
Pouch	+	∘	+	+	++	+	+	++	++	++	+
Clear film	++	∘	∘	++	∘	+	∘	+	∘	++	++
Outer packaging	∘	∘	+	++	++	+	+	++	+	++	-
Stretch film	∘	∘	∘	∘	∘	∘	∘	∘	+	++	∘
Shrink film	+	∘	∘	∘	∘	∘	+	+	++	+	+
Shopping, waste/bags	∘	∘	∘	∘	++	++	++	++	++	++	∘
Nets	∘	∘	∘	∘	+	++	+	++	+	++	∘
Labels	+	+	∘	∘	+	+	+	+	++	++	+

++, *Very suitable;* +, *Partly/mostly suitable; o, Not suitable; PBAT, Poly(butylene succinate-co-terephthalate); PBS, Poly(butylene succinate); Bio-PET, Biobased poly(ethylene terephthalate); PHA, Polyhydroxyalkanoate; PLA, Poly(lactic acid) or polylactide.*

Table 11.2 Representative Commercial Products of Flexible Plastic Packaging

Flexible Packaging Format	Bioplastic	Composition	Exemplary Uses	Reference
Pouch	Bio-Flex® F 2110/A 4100 CL (FKuR)	PLA (Ingeo™, NatureWorks)/ copolyester blend	Deep freeze pouch	[57]
	NatureFlex™ film (Futamura)/Mater-Bi® film (Novamont)	Cellulose-based film laminated to a starch-based blend film	Stand-up pouches for royal heirloom quinoa products	[58]
	Gualapack: Bio-PE	80% based bio-PE laminate	Spouted pouches for snacks for children	[59]
	Only Natural Pet: I'm green™ Biopolymer (Braskem)	Bio-PE (30 % biobased)	Pouches for dry dog food (Mindful meals)	[60]
	Bio-LDPE/CNF/ PLA/paper (VTT); Bio-HDPE, bio-HDPE/CNF, bio-HDPE, bio-HDPE/ CNF/bio-LDPE (VTT)	Bio-LDPE, bio-HDPE, PLA, paper, CNF	Bag-in-box, MAP pouch[a], and stand-up pouch; e.g., for dry food products (hazelnuts and cereals)	[61]
	BOPEF/bio-PE (Synvina)	BOPEF layer laminated to a bio-PE (55 % biobased) sealing layer	Foil pouches, e.g., fresh baby food pouches	[25]

(*Continued*)

Table 11.2 Representative Commercial Products of Flexible Plastic Packaging (*Continued*)

Flexible Packaging Format	Bioplastic	Composition	Exemplary Uses	Reference
	NOTPLA (Ooho) (Skipping Rocks Lab Ltd.)	Alginate and thickener	Pouches and sachets for beverages and sauces	[62]
Film	NaturePlus Compostable PLA (Amcor)	PLA	Fresh produce	[63]
	NaturePlus Renewable PE	Bio-PE	Bags, pouches, and lidding	[64]
Stretch film	Fkur: Green LLDPE SLH 118, Green LLDPE SLH 218, Green LLDPE SLH 118, Green LLDPE SLL 118, Green LLDPE SLL 318 (Braskem)	LLDPE	Stretch film applications	[65]
	Nativia® (Tagleef)	BOPLA	Food packaging (from bakery items to pet food) and nonfood packaging	[66]

Shrink film	Ecovio® FS Shrink Film (BASF)	Blend of PLA and PBAT (Ecoflex®)	Drink-six-packs	[67]
	Fkur: Green LDPE SBF 0323 HC, Green LDPE SBF 0323/12HC (Braskem)	Bio-LDPE	Shrink film applications	[68]
Bags	Bio-Flex® F 2110 (FKuR)	PLA (Ingeo™, NatureWorks)/ copolyester blend	Waste bags	[58]
	Bio-Flex® F 1130/ Bio-Flex F 2110/Bio-Flex F 1130	PLA (Ingeo™, NatureWorks)/ copolyester blend	T-shirt shopping bags and waste bags	[69,70]
	Bio-Flex® F 1130 (FKuR)	PLA (Ingeo™, NatureWorks)/ copolyester blend	Waste bags, carrier bags and air pillow bags	[71]
	Bio-Flex® F 1137 (FKuR)	PLA (Ingeo™, NatureWorks)/ copolyester blend	Waste bags and shopping bags	[72]
	Ecovio® (BASF)	Blend of PLA and PBAT (Ecoflex®)	Fruit and vegetable bags, waste bags, and dual use	[73]

(*Continued*)

Table 11.2 Representative Commercial Products of Flexible Plastic Packaging (*Continued*)

Flexible Packaging Format	Bioplastic	Composition	Exemplary Uses	Reference
	Mater-Bi® (Novamont)	Starch-based blend with aliphatic polyester	Shopping bags and garden waste bag	[74]
	Huhtamaki Films	Various kinds of biobased films, i.e., TPS, bio-blends or bio-PE	Customer-tailored bags for diapers	[75]
Nets	Bio-Flex F 1130/Bio-Flex™ F 2110	PLA (Ingeo™, NatureWorks)/copolyester blend	Fruit netting	[58]
	Giró (SP): Bio-Flex® F 1130 (for the knitted net itself) and F 2110 (for the etiquette) (Fkur)	PLA (Ingeo™, NatureWorks)/copolyester blend	Fruit net bag	[76,77]
Labels	NatureWorks® PLA	PLA	Shrink sleeve labels	[78]
	Self-adhesive label (Bio4life)	BOPLA film	Self-adhesive label	

Blisters	Eastlon PET CB-602AB (FKuR)	Partially bio-PET	Pharmaceuticals	[79]
	PLA (FKuR)	PLA	Pharmaceuticals	[80]
Tubes	Fkur: (Green PE, Braskem)	Bio-PE	Cosmetics	[80]
	LageenTubes: PCR[b]/bio-PE	50% PCR material from milk containers and bio-PE	Cosmetics	[81]

Bio-LDPE, biobased low-density polyethylene; Bio-HDPE, biobased high-density polyethylene; Bio-PE, Biobased polyethylene; BoPEF, Biaxially oriented poly(ethylene furanoate); BOPLA, Biaxially oriented PLA; CNF, Microfibrillated cellulose; LLDPE, Linear low-density polyethylene; PBAT, Poly(butylene succinate-co-terephthalate); PLA, Poly(lactic acid) or polylactide; TPS, Thermoplastic starch.
[a] *Modified atmosphere packaging.*
[b] *Postconsumer recycled.*

Figure 11.3 Ooho pouch made from alginate. *Courtesy of Skipping Rocks Lab Ltd. NOTPLA; 2019. https://www.notpla.com/technology/.*

Skipping Rocks Lab Ltd. (UK) developed the so-called Ooho pouches and sachets for beverages and sauces made from alginate (extracted from seaweed) and thickener (NOTPLA), future products bag nets for carrying produces (e.g., oranges and garlic) and sachets for nonfood products [62] (2018, **WO2018172781** A1, SKIPPING ROCKS LAB LTD) (Fig. 11.3).

Although bioplastics have the potential to improve environmental performance, they are not a panacea to the problem of environmental pollution (see Chapter 2, Section 2.1).

11.4.6 Recycled and Reused Packaging

11.4.6.1 Recycled Packaging

The complexity of films used in packaging, incompatibility of different plastics with each other, and differences in recyclability and market demand for the different types of films all present challenges to the recycling of packaging films [11]. The main issues complicating plastic recycling are the quality and price of the recycled product, compared with their unrecycled counterpart. Plastic processors require large quantities of recycled plastic, manufactured to strictly controlled specifications and at a competitive price. The poor quality of recyclates is a major barrier to increasing the amount of flexible plastic packaging that is recycled [84]. Presently, the demand for recycled plastics accounts for only 6% of plastic demand in Europe [85]. Higher plastic waste recycling rates, more and better quality recyclates, in combination with better design of plastic products, will help boosting the market for recycled plastics [39].

For most plastic materials, the difference in energy intensity between virgin and recycled sources can be very large, which translates into a significantly reduced carbon footprint of recycled plastics. According to a Sustainable Packaging Coalition report [86], the use of 30% recycled content in polyethylene films has been estimated to reduce energy consumption by a quarter and reduce GHG emissions by over a third during manufacturing. Hence, by using recycled plastic materials, companies can help to reduce the carbon intensity of new products, while also reducing emissions from landfill or incineration. Further, the use of recycled plastics can bring competitive advantages to flexible food packaging producers other than the improved environmental performance of their products, such as cost savings, improvement of corporate image, green marketing and access to new markets, encouragement of eco-innovation, and preparation for future environmental regulations [87].

The European Parliament proposed a set of measures to stimulate the market for recycled plastics [85]:

- creating quality standards for secondary plastics;
- encouraging certification to increase the trust of both industry and consumers;
- introducing mandatory rules on minimum recycled content in certain products; and
- encouraging member states to consider reducing VAT on recycled products.

Other measures could include less downcycling of flexible plastic packaging films into lower grade applications such as cheap moldings and use of recovered materials to more valuable plastic products.

Axion Group [37] proposes the blending of small format household polyethylene (LDPE) and polypropylene films to produce an injection molding or extrusion-grade polymer. The melt characteristics of LDPE films cannot be modified, and, therefore, they have to recycle it back into film, which is very demanding from a quality point of view. On the other hand, polypropylene has the ability to modify the flow characteristics and take it from a film to an injection molded rigid item. Axion is currently involved in the Wrap Recycling Action Program (WRAP) project (see Section 11.5) researching end markets for a polyethylene/polypropylene-blended material that could potentially go back into rigid applications.

Henkel in cooperation with Mondi have developed a technology for incorporating more of its scrap plastic into a flexible OPP/PE multilayer packaging for its powder laundry detergents; 30% of the package's polyethylene layer consists of industrial waste reclaimed from Mondi. Mondi aims to achieve a 50% regranulate in the full OPP/PE multilayer structure, which consists entirely of polyolefin materials [88] (see Chapter 4; Section 4.3.2 and Chapter 8, Section 8.7).

Some recent developments include the incorporation of mechanically recycled materials in flexible multilayer food packaging. Three different options are investigated for this purpose: (1) use of offcuts and scraps from the production of plastic food contact materials (i.e., preconsumer or postindustrial waste); (2) use of recycled plastics from processes authorized by the European Food Safety Authority (EFSA); and (3) use of recycled plastics behind a functional barrier. The use of functional barriers is the only option allowing the use of recycled postconsumer plastics from waste with nonfood contact origin [87].

11.4.6.2 Reused Packaging

Reusable packaging is a critical part of the solution to eliminate plastic pollution. The Ellen MacArthur Foundation proposes four reuse models to be applied where relevant, to reduce the need for single-use packaging [33]:

- refill at home;
- refill on the go;
- return from home; and
- return on the go.

Refill at home: Users refill their useable container at home (e.g., with refills delivered through a subscription service). Refill at home can work in both traditional and online retail. The model works particularly well with e-commerce as the online interface enables communication of an integrated solution.

Refill on the go: Users refill their reusable container away from home (e.g., at an in-store dispensing system). Refill on the go requires a physical store or dispensing point, which makes it better to traditional outlets and urban environments.

Return from home: Packaging is picked up from home by a pickup service (e.g., by a logistic company). Return from home is suitable for e-commerce as the pickup of empty packaging can be combined with the delivery of new products.

Return on the go: Users return the packaging at a store or drop-off point (e.g., in a deposit return machine or i-mail box[6]). Return on the go is widely applicable as it can substitute most single-use packaging without changing the fundamental purchase situation.

A traditional approach involves the reuse of selected flexible packaging items such as shopping bags, even though they lack the convenience of plastic bags. During its lifetime, a reusable bag can substitute for hundreds of plastic bags. The marketing of reusable bags based on an environmental message has been so well received that customers voluntarily bear the cost of purchasing the bags. Reusable shopping bags are usually made of a woven textile, particularly lightweight cotton textiles or heavier cotton textiles such as denim or canvas including synthetic fibers for providing sufficient strength.

11.4.7 Legislative Initiatives and Policy Recommendations

Some legislative initiatives and policy recommendations for tackling the problem of flexible plastic packaging waste are listed below:

- Merge sustainable materials management (SMM) and CE [32].
- Create more legislation with focus on end of life [32].
- Set up an overall, harmonized legal framework.
- Establish wide-quality standards for sorted plastics, harmonization of tests methods for recycled plastic materials, and certification of plastic recycling operations.
- Develop packaging design guidelines and assessment protocols according to the principles of the CE.
- Implementing an improved monitoring framework for EU exports would provide for a more transparent and reliable information on the waste market [10].
- Promote policy measures supporting the implementation of reusable packaging [17].
- Develop policies that incentivize ecodesign measures that support the implementation of the waste hierarchy for packaging [17].

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[6] Invisible mail, also referred to as Bote mail.

- Regulate packaging practices that drive food waste such as trimmings and the use of multipacks [17].
- Create an EU-wide right for customers to return any plastic packaging to the point of sale [17].
- Measures and incentives to ban landfill must be enforced to retain the maximum of the resource.

11.5 Projects

The FIACE project was a European initiative, whose aim was to assess the value added by flexible packaging in a CE and identify both the opportunities and challenges to increase this value by further closing the loop. Flexible Packaging Europe has been an active partner in the project together with the TU Delft University and 17 companies covering the entire flexible packaging value chain from raw material to postconsumer recycling and all steps in between [89].

One of the key findings of the FIACE project was that flexible packaging not only helps to prevent food waste by offering optimized fit-for-purpose solutions but it also makes a much more efficient use of packaging material than alternative packaging formats with higher recycling rates. The FIACE project highlighted the significant contribution flexible packaging makes to a CE and identified opportunities to optimize end-of-life solutions. Flexible packaging is often not considered sufficiently "valuable" by national extended producer responsibility schemes to be widely collected. This needs to be addressed to increase the yield of secondary markets [90]. These conclusions were mirrored by those of a similar initiative on flexible packaging conducted at the UK level (REFLEX) [91,92]. REFLEX demonstrated and evaluated the sorting and recycling of flexible packaging using existing and established technologies such as NIR to identify polyethylene, polypropylene, or mixed polyolefin streams as well as multilayer structures.

After the completion of the FIACE project and the REFLEX project, the project was continued with a wider scope under the new name of CEFLEX (Circular Economy for Flexible Packaging). CEFLEX is a collaborative project of about 50 European companies representing the entire value chain of flexible packaging working toward the common goal of increasing the collection and recycling of flexible packaging by 2025 (see Fig. 11.4). This will take "end-of-life" technologies and processes, which deliver the best economic, technical, and environmental outcome for a CE, into account. To achieve its goal, the CEFLEX project intends to

Figure 11.4 The CEFLEX logo [14].

develop European-wide guidelines for flexible packaging and an "end-of-cycle" infrastructure by 2020, which will enable used packs to be collected, sorted, and recycled. These guidelines are intended to influence decisions during the early stages of package design, e.g., materials that are recyclable and could potentially be substituted. CEFLEX will also identify technologies, infrastructure, business models, and markets for recycled material. The initiative is not only relevant to the packaging producer, but it encourages collaboration among all companies that are part of the supply chain to find common solutions—from raw material producers to manufacturers of packaging and consumer products and waste management and recycling companies [4,14].

WRAP is an initiative of the Flexible Film Recycling Group (FFRG) of the American Chemistry Council [93]. WRAP is a US-National public awareness and outreach program designed to make plastic flexible plastic packaging a commonly recycled material with a strong and evergrowing recycling rate [94]. WRAP works with stakeholders including local and state governments, retailers, and MRFs to educate consumers about what types of plastic film are recyclable and how and where to recycle it. Many successful WRAP campaigns across the United States have helped communities keep plastic film out of their MRFs and increase the amount of plastic film collected for recycling at drop-off locations.

FFRG is working to significantly increase the collection and recycling of all flexible films and to educate the public about the importance of

Figure 11.5 The Wrap Recycling Action Program (WRAP) logo [94].

recycling. The FFRG's members are from the entire polyethylene film value chain, including major resin suppliers, manufacturers (also known as converters), brand owners, and recyclers.

The FFRG's goal is to double plastic film recycling to two billion lb (0.9 MMT) by 2020. To achieve this goal, the FFRG works to increase access to and participation in plastic film recycling for both consumers and businesses (Fig. 11.5).

The Materials Recovery for the Future (MRFF) project is an industry collaborative project administered by The Foundation for Chemistry Research and Initiatives at the American Chemistry Council (ACC). The MRFF project and partners are working to increase and enhance recycling options for flexible plastic packaging. The project vision is that flexible packaging is recycled, and the recovery community captures value from it. The findings of the research program showed that automated sorting technologies in use today can be optimized to capture flexible plastic packaging—potentially creating a new stream of recovered materials while improving the quality of other recycling streams [95].

The Hefty® EnergyBag™ program is a collaborative effort between The Dow Chemical Company, Reynolds Consumer Products, and First Star Recycling that aims at diverting hard-to-recycle plastics, including flexible multilayer plastic packaging and materials contaminated with food waste, from landfills and converting them into valuable energy resources [96]. Consumers use an easily identifiable orange bag into which they place nonrecyclable plastic packaging such as bags, pouches, and wrapper. The bag is then placed in the single-stream recycling bin or next to the bin for collection and pulled off the sortation line at the MRF. Flexible packaging items that can be collected as part of the program include flexible drink pouches, candy bar wrappers, plastic pet food bags, and shredded cheese bags (see also Chapter 5, Section 5.2.1.1).

The North American Plastics Recycling Alliance (NAPRA) is a coalition of trade associations and nonprofits with the mission to grow plastics recycling in the United States and Canada. NAPRA represents the full plastics and recycling value chain from resin manufacturers and processors to brand owners and recyclers, each sharing a vision in which plastics are recognized for their value and recovered for their highest and best use. NAPRA aims to promote education, research, and the advancement of technologies that will continuously improve the sustained recovery of plastics. NAPRA will do this through the development of strong economic foundations, advocacy, and the creation of relationships between the public and private sectors [97].

A recycling research project funded by the REMADE[7] Institute (Reducing Embodied Energy and Decreasing Emissions) and called Determining Material, Environmental, and Economic Efficiency of Sorting and Recycling Mixed Flexible Packaging and Plastic Wrap, seeks to examine barriers along every stage of the recovery process [98]. This project aims to develop technology to recover flexible plastic film from an MRF. The project examines market opportunities for the recovered film and evaluates the resulting economic and environmental impacts. The technology to be developed in the project, if implemented broadly, has the potential of capturing almost 11 billion lb (about 5 MMT) of flexible plastic packaging and plastic wrap that is currently landfilled each year. The project is a joint effort between the ACC, Idaho National Lab (INL), and Resource Recycling Systems (RRS).

A summary of the major programs/projects and reports for the recycling of flexible plastic packaging are given in Tables 11.3 and 11.4.

11.6 Initiatives

The New Plastics Economy Global Commitment brings together key stakeholders behind a common vision of a CE for plastics and targets to

[7] Launched in early 2017, the REMADE Institute is one of 14 National Manufacturing Institutes that make up the Manufacturing USA Federal initiative.

Table 11.3 Summary of Major Programs/Projects for the Recycling of Flexible Plastic Packaging

Program	Title	Type	Material	Reference
WRAP	Wrap Recycling action Program	Collaboration	PE films	[94]
FIACE	Flexibles in a Circular Economy	Collaboration	Films	[89,90]
REFLEX	Recycling of Flexible Packaging	Collaboration	PE, PP films	[91,92]
CEFLEX	Circular Economy for Flexible packaging	Collaboration	Films, multilayers	[4,14]
MRFF	Materials Recovery for the Future	Study/Pilot	PE films, Multilayer	[95,99]
Hefty® EnergyBag™	Hefty EnergyBag™	Pilot	Films, multilayers	[96]
NAPRA	North America Plastic Recycling alliance	Collaboration	Films, multilayers	[97]
REMADE project	Determining Material, Environmental, and Economic Efficiency of Sorting and Recycling Mixed Flexible Packaging and Plastic Wrap	Collaboration	PE films	[98]

Table 11.4 Summary of Selected Reports for the Recycling of Flexible Plastic Packaging

Report	Title	Type		
Prepared by RSE USA	Film Recycling Investment Report	Study	Films	[100]
NEMO	New End Market Opportunities Project	Study	PE films	[101]
Prepared by More Recycling	End Market Demand for Recycled Plastics	Study	PE, PP, PS	[102]

PE, Polyethylene; PP, Polypropylene; PS, Polystyrene.

address plastic waste and pollution at its source, starting with packaging. It is led by the Ellen MacArthur Foundation in collaboration with UN environment. From October 2018 till June 2019, more than 400 organizations have endorsed the Global Commitment. Many of the world's leading fast-moving consumer goods companies (6 of the top 10), plastic packaging producers (7 of the top 10), retailers (5 of the top 15), and recyclers have signed up to the Global Commitment [103] (see Table 11.5).

The American Chemical Council's Plastics Division announced targets of 100% of plastic packaging being recyclable or recoverable by 2030 and 100% of plastics packaging being reused, recycled, or recovered by 2040. In 2016, the Plastics Industry Association launched the Zero Net Waste program, which recognizes plastic companies that takes step to reduce net waste in plastics manufacturing [104]. These goals fit in well with the drive toward the CE idea that is being pushed by the European Union as a way of meeting the dual objective of minimizing waste and reducing the use of raw materials and energy [105].

Table 11.5 Participation of the Largest (by Revenue) Fast-Moving Consumer Goods (FMCG) firms, Plastic Packaging Producers, and Retail Companies in the Global Commitment

Number	**FMCG**	**Plastic Packaging**	**Retail**
1	**Nestlé**	Reynolds	**WalMart Inc.**
2	Procter & Gamble	**Amcor**	Costco
3	**PepsiCo**	Berry Global	The Kroger Co.
4	**Unilever**	**Sealed Air Corporation**	**Schwarz Group**
5	AB Inbev	RPC Group	Walgreens boots alliance
6	JBS	Bemis	Amazon.com, Inc.
7	Tyson Foods	**ALPLA Group**	Home Depot, Inc.
8	**The Coca-Cola Company**	Interplast	Aldi
9	**L'Oréal**	**Aptargroup Inc.**	**Carrefour**
10	**Mars, Inc.**	Silgan	CVS Health
11			Tesco PLC
12			Aeon Co., ltd
13			**Target**
14			**Ahold Delhaize**
15			Lowe's Companies, Inc.

*Those in **bold** have signed the Global Commitment.*
(Courtesy of the Ellen MacArthur Foundation) [103]

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Patents

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US2018171094 A1	20180621	EP3339359 A1 20180627		LAYMAN JOHN MONCRIEF; COLLIAS DIMITRIS IOANNIS; SCHONEMANN HANS; WILLIAMS KARA	PROCTER & GAMBLE	Method for purifying reclaimed polypropylene
US2018171095 A1	20180621	EP3339360 A1 20180627	US201715839911 20171213; US201662436475P 20161220	LAYMAN JOHN MONCRIEF; COLLIAS DIMITRIS IOANNIS; SCHONEMANN HANS; WILLIAMS KARA	PROCTER & GAMBLE	Method for purifying reclaimed polyethylene
WO2018172781 A1	20180927		GB20170004547 20170322	PASLIER PIERRE-YVES; GARCÍA GONZÁLEZ RODRIGO	SKIPPING ROCKS LAB LTD	Method of encapsulating liquid products