WHITE PAPER

ExxonMobil

An overview of advanced recycling technologies

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Advanced recycling encompasses a range of technologies that can help unlock the value of used plastics. Globally, only a small percentage of plastic waste gets collected today, and even a smaller percentage gets recycled – mostly through a mechanical recycling process. However, advanced recycling represents an opportunity to help unlock the inherent value of used plastics that might otherwise wind up in a landfill or incineration.

This white paper explores different end-of-life options for plastic waste and highlights ExxonMobil's Exxtend™ technology for advanced recycling as a viable option that can help enable plastic circularity – a key consideration for many in the plastics value chain based on consumer demand.

What is advanced recycling?

Exxtend technology transforms plastic waste at a molecular level into usable raw materials that are attributed via ISCC PLUS mass balance approach using the "determined by mass" option with "certified free attribution" applied to the amount of certified-circular polymers we sell. Because certified-circular polymers are identical to virgin plastics, they have the same quality and performance, so customers can have confidence incorporating certified-circular polymers into sensitive applications, including hygiene and personal care products.

Advanced recycling can divert difficult-to-recycle plastic that might have otherwise gone to landfill or incineration. With the ability to process complex, multi-polymer material and remove contaminants, this technology can be a complement to mechanical recycling. Our technology, built on decades of innovation and operational excellence, is helping to enable

a circular economy for plastics. We are collaborating with the value chain to develop an infrastructure to more effectively collect, sort, and process used plastics at scale.

Solutions for packaging that enable sustainability benefits

It is important to understand that advanced recycling is an emerging technology among a range of technologies deployed to support solutions that can enable plastic circularity. ExxonMobil has a portfolio of products and services that can help enable packaging solutions with sustainability benefits from product design through end-of-life.

Figure 1. Packaging solutions with sustainability benefits

*Recyclable in communities with programs and facilities in place that collect and recycle flexible film.

Doing more with less through downgauging is about reducing the thickness of the packaging film, while conserving its full functionality. For example, 25 years ago the bags ExxonMobil transported its resins in – that could hold up to 25 kilograms – were made of polyethylene and were 200 microns thick. Today, that material is only 100 microns thick but still gets the job done. ExxonMobil continues expanding portfolio of enabling molecules and pushing the envelope of film performance with products like Exceed™, Exceed™ XP and Exceed™ S performance PE.

Designing for recyclability* refers primarily to simplifying the structures of plastic products, going to a mono-material, or reducing or changing additives to have something that is more recyclable through mechanical or advanced recycling. In other words, the products are made such that they can actually be recycled when they reach the sorting center at end of life.

Increasing recycled content can be facilitated with compatibilizers, which help create bonds between polyethylene and polypropylene. These molecules don't normally bond well, but compatibilizers can help packaging manufacturers see fewer issues with sealing or producing a brittle product. By improving the performance of formulations incorporating mixed plastic waste, we help create opportunities for its use in more applications.

When you have a recycle stream that is clean, adding high-performance polymers, like Exceed™ XP, can help to overcome property loss while incorporating as much recycled content into your applications as possible. This solution is most commonly used for industrial packaging applications, such as palletization film and heavy-duty bag applications.

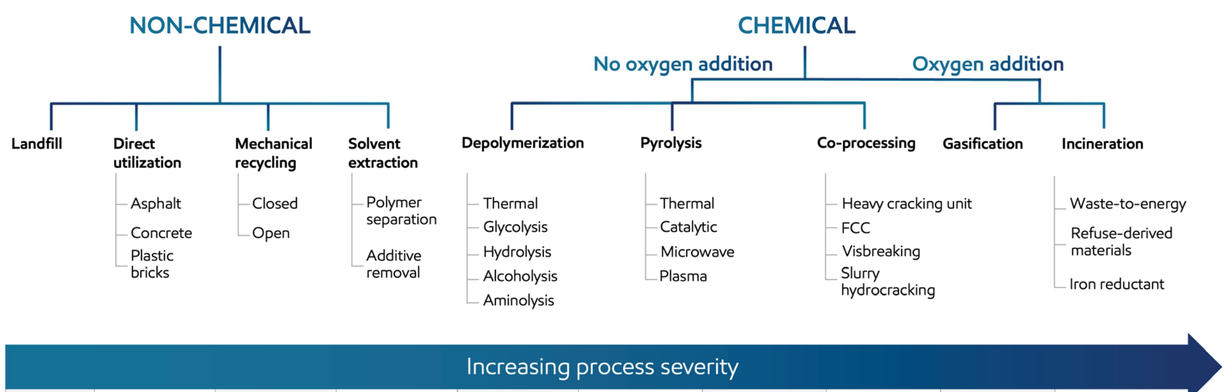
End-of-life options for plastics

There are two categories of end-of-life options: non-chemical and chemical (see Figure 2). Non-chemical end-of-life options include landfills, direct utilization, mechanical recycling, and solvent extraction. Typically, these technologies do not change the molecular structure of the polymer.

Direct utilization is about an efficient use of cheap resources, typically mixed plastics, that are used in construction, bricks, asphalt, and even garden furniture.

Mechanical recycling is the most common recycling method. This involves melting and pelletizing sorted plastic waste, which has been washed for use in different applications (mainly industrial).

Solvent extraction is a process that dissolves the polymer so that it is possible to clean it from other components, such as additives. The solvents can also be used to de-laminate and de-ink, for example. The output of solvent extraction is typically very high-quality recycled resins.



Typical feed	Unsorted waste	Mixed plastic scrap	Monopolymer plastic scrap	Multi-layer scrap	PET or PS scrap	Mixed PO scrap	Mixed PO scrap	Mixed PO scrap	Unsorted waste	Unsorted waste
Products	None	Construction materials	Recycled resin*	Recycled resin*	Basic chemicals	Basic chemicals	Fuels & lubes	Fuels & chemicals	Syngas	Heat & electricity

Figure 2. End-of-life technologies for plastics

The chemical category can be broken down further into processes that incorporate oxygen and processes that do not. When oxygen is not present in the process, we see two main trends: depolymerization or pyrolysis. In depolymerization, the typical feed would be polyester or polystyrene. These polymers are reduced to their base monomers and different processes are possible – with the difference being the type of chemical reaction that is applied.

At ExxonMobil, we are currently focused on pyrolysis. In this case, polyolefins are transformed at the molecular level into smaller hydrocarbon chains, liquids, or gases that can be used to make new products.

There are two additional processes that involve oxygen: gasification and incineration. Gasification can use a very wide variety of waste streams. Polymers are exposed to very high temperatures with oxygen, which produces syngas – a mixture of hydrogen and carbon monoxide. Incineration is about heat and power generation. When unsorted waste is burned, as much of the heat as possible is captured from that reaction and used to generate power.

Advanced recycling scenarios

There are two primary approaches for pyrolysis-based advanced recycling: standalone pyrolysis units that produce pyrolysis oil and facilities units are integrated into a petrochemical complex. At ExxonMobil, we use the latter approach. For example, our Exxtend technology for advanced recycling, a proprietary technology developed at our site in Baytown, Texas, utilizes existing infrastructure to co-process plastic waste alongside fossil-based feedstocks in our Baytown petrochemical complex.

In both cases, the first step is pre-processing plastic waste to prepare the feedstock. It involves washing, shredding, drying, homogenization, and aggregation, which is consistent with the feedstock specifications. Pre-processing is an important step to help maximize the polyolefin content and eliminate or reduce other polymers like polyesters, polystyrenes, or PVC, for example. During pre-processing, plastic waste is characterized, contaminants are identified, and strategies are developed for processing the waste to meet a recycler's specifications.

The heart of the process is the pyrolysis, for which we use heat to crack the polymer into smaller carbon chains. Polymers are melted and put in the pyrolysis reactor in which they are exposed to a high temperature (300 degrees Celsius, 600 degrees Fahrenheit) without oxygen so that the polymer is not burned, but instead are converted to smaller carbon chains, such as ethane or naphtha in oil and gas forms. Pyrolysis oil and gas are recovered in ExxonMobil's units and then sent for further refining and purification.

Finally, these small molecules are transformed into usable raw materials that can be attributed to certified-circular polymers via International Sustainability and Carbon Certification (ISCC) PLUS mass balance approach using the "determined by mass" option with "certified free attribution" applied. ExxonMobil has obtained certifications through the ISCC PLUS for several of its facilities including its Baytown, Texas, advanced recycling facility. ISCC PLUS is widely recognized as an effective and robust mass balance attribution system for plastic waste processed at a certified advanced recycling facility.

Our goal is to process plastic waste, using existing infrastructure and embedded units at our various existing facilities, which we believe will enable us to quickly scale up globally.

What are the desirable feedstocks for Exxtend technology?

Figure 3 illustrates the types of feedstocks that are typically best suited for advanced recycling technologies and, specifically, which types we look for to use with our Exxtend technology.

The preferred feeds are the polyolefins: polypropylene, polyethylene, mixed multilayer films, rigid or flexibles, in all their shapes. Other material that ExxonMobil has processed using Exxtend technology include metalized film, barrier films, nylon, EVOH, laminate, and artificial grass. Less desirable feeds include polystyrenes and polyesters. The polyester molecule introduces oxygen into the process, which we do not want in pyrolysis.

PVC, halogenated materials, and all non-plastic material are avoided.

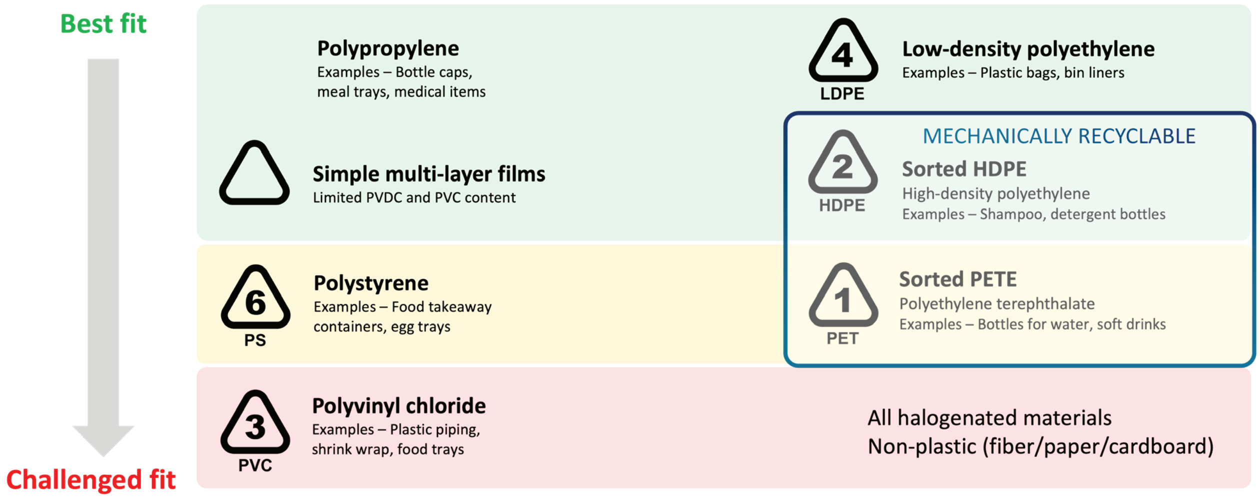


Figure 3. Desirable feedstock for Exxtend technology

Conclusion

Advanced recycling technologies present a promising avenue to help address the plastic waste challenge. Because advanced recycling is complementary to mechanical recycling, it can help widen the range of plastics that are being recycled.

By unlocking the inherent value of used plastics through methods like ExxonMobil's Exxtend technology for advanced recycling, we can increase the amount of waste that we divert from landfills and incineration. These technologies also support the development of a circular economy for plastics.

As we continue to innovate and implement these advanced recycling methods, we can hopefully move closer to a future where plastic waste is effectively managed.

Contact us for more information:
exxonmobilchemical.com/exxtend