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Research into the recycling of plastic PET bottles into virgin-grade polyester for textile end-uses continues. The new chemical and biotech techniques in development claim to be more flexible and cost-competitive than mechanical processes.

Closing the polyester loop

Turning post-consumer plastics and textiles into high-grade materials that can be infinitely reprocessed is no longer a distant dream for polyester as new depolymerising techniques come into being. PET (polyethylene terephthalate) bottles are most often recycled using a mechanical process in which they are broken down into flakes that are, roughly, melted and then respun. But the resulting filament or staple yarns do not always have the same properties as oil-derived or 'virgin' polyester. Chemical recycling processes convert PET bottles or polyester textiles back into the original monomers, and are said to produce a polymer that is indistinguishable from conventional polyester. The good news is that progress is being made on both fronts, with the most promising in the latter category.

The chemical recycling of PET bottles and clothing was first introduced in 2002 by Teijin, a Japanese textile conglomerate, as Ecocircle. Patagonia was an early adopter of the programme, and began sending used clothing to the company in 2005. Now, more than 150 companies supply reclaimed garments to a recycling plant Teijin established in China in 2012. Ecocircle depolymerises these using a two-step process based on hydrolysis and methanolysis to obtain raw ingredients that can be turned into 'new' polyester. Along with glycolysis, a third chemical reaction, reverse polymerisation methods are now being applied in new ways using enzymes, microwaves or ferrofluids.

Recycling coloured PET bottles

Among the new chemical recycling processes in development, London-based PerPETual Global Technologies, established by Aloe, a private equity firm, is one of the most advanced with a plant up and running in India. In 2008, Aloe acquired the rights to ReNEW, a technology invented in 1993 by Dr Simon West, an Australian with several commercially successful patents to his name. The same year, Aloe purchased a majority stake in Polygenta Technologies, based in Nasik, India, which has since been converted to the ReNEW process, in operation since 2010.

Thanks to its patented filtration processes, ReNEW can depolymerise all types of post-consumer PET bottles back into esters. "We take PET bottles which are rinsed, cut into flakes and environmentally processed into a liquid oligomer. This oligomer is then filtered to remove impurities and the resulting esters can be used to make any polyester-based product such as film, bottles, packaging and textile yarns," Dr Vivek Tandon, chairman and CEO of perPETual, told *WSA*. "Our process is highly profitable with very little waste; one tonne of flakes yields over 950 kilograms of esters."

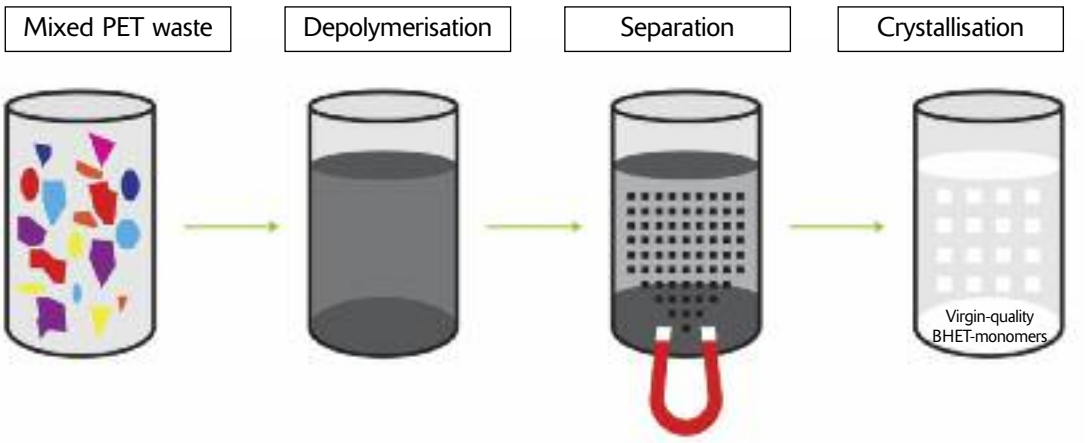
The company currently recycles up to two million PET bottles a day and plans to treble the facility's capacity to meet demand. "Today our ester is used to produce very high quality sustainable filament yarn for the textile industry," Dr Tandon said. "Our target is to be able to process over 100 million bottles a day by 2022." For this, the company is seeking financial and industrial partners. Stefano Cochis, formerly at Newlife, has recently joined the company' sales team.

The Magnetic Smart Materials-based recycling process developed by Dutch company Ioniqa Technologies, a spin-off from the Eindhoven University of Technology, also converts all types of post-consumer PET waste into its original building blocks, "pure colourless monomers", it claims. Founded in 2009, the company began testing its method on PET waste in in 2011, achieved proof of concept in 2013 and is currently running a 1,000-litre capacity facility in Rotterdam. "We hope to have the first 10,000 tonne plant in operation in 2018," says Ioniqa's director of communications, Gert van Exel. This will then be the blueprint to license out the technology.

Ioniqa's technology takes mixed PET waste that is shredded into flakes and then dissolved in

Sympatex plans to close the loop by 2020. The polyester membrane is now fully recycled and laminated to recycled polyester fabrics.

Sympatex



Dutch start-up Ioniqa believes it has found a profitable circular recycling solution for PET waste with its Magnetic Smart Materials that filter out colourants and contaminants.

Ioniqa

an ionic liquid, as its name suggests. Magnetic Smart Materials, a catalyst containing nanoparticles of iron oxide, are added, the brew heated to a temperature below 200°C at atmospheric pressure, enabling the depolymerisation of PET. After this first stage, colourants and contaminants are magnetically separated to obtain 'virgin-grade' PET monomers. "The magnetic separation process takes three hours and the resulting monomers are crystallised to make new polyester pellets," says Mr van Exel. The catalyst liquid can be recovered after each process, though it needs to be purified to remove colourants and contaminants.

Ioniqa can recycle both PET plastic and polyester textile waste to virgin-grade raw materials. "However, polyester textiles, like all textiles, contain more colorants than plastic packaging and will demand more effort to separate them as fast and effectively as PET plastics, so we're busy optimising the process for polyester textiles," says Mr van Exel. He says the Ioniqa process is a platform technology and that the company is experimenting with other waste materials, which could be other types of plastics or organic waste such as cotton or paper.

Enzymatic bioprocesses

A number of academic labs and start-ups are betting on enzymes to reverse polymerise PET waste. The most advanced appears to be French company Carbios, based in Clermont-Ferrand. Since 2012, it has been working on its project thanks to five-year public-private funding that granted the young company € 15 million. "Up to 60 scientists, many of whom work at a leading enzymology lab at the University of Toulouse, have helped develop the process," company COO Martin Stephan told *WSA*. Carbios first identified an enzyme capable of degrading PLA plastics. "These can be integrated into the polymer to make plastics that have a programmed lifespan and can be used to make self-biodegradable mulching films for agriculture or grocery shopping bags," he says.

Further research led to the discovery of a family of enzymes capable of depolymerising polyester back into MEG (Monoethylene glycol) and terephthalic acid, making it possible to recycle PET ad infinitum without loss of quality in a truly circular loop. "The enzyme specifically degrades polyester and fully degrades it," says Mr Stephan. This method has been found to apply to a wide variety of PET-based packaging including opaque milk bottles, shampoo and detergent containers. The company's patented process is followed by filtration and purification operations which are conducted at low temperatures and require little energy, says Mr Stephan, making it less costly than other recycling methods. Carbios intends to start experimenting with polyester textiles, which represent a larger waste stream. "In 2020 a European directive will make it mandatory to sort textile waste. This will make it easier to recycle it," he says.

Carbios says it will soon operate a 5,000-litre pilot plant and expects to build an industrial scale demonstration facility by late 2019 or early 2020. If all goes as planned, a fully operational facility could be on stream in 2022. The technology will then be licensed out to PET producers looking for circular economy certification. "This is increasingly considered an asset by consumers and engineers as well as by employees and investors," Mr Stephan points out.

Other enzyme-based biotech processes in development include Ambercycle. A recipient of H&M's Global Change Awards in 2016, it was granted € 250,000 to pursue research on what it calls a "polyester digester". Contacted by *WSA*, company founder Akshay Sethi could not comment on the details of his project. A research team at Kyoto University, Japan, has also isolated a species of bacteria that degrades PET and that it has named Ideonella sakaiensis, as published in *Science* in March 2016.

Microwave catalysis

Yet another novel method for depolymerising PET harnesses microwaves and has received funding from the European Union Horizon 2020 programme to build a demonstration plant. The process developed by Swiss start-up gr3n is

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known as Demeto (for Depolymerization by MicrowavE TechnolOgy) and can be applied to bottles of all colours as well as polyester textiles.

"Microwaves cut the polymer chains down and release contaminants, including chemicals, colour and all foreign matter," says Maurizio Crippa, one of the two inventors. The result is a polyester monomer of the same quality and characteristics as that made from oil. The gr3n Demeto process is said to dramatically reduce reaction time to 10 minutes as opposed to 120-180 minutes required for chemical recycling via classic conditions. "Microwaves have a catalytic effect that accelerates reaction rates in a one-step process," says Mr Crippa. "Our technology produces the sodium chloride used in the depolymerisation process, making it a truly closed-loop system that is also cost competitive, in part because of the wide array of feedstock that can be treated."

Mr Crippa began working on the concept in 2011, launched it in 2012, and established gr3n in Switzerland to take advantage of the Swiss Commission for Technology and Innovation (CTI) that offers support and coaching for start-ups. It is now a member of Symbioptima, a European consortium, and is constructing its first industrial reactor. "We hope to start producing by the end of 2017," says Mr Crippa, who adds that it will be a small-scale industrial plant (with a capacity of one tenth of an industrial facility). He believes the process will also be able to recycle blended fabrics and even laminated textiles. The synthetic or natural fibres will either be depolymerised and filtered out or left "unreacted" and easy to separate, he says. Mr Crippa does not exclude the possibility of depolymerising polyamide or polyurethane in the future.

Clarity counts

These innovative processes in development all potentially offer a low-cost alternative to mechanically recycled PET bottles. As pointed out by the persons interviewed for this article, the quality of the recyclate depends heavily on the ability of the sorting process to remove coloured bottles and carbonated beverage bottles that contain a barrier layer to prevent gas from escaping. It also involves much scrubbing and cleaning to guarantee a high grade recycled material. These operations tend to increase the price of mechanical reprocessing.

Taiwan specialises in mechanical PET recycling, an activity where Libolon and Far Eastern stand out. The country has developed high-tech collecting and sorting facilities. About 90,000 tonnes of PET bottles are reclaimed each year, the equivalent of 4.5 billion water bottles,



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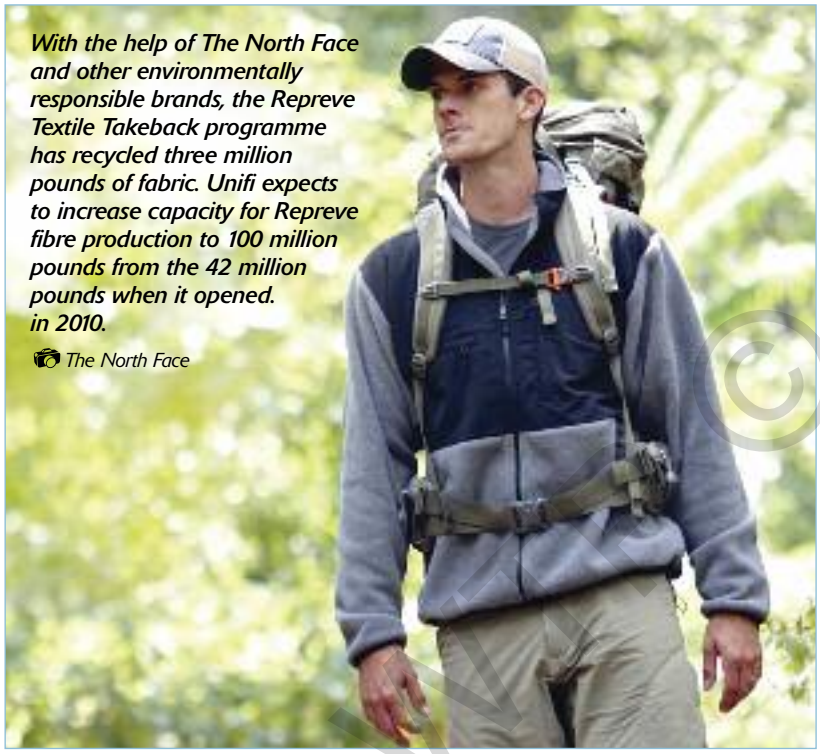
accroding to estimates the Taiwan Textile Federation (TTF).

In the United States, Unifi has also invested heavily in PET recycling since it launched Repreve, a branded recycled polyester, in 2007. It recently built a bottle-processing centre located in Yadkinville, with a capacity to produce 75 million pounds of bottle flake annually. Unifi's sorting process includes 10 stages before the bottles are ground into flakes. These are filtered before being melted into polymer chips that can be extruded as continuous filament or staple fibre. "Depending on the country of origin, a bale of bottles can contain a high percentage of non-PET materials," says Jay Hertwig, head of global sales, marketing and product development for Unifi. A bale might contain cans, wood, even rocks. On average, PET content represents 50% to 70% of the bales," he says.

The process developed by Unifi produces recycled polyester of a quality equivalent to non-recycled polyester, says Mr Hertwig. Unifi incorporates a tracer it calls Fiberprint into the polymer to enable the identification of recycled content in end products. "This gives brands the assurance that their product contains Repreve," he says. Repreve now accounts for 30% of Unifi's sales, and is offered in two grades: 100% post-consumer recycled PET and a hybrid blend made from a combination of post-consumer and post-industrial waste. Textiles that will be dyed require clean, clear flakes, while coloured flakes are recycled into solution-dyed staple fibre. All Repreve yarns are certified to GRS, the global recycling standard.

The US-based company has already moved on to the recycling of polyester textiles through a take back programme set up with The North Face for the outdoor brand's Denali jackets. Pure polyester cutting scraps from factories based in Central America are set aside and sent to Unifi, where they are recycled back into fibre. As these are generally multi-coloured, they are solution-dyed, points out Mr Hertwig. The company is evaluating other sources of PET waste including nonwovens and industrial waste from textile mills using Unifi polyester. "Interest level seems to be increasing," he says. "It will take time to set up a circular economy in textiles, but we are demonstrating that it is possible."

In Italy, Sinterama acquired Miroglio's Newlife mechanical PET recycling plant in 2012. The company has set up a supply chain within a 90km radius of the manufacturing site located in Saluzzo, near Torino. The GRS-certified polyester is also given a tracer during spinning to enable certification. "A drop-in technology, Newlife is of the same quality as standard polyester, there are no restrictions nor limitations, it possesses the mechanical and technical properties of non-recycled polyester," says product marketing manager Matteo Soppera.



With the help of The North Face and other environmentally responsible brands, the Repreve Textile Takeback programme has recycled three million pounds of fabric. Unifi expects to increase capacity for Repreve fibre production to 100 million pounds from the 42 million pounds when it opened. in 2010.

The North Face

The company introduced two new variants of Newlife at the recent Techtextil. Newlife Easy is a 100% recycled polyester that can be dyed at 98°C instead of 130-135°C. "This means it can be blended with an elastomer yarn, cotton, wool or nylon, and will have a lower environmental footprint," he says.

Newlife Thermal, the second new reference, is a 100% recycled polyester to which an additive that absorbs energy has been added to increase its thermal insulation. "Newlife Thermal can make a garment warmer by 5°C," says Mr Soppera.

Increasing rePET content

Newlife is one of the key partners of German membrane maker Sympatex that uses the recycled polyester fabrics to laminate them to its fully recycled polyester waterproof breathable membrane. The Unterföhring-based company has recently launched a programme to increase the recycled content of its products and compensate them to make them CO^2 neutral. At ISPO, it launched the 'Sympathy Index', a graduated colour scale indicating a product's recycled content from 10% to 100%. "We may not be able to achieve a perfectly closed loop system, but if we reach 50% that is better than nothing," says company CEO Dr Rüdiger Fox. Sympatex has also partnered with Schoeller in the recently launched wear2wear

Re-Kånken, a limited edition Kånken, the Swedish children's school bag, is made in recycled polyester that is solution-dyed (using SpinDye's process) and can be recycled anew.

Fjällräven



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textile recycling programme.

Italian insulation maker Thermore has a long history of using recycled polyester, which is present in most of its ranges. "We apply as much recycled polyester content as possible throughout our products, the minimum being 50%," says Oliver Brandes, sales manager for Europe.

The same upward trend can be seen at US-based Primaloft, which plans to reach 90% post-consumer recycled content by 2021 (up from 35% today). Some product categories already contain 100% recycled fibres, says Jochen Lagemann, managing director for Europe and Asia. Each year, progress is made, as seen in the Active Gold category that now boasts 55% recycled content.

US-based Burlington has entered into a partnership with Thread, a recycling outfit founded by Ian Rosenberger in the wake of the 2010 earthquake in Haiti, and is now the exclusive provider of woven fabrics using polyester made from bottles collected in Haiti and Honduras. "People like the story behind Thread, it is easy to understand and Ian Rosenberger is turning waste into something useful," says Helmut-Richard Autenrieth, Burlington's sales manager in Germany.

The organisation set up by Thread puts the emphasis not only on reducing waste but also on the positive social impact of recycling schemes. As the new methods in development can process a wider array of waste, polyester may become the first fibre to create a complete and infinite closed loop.

Polyester basics

Polyester is a synthetic polymer whose chemical name, polyethylene terephthalate, is abbreviated to PET in plastics and PS in textiles. Its wide use is due to several factors, these include not only its mechanical and chemical properties but also its recyclability.

In 2007, polyester became the single most common textile fibre, present in 52% of clothing globally. Over the past twenty years, it has maintained its lead in volume, representing 49.2 million metric tonnes in 2014, according to the American Fiber Manufacturers Association.

Global PET production is estimated to be 61 to 64 million tonnes per annum, 60% of which is believed to be used to make textiles and 30% plastic bottles.

Recycling rates

In Europe, 26%, or 6.6 million tonnes, of the post-consumer plastic produced in 2012 was recycled and 36% was incinerated, says the Worldwatch Institute. In the US, around 30% of PET bottles were recycled in 2015. In Asia, it is believed that up to 75% of beverage bottles are reprocessed.

China receives 56% (by weight) of waste plastic imports worldwide. The Worldwatch Institute says there is indirect evidence that most of this is reprocessed at low-tech facilities with no environmental protection controls.

