RECYCLING TECHNOLOGY

RECYCLING TECHNOLOGY
FOR POST-CONSUMER PLASTICS

circular economy, recycling and upcycling, **customized regranulate quality for highly contaminated and printed plastics,** odor reduction technology, **food contact materials,** rigids and flexibles

Starlinger

Circular economy: *reduce – reuse – recycle*

Although the buzzwords reduce – reuse – recycle date back many years, the idea to turn a linear into a circular economy has gotten a lot of traction lately and is here to stay.

The principal idea is to close loops wherever possible. This is a relevant topic for all sorts of materials, but since plastic packaging dominates our everyday life, especially the plastics industry is on the forefront of creating sustainable solutions.
To achieve a 100 % closed circle, a number of obstacles have to be overcome. Availability and quality of materials are a big challenge, as for the continuous production with secondary raw materials their supply in sufficient quantities needs to be ensured. This starts with an area-wide collection system – because if nothing is collected, nothing can be recycled.
Policy makers provide incentives for waste collection or set mandatory quotas but often fail to support the re-use of recycled material. Quotas for collection should be followed by mandates or incentives for recycled content in every new product so that the strictly social or ecological aspect is combined with an economically viable business case.
Another big challenge is the recyclability of the product. An important step for this is "design for recycling": This means that a product is designed in such a way that it can easily be recycled and processed into regranulate of high quality. This requires a lot of industry-wide cooperation since the product designer does not necessarily understand the recycling technologies required and hence the recyclability of the product. Industry associations play a vital role in bringing all players in the value chain to the same table to create design-for-recycling guidelines for various products.
Yet another obstacle is the attitude of the consumers towards recycled goods. In the past, recycled materials have often been dismissed as inferior compared to products made from virgin material. Lighthouse projects such as PET bottle-to-bottle recycling have helped to change that image and turned plastics recycling from an option into a matter of course.

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Flexible and rigid packaging:
Recycling solutions for a wide range of materials

Post-consumer plastics originate from sources such as household and curbside collection, supermarkets, furniture stores and distribution centers, agricultural applications, closed-loop collection and various others.
Due to the diversity of applications and collection systems there are a variety of contaminants that have to be removed in the recycling process.

In the first step, plastics are separated from other recyclables and waste, followed by the segregation of the various plastic fractions. The individually sorted plastic is then shredded and washed either cold or hot, or – depending on the source and application – with hot caustic soda. The washed, shredded flakes are then processed in a recycling extruder with a machine configuration suitable for the respective polymer and the impurities it contains.

The recycling process continues with the steps material preparation – that is usually cutting or drying and feeding – followed by melting and extruding with vacuum degassing, melt filtration, and finally pelletizing. Post-treatment may be odor reduction for polyolefines, or super-cleaning solutions for PET and HDPE for direct food-contact applications.
The final product are pellets that can be re-used for the same product again or for other applications.

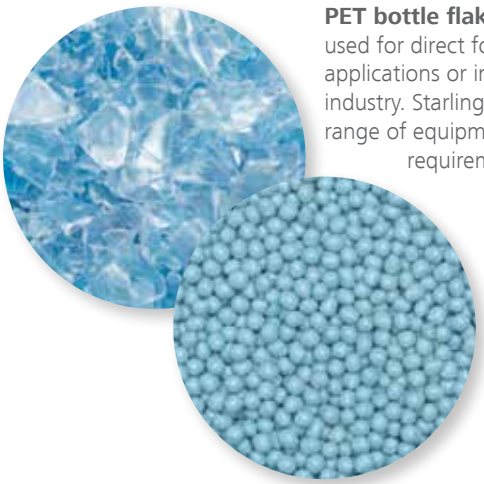
Agricultural film may show high levels of humidity and abrasive foreign particles even after the washing process. Selecting wear-resistant materials for the parts in contact with the polymer increases lifetime of the equipment and reduces operating costs.

Industrial packaging film often contains high paper content from labelling. Continuous melt filtration removes this kind of contamination before degassing and ensures the most efficient extraction of volatiles.

PO labels, a side product of PET bottle washing, are highly printed and often contaminated with PET flakes. With the Starlinger C-VAC module, PET contaminants are removed before entering the highly efficient degassing module.

PP big bags contain a high amount of humidity after the washing process that is evaporated in the SMART feeder. Micro-contaminants are removed in a second filtration step prior to pelletizing.

Rigid flakes from HDPE bottles or caps and PP food packaging trays often contain embedded unpleasant smells that are reduced with Starlinger's Odor Reduction Technology



PET bottle flakes are mainly used for direct food-contact applications or in the textile industry. Starlinger offers a wide range of equipment for all such requirements.

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ecoSTAR PET 165

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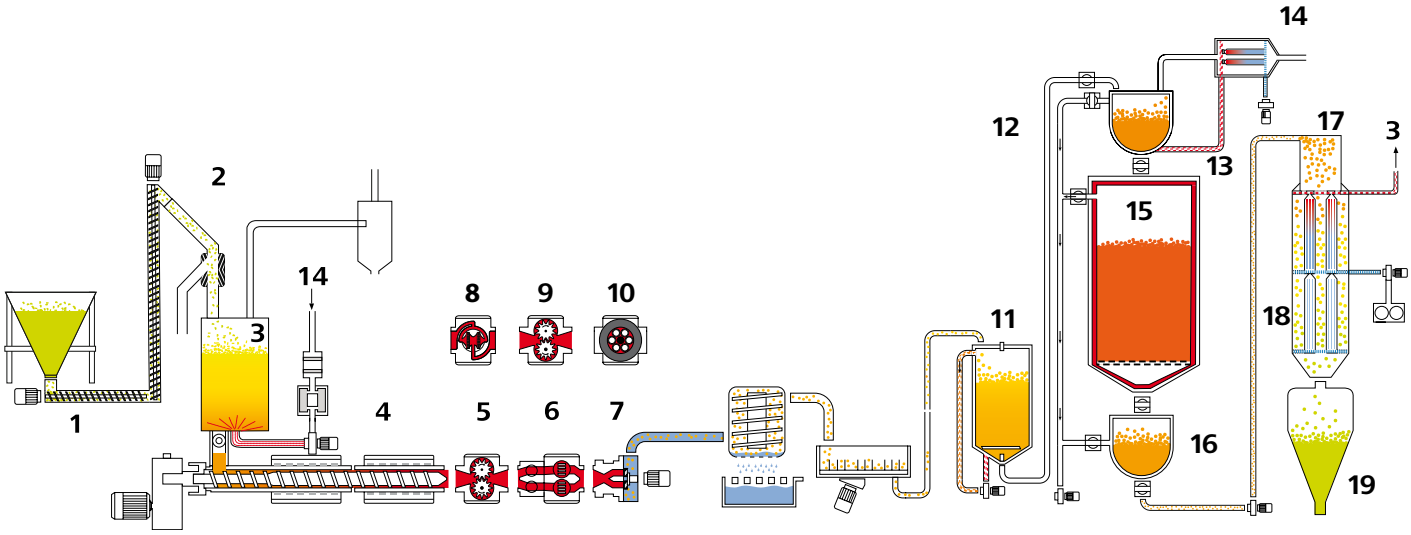
recoSTAR PET

The recoSTAR PET recycling line is the recommended system for PET bottle flake processing. In the FIFO dryer prior to extrusion both surface and hygroscopic moisture are reduced to control the IV of the material. **The FIFO dryer** is available in two configurations depending on the application. FIFO stands for **F**irst in & first out, **I**V adjustment & flake decontamination, **F**ood contact & traceability, **O**ptimized design & dust free drying.

The surface moisture of the washed PET bottle flakes as well as the embedded hygroscopic moisture is reduced to the desired level for bottle-to-bottle or flake-to-fiber applications.
With the bottle-to-bottle grade machine configuration, extrusion is carried out with minimal IV drop, while with the flake-to-fiber grade configuration the IV is deliberately but consistently reduced to match the requirements of fiber or continous filament production.

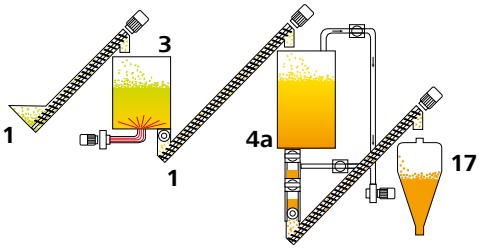
Either configuration includes an open-loop air dryer and is equipped with dust filtration for the exhaust air.
They operate with the FIFO first in-first out principle to ensure the exactly same residence time and treatment of every single PET bottle flake. Drying is done either electrically or with natural gas and without friction to avoid excessive build-up of fines.

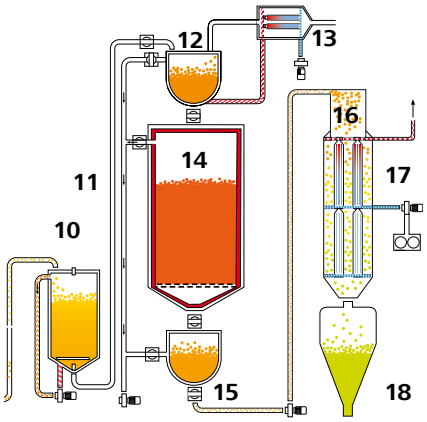


1. Feeding screw
2. Metal separator
3. Combined drying unit
4. Extruder
5. Melt pump
6. Melt filter with backflush
7. Underwater pelletizer with inline crystallization
8. Melt filter with power-backflushing
9. Melt pump
10. Sleeve filter
11. Post-crystallization unit
12. Separate vacuum feeding system
13. SSP preheater
14. Heat exchanger for preheater
15. SSP reactor
16. Discharge unit
17. Energy recovery kit
18. Pellet water cooler
19. Storage silo

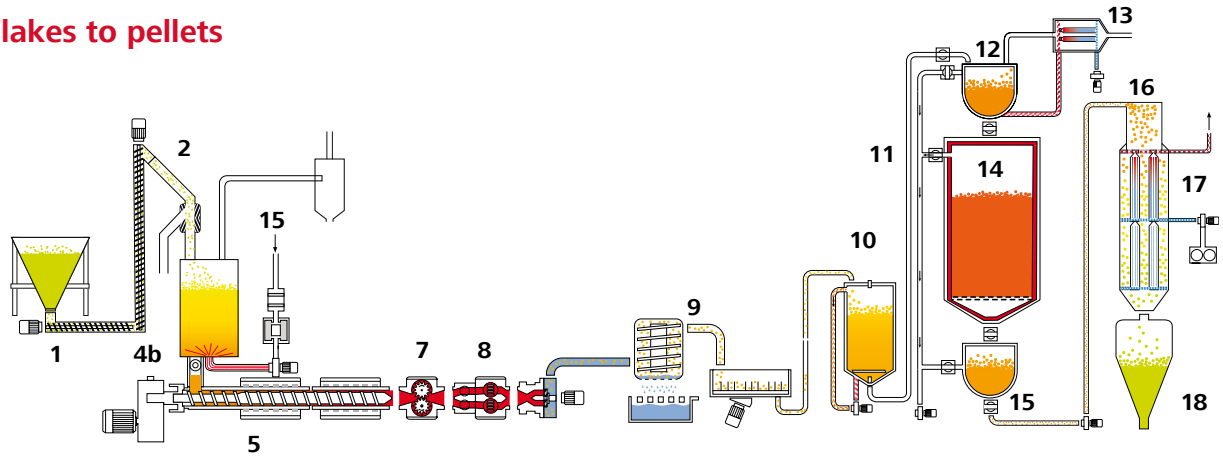
Flexibility through modular design: Flakes from production scrap such as preforms, bottles and sheet or post-consumer bottle flakes can either be recycled into pellets or processed inline into a final product. Depending on the application, the input material is decontaminated and/or its IV increased.

Flakes to flakes

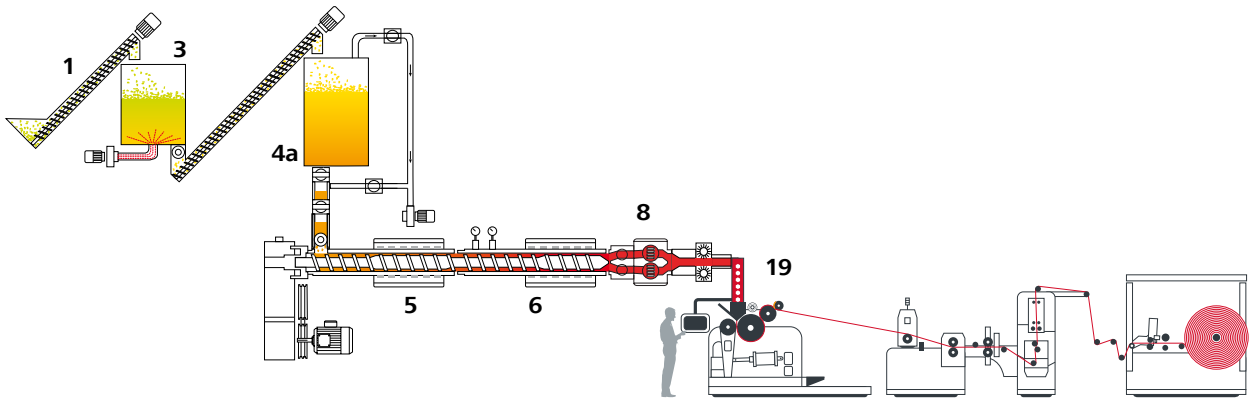




Flakes to pellets



Flakes to product



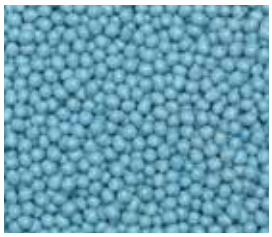
1. Conveyor screw
2. Metal separator
3. Hot air drying unit
4a. Pre-drying unit under vacuum
4b. Combined drying unit
4c. Pre-drying unit
5. Extruder
6. High-vacuum degassing extruder
7. Melt pump
8. Melt filter with backflushing
9. Underwater pelletizer with inline crystallization
10. Post-crystallization unit
11. Separate vacuum feeding system
12. SSP reactor
13. Heat exchanger for preheater
14. SSP reactor
15. Discharge unit
16. Energy recovery kit
17. Pellet water cooler
18. Storage silo
19. Thermoforming sheet production

	Food contact	FDA/EFSA	Bottle-to-bottle	Brand-owner approved	Decontamination	Low AA level	IV increase with full output
Flakes to flakes	✔	✔			✔✔	✔	✔✔

A variety of applications such as sheet or strapping bands allow the use of post-consumer PET flakes. For inline applications, the vacuum SSP reactor can be installed before the production extruder instead of a conventional dryer. A stand-alone SSP unit is used for increasing the IV of washed post-consumer flakes as well as for decontamination to allow direct food-contact packaging.

	Food contact	FDA/EFSA	Bottle-to-bottle	Brand-owner approved	Decontamination	Low AA level	IV increase with full output
Flakes to pellets	✔	✔	✔	✔	✔✔✔	✔✔	✔✔✔

Starlinger's state-of-the-art recycling technology turns post-consumer PET flakes into pellets that meet the highest requirements. Decontamination and IV increase can be carried out upstream and/or downstream of the recycling extruder. The modular design of the equipment ensures flexibility and adaptability to different input materials and the changing requirements of rPET users.



	Food contact	FDA/EFSA	Bottle-to-bottle	Brand-owner approved	Decontamination	Low AA level	IV increase with full output
Flakes to product	✔	✔			✔✔	✔	✔✔

The Starlinger inline recycling process for extrusion lines combines value-adding, energy saving and flexibility in one step. Flakes are heated and dried upstream of the recycling extruder. In this process, post-consumer flakes are decontaminated and their IV is increased before they are directly converted into a product.

Standard PET bottle

Bale feeder, breaker and metal separator: Bales of PET bottles are fed to the bale opener and breaker, metals are separated.

Pre-washing: Loose bottles are optionally pre-washed to improve the separation of PVC bottles and to remove labels.

Automatic and manual sorting: Depending on bale composition, a series of bottle sorting systems are installed. Off-spec material is compacted for selling.

Grinding: Bottles and caps are ground to flakes.

Washing: PET flakes are separated from other thermoplastics in the sink/float tank before hot washing and rinsing. Caustic soda is applied to dissolve the glue from the labels.

Flake sorting: After drying, the flakes go through a series of sorters to improve final flake quality.

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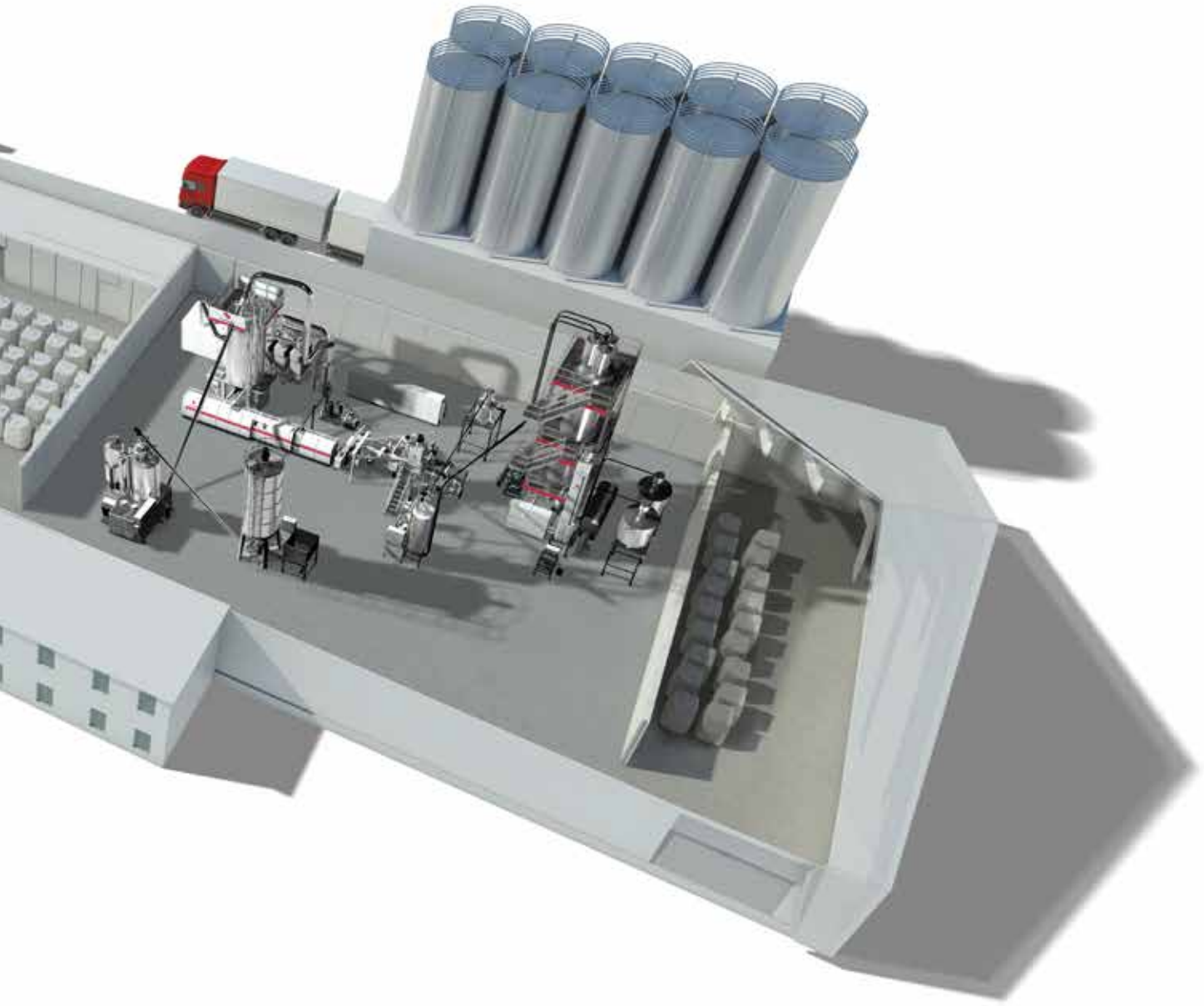
recycling plant



Sampling and buffer silo: Before extrusion, the flakes are checked for quality and stored for uninterrupted production.

recoSTAR PET art: Flakes are extruded, filtered and pelletized before going into the inline solid stating reactor for IV increase and decontamination.

Logistics: Food-grade pellets are filled into big bags or storage silos before truck loading; optionally, they can be fed directly into the production line while still hot.

Laboratory and office: Flakes and pellets are tested for food safety on a regular basis and archived for traceability.

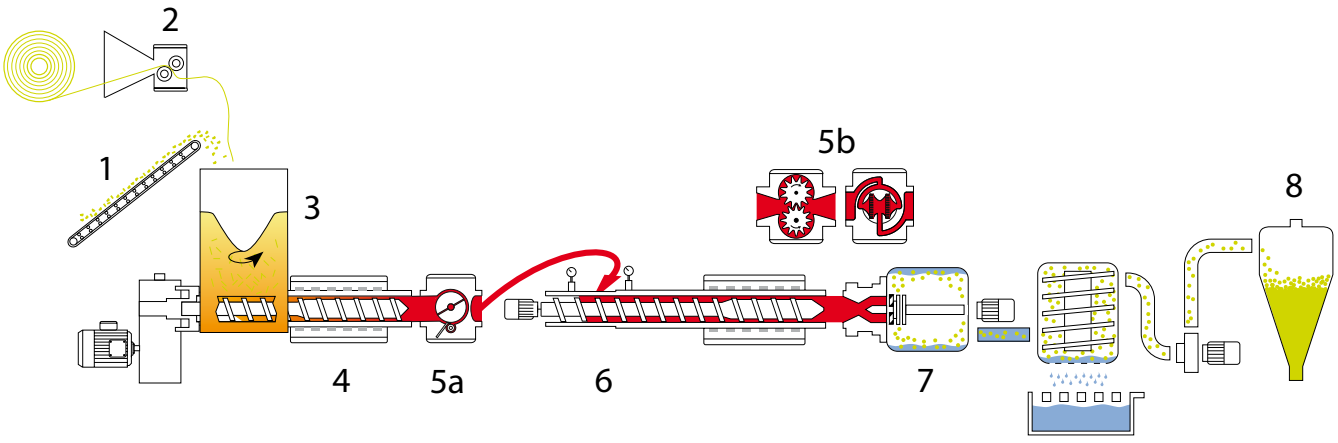
Post-consumer plastics have various forms and originate from different sources. Depending on the polymer type, recoSTAR dynamic or recoSTAR PET is the recycling system of choice. The physical shape of the plastic, its level of impurities, and the final application of the regranulate define the detailed machine configuration.

recoSTAR dynamic

The recoSTAR dynamic recycling line is a flexible system that processes both rigid and flexible post-consumer plastics such as LLDPE, LDPE, HDPE, PP, PS, ABS, SAN. Residual moisture after the washing line is effectively removed in the SMART feeder.

The SMART feeder ensures ideal material preparation prior to extrusion by simultaneously performing the following functions: **S**hrink & cut, **M**ix & homogenize, **A**ctive feed & control, **R**otate & friction, **T**emperature & dry.
The dynamic automation package regulates the ideal operating point.
The automatic speed adjustment of the rotating disc and positioning of the load-controlled intake slider increase the output and allow the processing of materials with higher levels of humidity.

Melt filtration is essential for high quality applications: The continuous melt filter in the center of the machine removes any solid contaminants immediately. The C-VAC degassing unit with its modern cascade set-up increases the melt surface by 300 % and ensures perfect pellet quality.
Depending on the application and quality requirements, a second filter, placed in front of the pelletizer,can be added.



1. Conveyor belt with metal detector
2. Nip roll feeder
3. SMART feeder
4. Extruder
5a. Continuous melt filter
5b. Melt pump and melt filter with power backflushing
6. C-VAC degassing extruder
7. Water ring pelletizer
8. Storage silo

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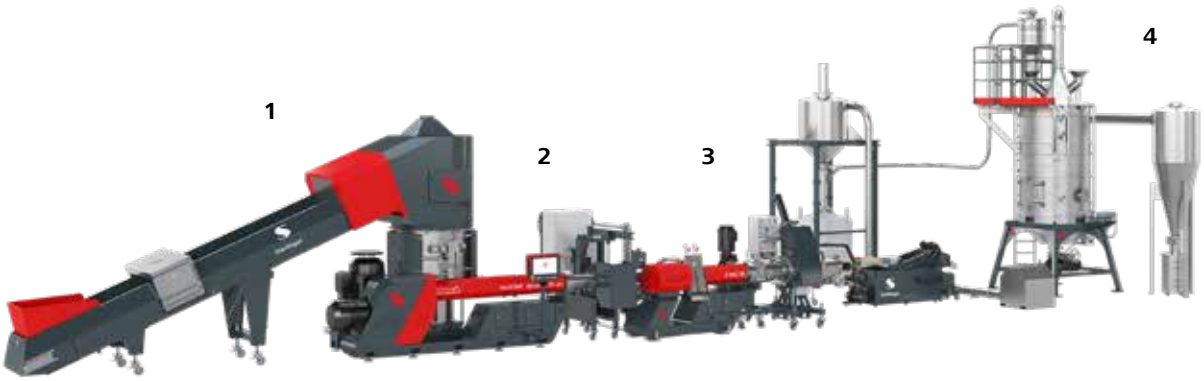
Odor reduction technology

Post-consumer plastics often contain migrated substances from food, cosmetics or detergents, which cause an unpleasant smell during the recycling process. But also residues of monomers, oxidation, as well as decomposition products (VOCs – volatile organic compounds) can be the reason for unwanted smells in regranulate.
Depending on the polymer type, source or type of the odor, its intensity, and the specifications of the produced regranulate, Starlinger recycling technology individually adapts the recycling and odor reduction process. It includes the steps material preparation, melt filtration, degassing and post-treatment.

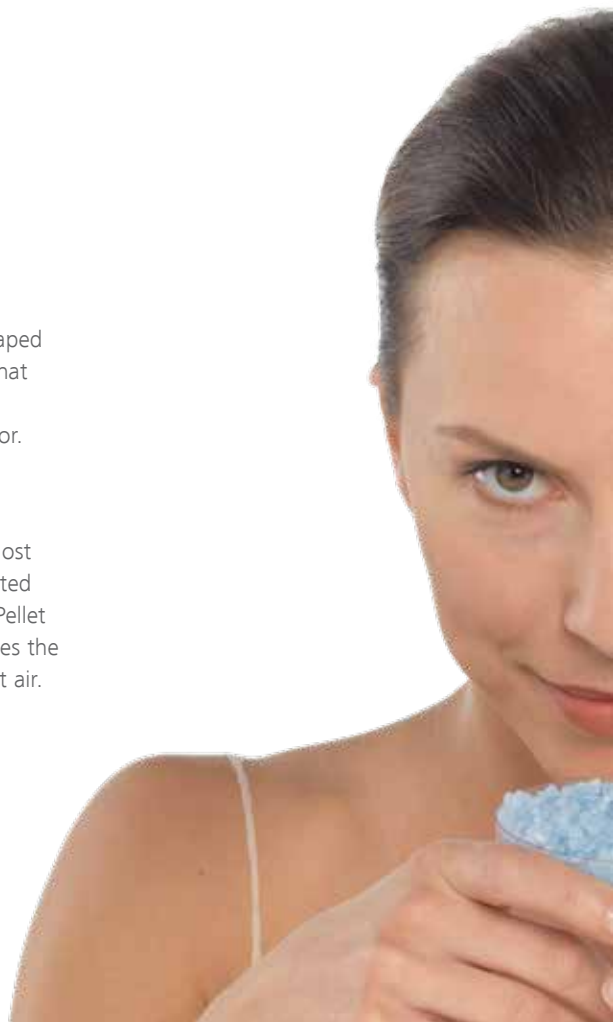


1. Material preparation:
The SMART feeder heats and homogenises the input material until the ideal operating point is reached.
Highly volatile odors are already extracted during this process.

2. Melt filtration:
In continuous melt filters, solid contaminants are immediately scraped off the filter media. This ensures that contaminants such as paper and organics can no longer release odor.

3. Degassing:
The C-VAC degassing module placed after the melt filter increases the melt surface by 300 %, thus achieving an extremely high degassing efficiency. This results in permanently removing also deeply embedded odors.

4. Post-treatment:
The odor reduction process is completed after pelletizing. The most persistent odors are reliably extracted and permanently removed in the Pellet Conditioning Unit (PCU) that flushes the granulate with ozon-enhanced hot air.



PP meal trays

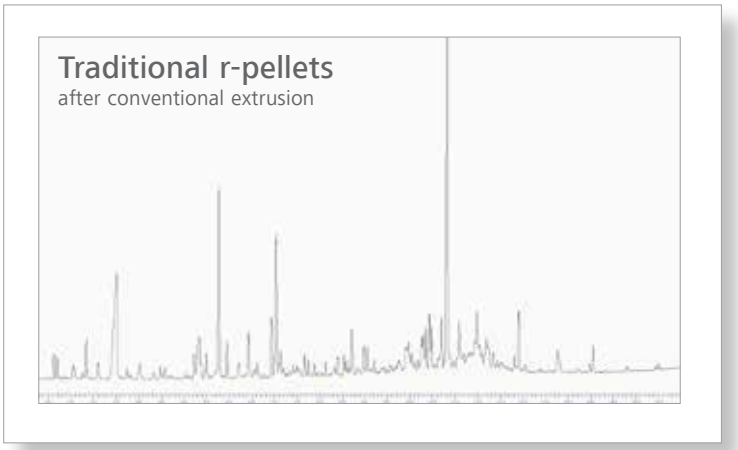
Recycling of post-consumer plastic packaging scrap from polyolefines involves different steps: collection, sorting, washing, and mechanical recycling. In the last process step ground and washed PP or PE flakes are processed on a recoSTAR dynamic recycling line with odor reduction technology. The result is permanently odor improved regranulate with an excellent and homogenous quality which can be reused up to 100 % also in demanding applications.

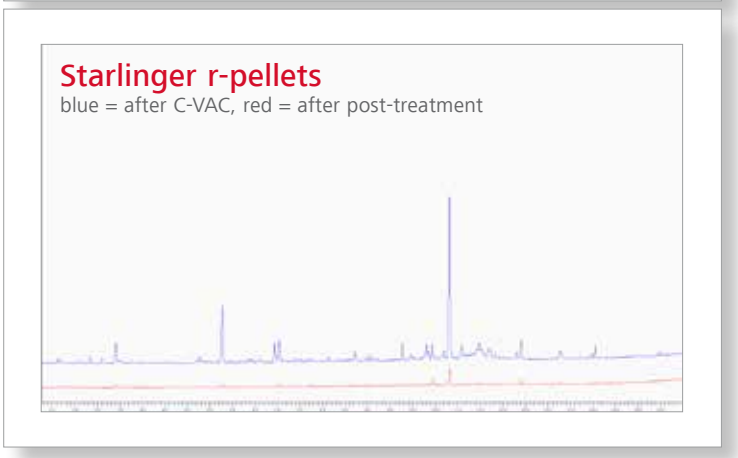
HDPE detergent bottles

Odor measurement of r-pellets

Odor measurement laboratories are working with a panel of well-trained human assessors for sensory analysis. Alternatively, the smell reduction can be quantified in gas chromatograph measurements. The odor reduction technology from Starlinger has achieved excellent results.

The graphs show an overlay of regranulate from conventional recycling processes vs. regranulate from Starlinger recycling technology's signature odor reduction process.



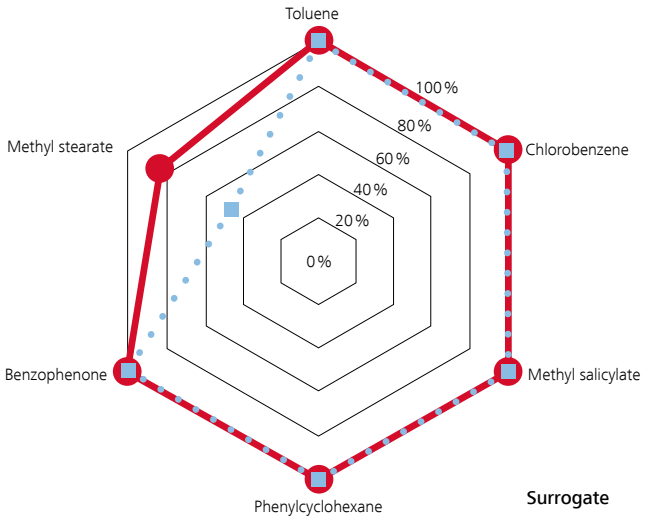


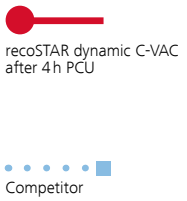
Super-cleaning solutions *for packaging with direct food contact*

Plastic packaging may absorb unwanted chemical substances during its life cycle. This can happen due to wrong storage, handling or waste management, or if the food-contact packaging is misused after its first life cycle.
If this packaging is returned to the proper waste management stream for recycling, it is no longer safe for direct food contact. Such materials can only be used for direct food contact again after being treated in a so-called super-cleaning process. Alternatively, it may be buried in the middle layer of a film or sheet behind a so-called functional barrier. Such functional barriers have been popular in sheet applications but since the sheet will later be deep-drawn or vacuum-formed into products such as cups or clamshells there is a high chance that during the deep-drawing or vacuum-forming process the non-food contact middle layer may be exposed to the food in the packaging.
Keeping the circular economy in mind, such hidden contaminants could potentially create problems in the next loop.

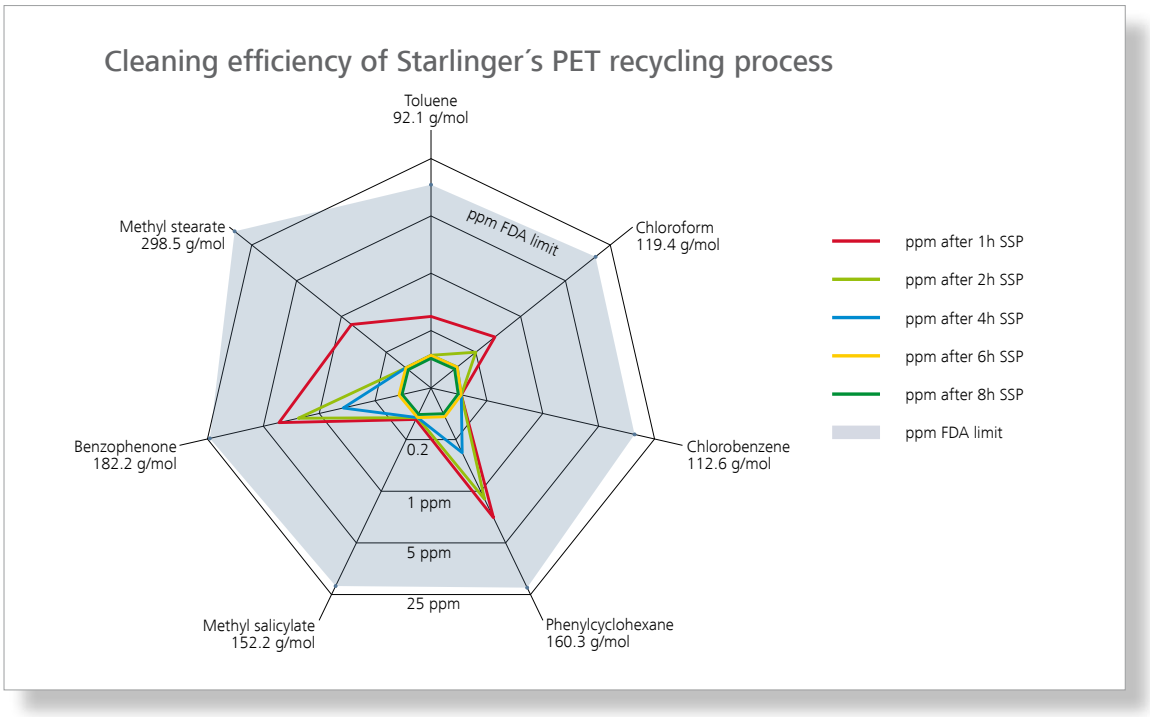
That is why Starlinger has always followed its vision of **food grade without compromise.** Only a super-cleaning process will ensure total consumer safety. Starlinger offers various super-cleaning solutions depending on the polymer and the packaging application. The processes work with temperature, vacuum or overpressure as well as required residence time, and are available for **HDPE and PET.**

Cleaning efficiency of Starlinger´s HDPE recycling process

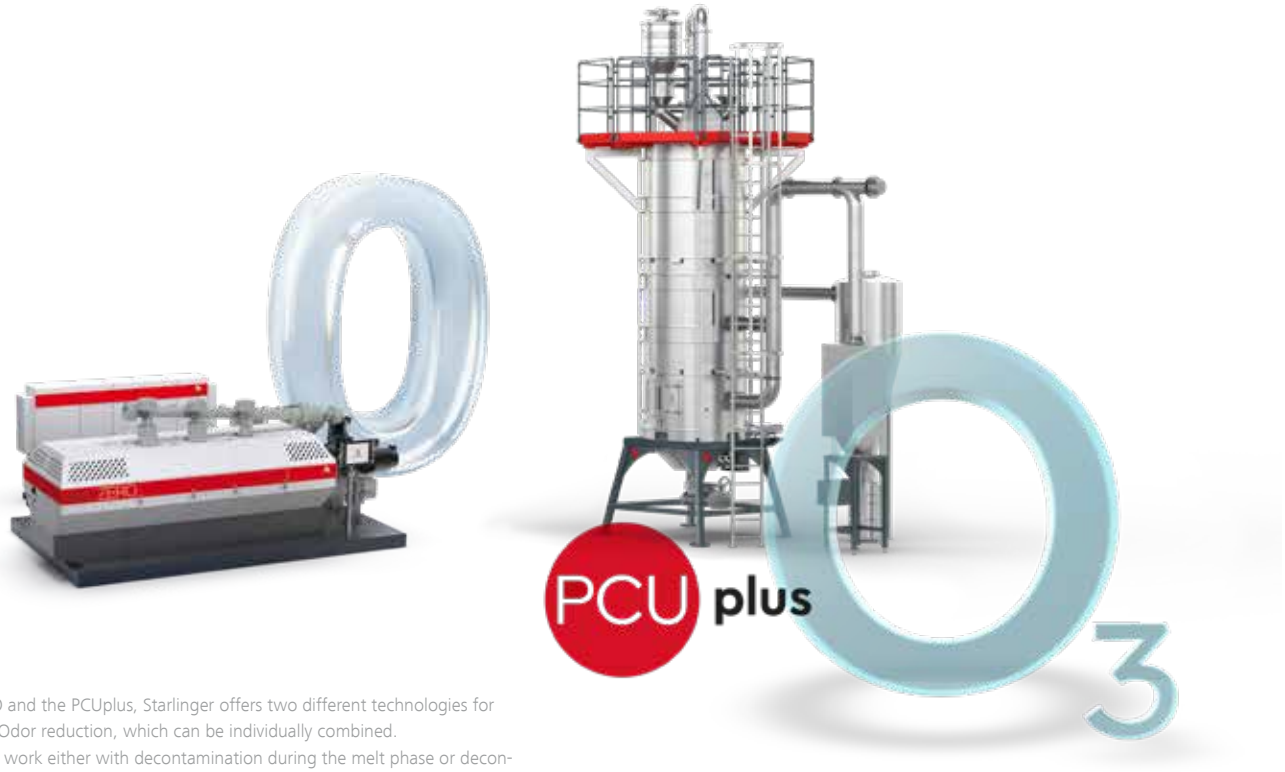




Surrogate	Mol. weight	recoSTAR dynamic C-VAC after 4h PCU	competitor
Toluene	92	99.8 %	99.6 %
Chlorobenzene	113	99.9 %	99.6 %
Methyl salicylate	152	99.9 %	99.9 %
Phenylcyclohexane	160	99.9 %	99.9 %
Benzophenone	182	99.9 %	99.5 %
Methyl stearate	298	82.8 %	46.5 %



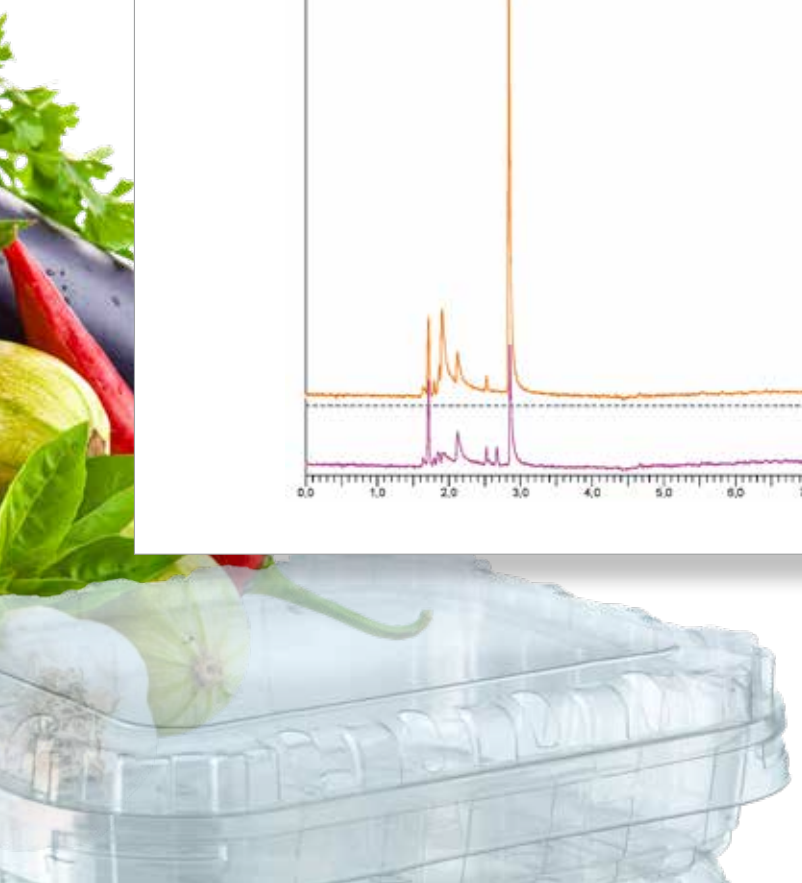
Several FDA Letters of Non-Objection, positive EFSA opinions, country-specific food contact approvals as well as approvals of multinational food and beverage brand owners confirm the outstanding decontamination performance of the Starlinger super-cleaning processes for food contact safety.

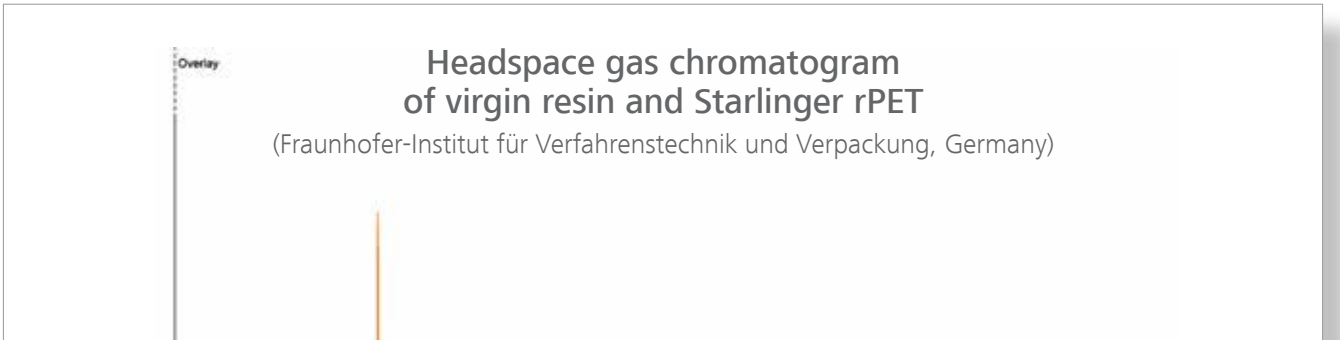


With the viscoZERO and the PCUplus, Starlinger offers two different technologies for supercleaning and Odor reduction, which can be individually combined.
These technologies work either with decontamination during the melt phase or decontamination of the pellets, or a combination of both. This ensures permanent removal of volatile organic compounds.

food contact safety first

The recoSTAR super-cleaning technologies have received various national approvals for applications in direct food contact, as well as approvals by multinational food and beverage brand owners.





Headspace gas chromatogram of virgin resin and Starlinger rPET
(Fraunhofer-Institut für Verfahrenstechnik und Verpackung, Germany)

Gas chromatography tests with rPET deliver better VOC results than virgin resin. Starlinger recycling technology guarantees adequate decontamination of rPET for reuse in direct food contact: The AA content is lowered to less than 1 ppm, and other unwanted substances such as limonene are also reduced.

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