

vinyl^{plus}

PVC recycling technologies



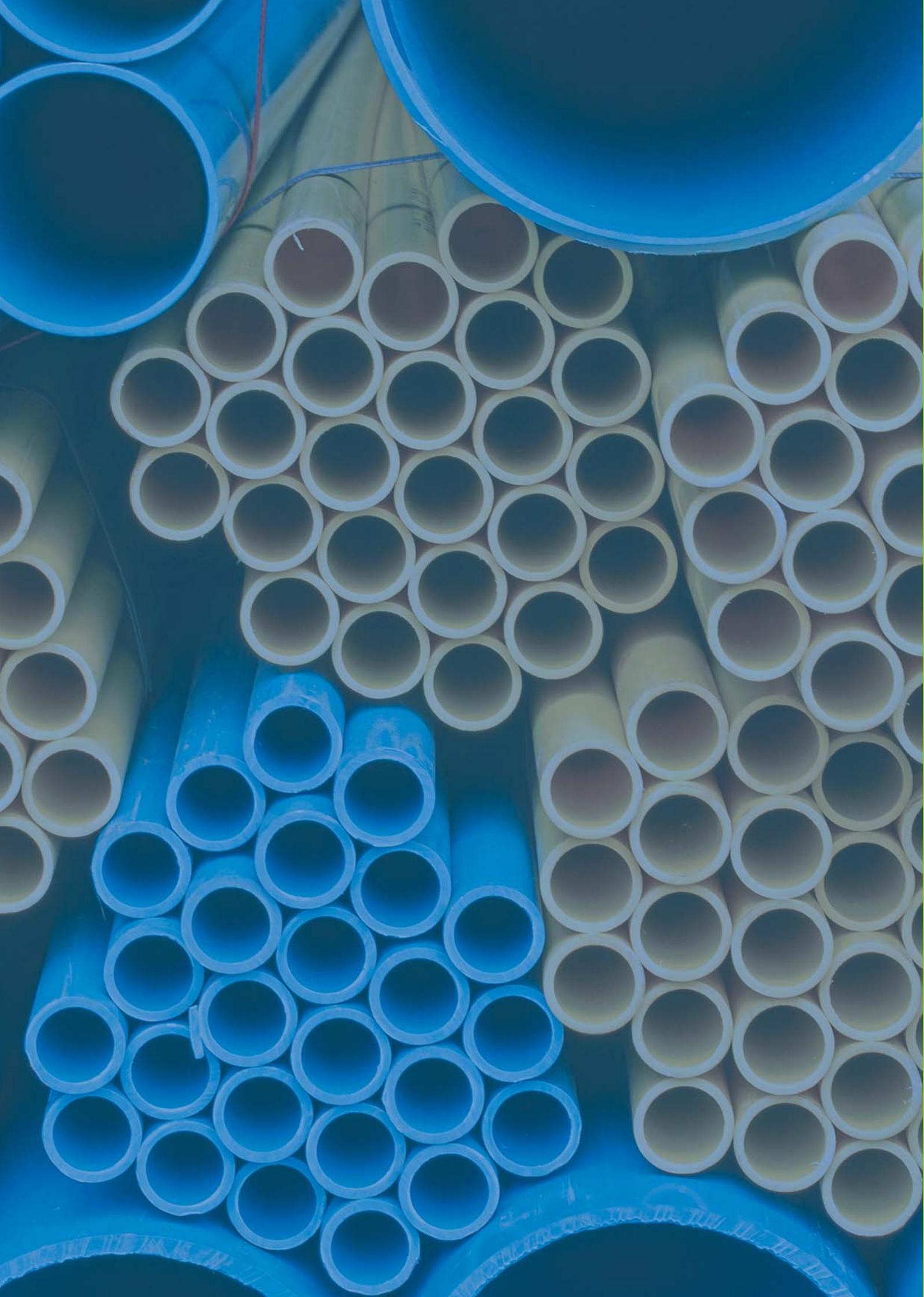


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Introduction



VinylPlus is the 10-year Voluntary Commitment to sustainable development by the European PVC industry. The regional scope is the EU-28 plus Norway and Germany. One of the five sustainability challenges that are at the heart of the VinylPlus initiative is the challenge of controlled-loop management: the more efficient use and control of PVC throughout its life cycle.

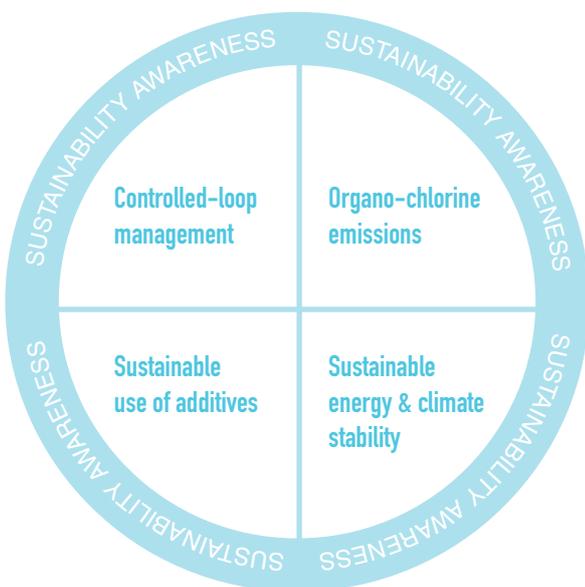
A key element of this challenge is the development and promotion of innovative recycling to further extend the scope and efficiency of PVC recycling in the European market.

Building on learning from 12 years' experience in recycling, including the Vinyl 2010 voluntary commitment to sustainable development, VinylPlus is using the lessons learnt and acquiring new knowledge to embed sustainable development across the PVC industry in Europe.

This brochure outlines the context and opportunities for recycling in Europe, as well as some of the challenges and solutions for extending the recycling of waste PVC. The emphasis is on the emerging PVC recycling technologies that can access the 'more difficult to recycle' waste streams.

VinylPlus has the challenging target of recycling 800 000 tonnes/year of PVC annually by 2020. One or more of the technologies described here must play an essential role in achieving this ambitious target.

www.vinylplus.eu/documents/42/68/New-Progress-Report-2016



VinylPlus in a nutshell. Based on The Natural Step System Conditions for a Sustainable Society.



PVC: popular,
sustainable, recyclable



PVC (polyvinyl chloride) is one of the most widely used polymers in the world.

The polymer was one of the first modern plastic materials to be discovered. Although first synthesised in the laboratory in the 19th century, commercial development of the polymer commenced in the mid-1920s and saw a dramatic growth during the 1950s.

Today, about 37 million tonnes of PVC is produced worldwide, of which around 5.5 million tonnes is made in Europe – making PVC Europe’s third most popular plastic.

The European PVC industry, from polymer suppliers to product manufacturers, employs around half a million people in some 21 000 companies from large corporations to small family businesses.

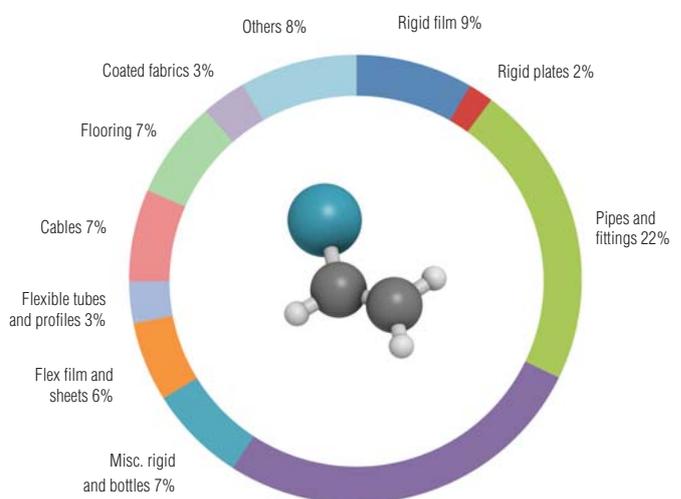
Diverse applications

Due to its versatile nature, PVC has found applications across a broad range of industrial, technical and household uses.

In Europe, around two-thirds of PVC produced is used in building applications such as PVC window frames and other ‘profile’ applications, pipes and fittings, flooring, electric cables and conduits, a variety of plastic linings, membranes and waterproofing applications, and in coated fabrics.

PVC (polyvinyl chloride) is one of the most widely used polymers in the world

Other important applications include packaging blisters, trays and films, the automotive sector which uses materials for vehicle interior and exterior trims, a wide range of furniture, leisure and rainwear, and medical devices.



PVC by application in the EU, 2015

VinylPlus, 2015



A sustainable polymer...

PVC has inherent sustainability characteristics. It is made from common rock salt (57%) and hydrocarbons from oil (43%) making it far less oil dependent (with a lower carbon footprint) than other major thermoplastics. It is highly durable and energy efficient across a range of applications and is also highly resource efficient.

PVC has inherent sustainability characteristics

And PVC is a recyclable material. The European industry has been working very hard to boost collection of PVC waste and to optimise recycling technologies. The goal is to minimise waste and energy use while boosting the percentage of recyclate in new products.

A study completed in 2011 on behalf of the Directorate General – Environment, European Commission, estimated the amount of construction/demolition waste to be around 460 million tonnes in 2005. Plastics waste accounted for less than 2% of this waste. Since the amount of PVC waste available in 2013 was estimated by Consultic to be less than 2.5 million tonnes, PVC represented less than 0.4 % of the total amount of construction waste.

... with sustainable uses

PVC is highly versatile. Compared to other materials, it offers the possibility to change formulation parameters to improve the safety and eco-efficiency characteristics of the final product without compromising technical performance.

The wide range of formulation possibilities is also useful in enabling the reuse and recycling of PVC into new products, without loss of performance. Re-use boosts the sustainability characteristics of PVC products – recycled PVC yields significant energy savings during production and reduces process emissions.

It also plays a major role in delivering and sustaining the quality, comfort and safety of modern lifestyles. PVC products help to improve people's lives and conserve natural resources in a world where the growing population requires safe water, food, shelter, sanitation, energy, health services and economic security.

PVC is an essential, durable material to enable these vital services. In addition, it has a minimal environmental load in terms of CO₂ emissions when compared with metal or glass products in the same applications.

PVC products contribute significantly to energy efficiency through low thermal conductivity.

Similarly, PVC products contribute significantly to energy efficiency through low thermal conductivity. PVC window profiles have three times the heat insulation efficiency of aluminium profiles, increasing the energy efficiency of our homes and workplaces while maintaining our comfort.

The PVC industry has a comprehensive understanding of its product's sustainability characteristics and is working systematically to ensure that the polymer will continue to play a useful role in enabling a more sustainable future for humanity and clearly demonstrating a circular economy.



Why recycle?



The European PVC production and converting value chain takes corporate social responsibility very seriously and has been working hard since the mid-1990s to ensure that the sustainability challenges posed by PVC are tackled.

Recycling PVC has the following benefits:

- PVC is well suited to recycling: it has the longest history of recycling of all plastics;
- PVC has advanced mechanical recycling systems;
- Large volumes of recyclable PVC waste are available;
- Using recycled PVC helps meet resource-efficiency objectives and allows for the preservation of raw materials;
- Using recycled PVC reduces emission and landfill requirements.

Manufacturing window profiles with 70% recycled PVC rather than all new PVC reveals savings of up to 50% in energy, over 60% in air emissions and more than 60% in water emissions.¹

In addition, due to its thermoplastic nature, PVC can be recycled several times without significant loss of performance.



Recycling success

Over the past ten years or more, the European PVC industry has strived to increase the recycling of PVC. Under the initial Vinyl 2010 initiative – and now under VinylPlus – rates of PVC recycling have grown enormously.

Vinyl 2010's main recycling objective was to increase recycling of post-consumer PVC waste for non-regulated applications (i.e. not packaging, electric and electronics waste or waste from the automotive sector). This meant that most of the waste came from the building sector and demolition.

The Vinyl 2010 initiative was very successful in beating its target for recycling 200 000 tonnes of waste PVC per annum in 2010 by a considerable margin.

> Repeatable recycling

PVC can be recycled several times depending on the application, because the recycling process does not measurably decrease the chain length of PVC molecules. This has been proven by tests performed on PVC pipes.

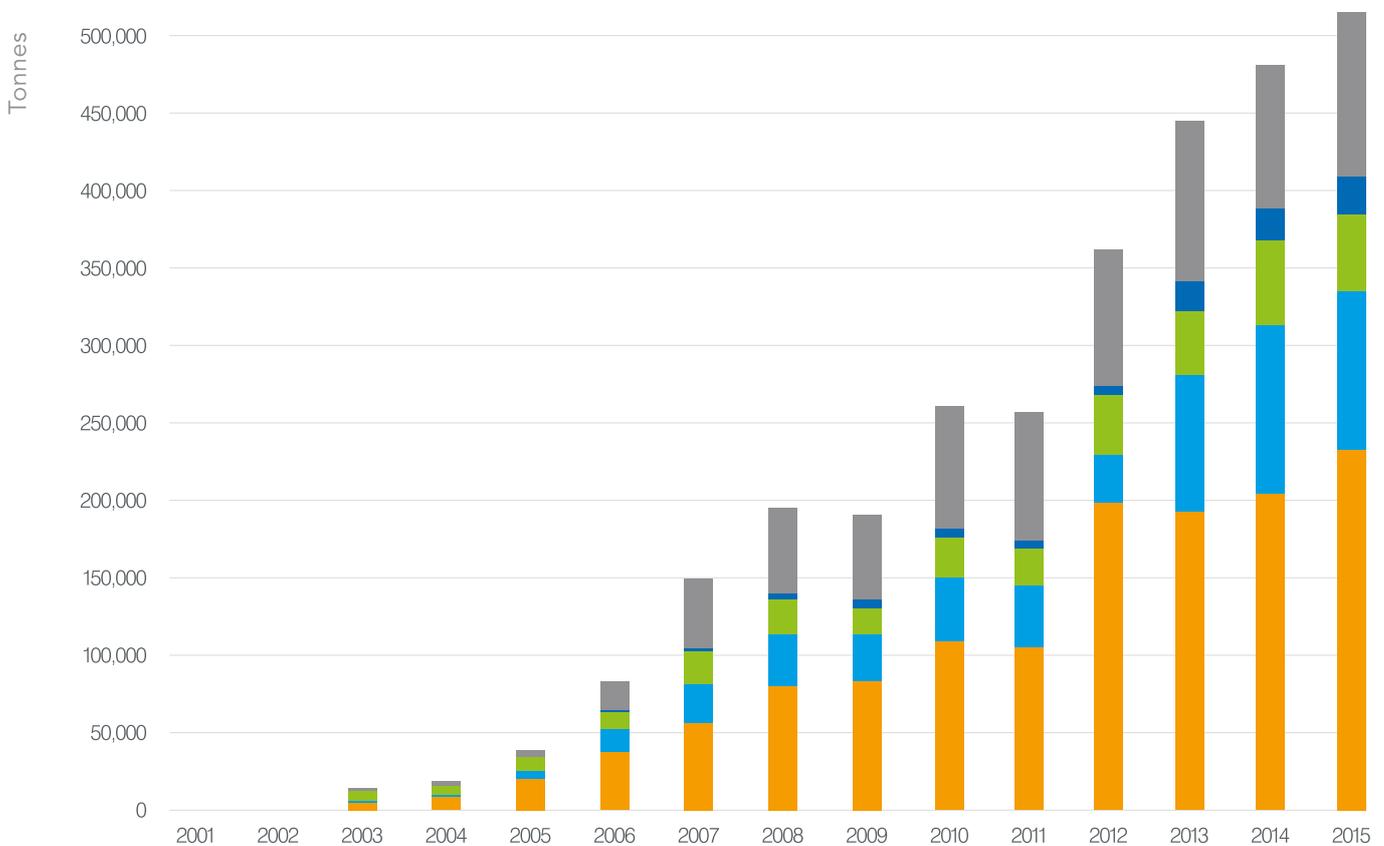
¹ www.pvcinfo.be/bestanden/Hermes%20Study%20-%20PVC%20windows-English.pdf

Where does recycled PVC come from?

Under VinylPlus, a new annual recycling target of 800 000 tonnes/year has been set for 2020. In 2015, using a new agreed unified definition of recycled PVC (see graph below), 514,913 tonnes were recycled in Europe within the VinylPlus framework.

In the graph below, the sources of PVC for recycling are analysed. It can be seen that the majority of recycled PVC comes from window profiles and other related building products.

PVC recycled within the Vinyl 2010 and VinylPlus Frameworks



- Cables
- Rigid PVC films
- Pipes & fittings
- Flexible PVC applications (including roofing and waterproofing membranes, flooring and coated fabrics)
- Window profiles & related products

Total in 2015
514 913
 tonnes recycled

Other significant contributions are made by pipes and fittings, cables, and flexible PVC applications, including roofing and waterproof membranes, flooring and coated fabrics.

Rigid PVC composite films from industrial waste also made a contribution of 10 850 tonnes in 2015.

Estimates for PVC waste availability in Europe in 2020 show that considerable amounts of waste will be generated. Up to 2.9 million tonnes may be defined as available waste (see page 15), with the total amount of available waste from building applications being around 1 million tonnes.

The 800 000-tonne/year recycling target for 2020 is indeed challenging. This requires, among others, developing and exploiting innovative technologies to recycle 'difficult-to-recycle' PVC material, such as composite materials and materials from mixed waste streams.

The total amount of available waste from building applications is around 1 million tonnes

The ability to access more difficult waste streams will become increasingly important as conventional recycling schemes reach the limits of the easily recyclable waste. Much of the available waste is in more complex waste streams and requires more advanced processing to yield reusable products.



> More and more recycling plants

There are currently more than 100 operations in Europe which recycle PVC pipes, profiles, flooring, coated fabrics and membranes. The European PVC industry is committed to further increase this number.



End-of-life options

End-of-life treatments for PVC currently encompass three common options:

- **Landfill** – PVC products that are deposited in landfill pose no long-term problems for human health or the environment. However, they do represent loss of a valuable material resource which, from a sustainable development point of view, is not acceptable. Many countries have already banned landfilling of untreated organic wastes (e.g. Germany) or are planning to do so.
- **Incineration with energy recovery**
– PVC has a heat value of approximately 19 megajoules per kilogram (MJ/kg), which is similar to brown coal, and higher than the average heat value of municipal waste (11 MJ/kg) used to generate electricity.

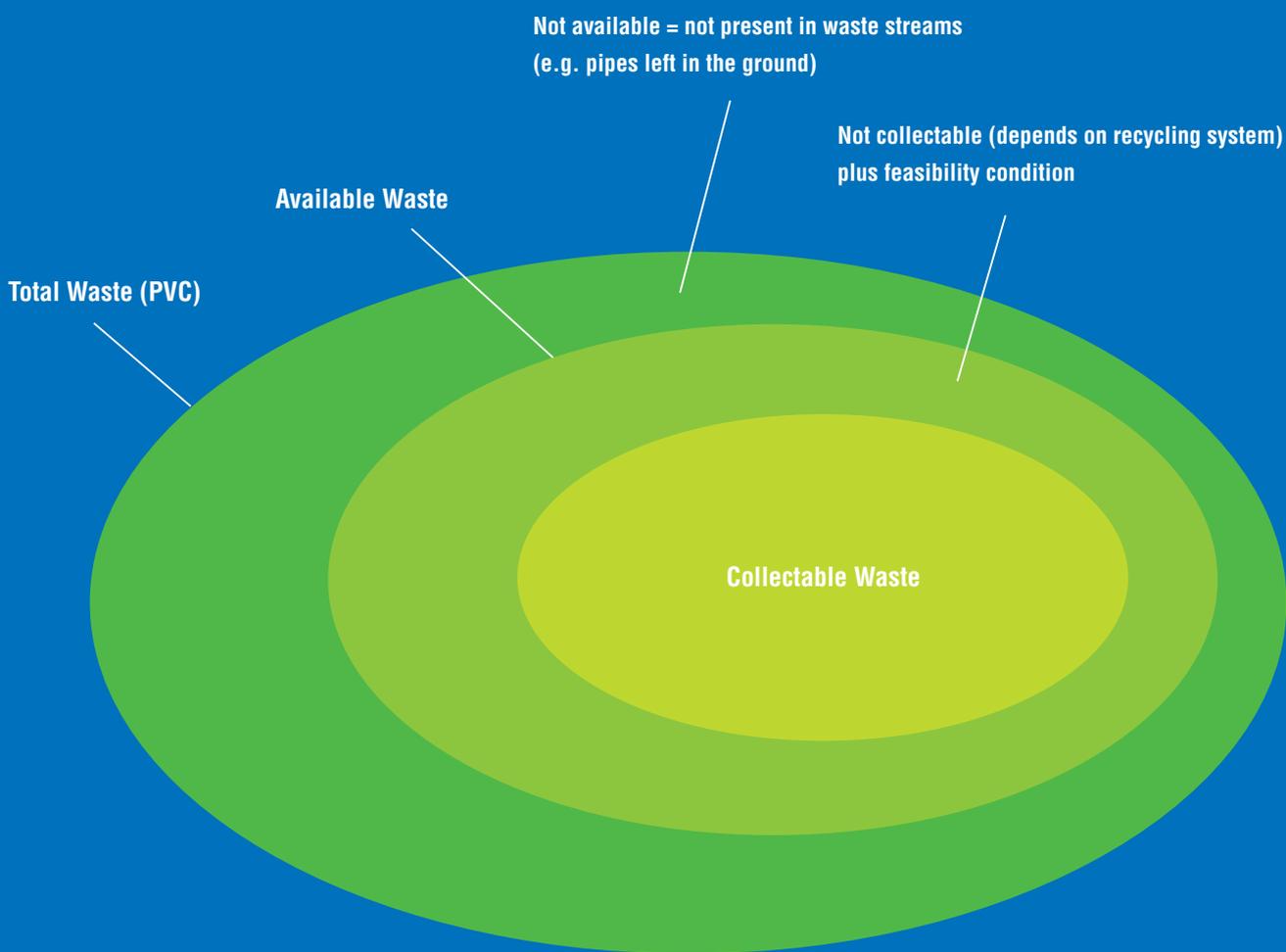
Therefore, it can make a useful contribution as a fuel for power generation through waste incineration.
- **Mechanical recycling** – This option has been used in PVC production and processing for many decades. The largest proportion of unmixed PVC waste flows directly back into production and the PVC industry has developed a number of initiatives for the recovery of post-consumer waste that are well established in the market.



> Recycled PVC defined

There has been some variation in how 'recycled PVC' is defined by different industry sectors. VinylPlus has agreed an updated definition, as follows:

"Recycled PVC is a discarded PVC product, or semi-finished product, that is diverted from waste for use within a new product; processing waste is included provided it cannot be reused in the same process that generated the waste."



Regulatory issues



With a view to enforce legal requirements to protect the environment, the European Commission aims to restrict incineration and landfilling of plastics in Europe through a Green Paper on Plastics Waste. Whilst recycling is the favoured option, issues related to legacy additives in long-lasting applications are still being addressed.

Regulatory framework

From a regulatory point of view, the main driver for improving sustainability within the European Union has been the Waste Framework Directive (EU Directive 2008/98/EC) and subsequent amendments. Other European Directives impact specific sectors, such as the European Directives on End-of-Life Vehicles, Packaging and Waste Electric and Electronic Equipment (WEEE), and comprise 'regulated' recyclable materials waste.

In addition, many Member States restrict disposal of plastics in landfill through national regulation.

Legacy additives

Legacy substances are substances which were fully within the legal framework in the past, but are no longer used in the production of new PVC products. Most have been or are being replaced by alternatives on a voluntary basis, but may still be found in recycled PVC from long lasting applications. Among these, some stabilisers and plasticisers are subject to regulatory constraints.



Waste hierarchy according to the waste framework directive

In the past PVC converters used small quantities of heavy metal-based additives (lead and cadmium): stabilisers to protect their products from thermal degradation and also pigments. The PVC industry has substituted cadmium and lead-based stabilisers from all virgin PVC products.

Alternative stabiliser systems include, in particular, calcium-based formulations; PVC compounds containing these stabilisers now account for the majority of the European market.

Plasticisers, on the other hand, include substances such as low-molecular-weight phthalates. VinylPlus is working with the wider industry and the regulatory authorities to address this issue.

The industry has moved to replace low-molecular-phthalates with plasticisers which

are not substances of very high concern under Reach, and are subject to restricted use by certain European Commission regulations, in particular with regard to children's toys and feeding equipment.

> Do legacy additives leach out from PVC?

Independent studies have shown that products such as pipes and profiles, which contain recyclate as part of the industries' drive for sustainability, do not leach out legacy substances. These substances are firmly embedded in the PVC polymer matrix.

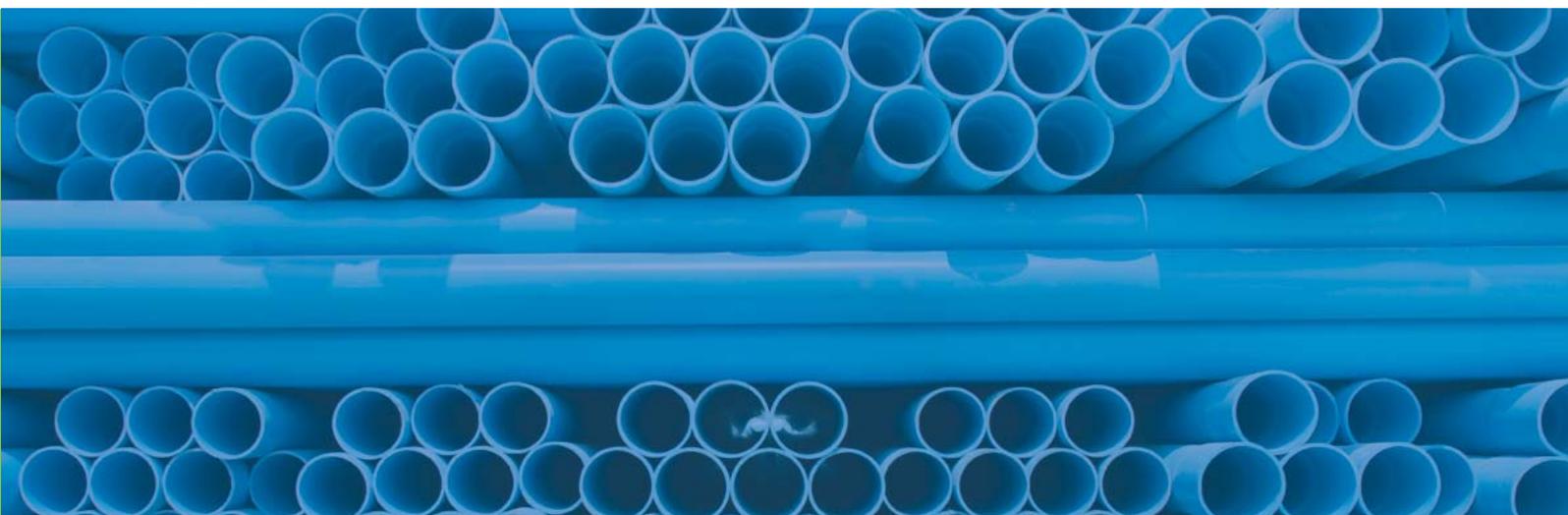


Recycling issues

Recycled waste streams may contain cadmium. The placing on the market of polymers containing cadmium is restricted by an amendment (Regulation 494/2011 of 20 May 2011) of Annex XVII of the REACH Regulation. This amendment allows a higher cadmium content in rigid construction products if the cadmium originates from recycling.

The industry is working with the regulatory authorities to ensure that recycling activities

remain sustainable while complying with the regulatory regime. An online database of polymers and applications has been developed to support PVC recyclers to comply with the European REACH Regulation requirements. This tool enables recyclers to access the necessary 'Safety Data Sheets for Recyclers' (www.sdsrtool.com) and published guidance documents.



> How reliable are PVC recyclates?

The industry ensures that the quality and durability of products with recyclate are the same as that of new PVC polymer. Pipes and profiles with recyclate can be recycled more than eight times, making PVC very sustainable with a life time of hundreds of years.



Recyclates from swimming pool membranes

Recovinyl: collect and certify



Established in 2003, Recovinyl is an initiative by the European PVC value chain aimed at facilitating PVC waste collection and recycling under the Voluntary Commitments of Vinyl 2010 and now VinylPlus.

The organisation has been successful in achieving all of its goals, most notably the huge increase in PVC recycling across Europe during its ten years in operation. In 2011, the PVC industry redefined the role of Recovinyl as part of the new VinylPlus programme.

Today, the Recovinyl organisation stretches beyond simply ensuring that the volumes of PVC being recycled each year increase. The organisation's mission now extends to optimising the resource efficiency of the PVC industry by linking recyclers and converters to establish a trustworthy relationship and material flow based on a recycled PVC material (recyclate) certification system.

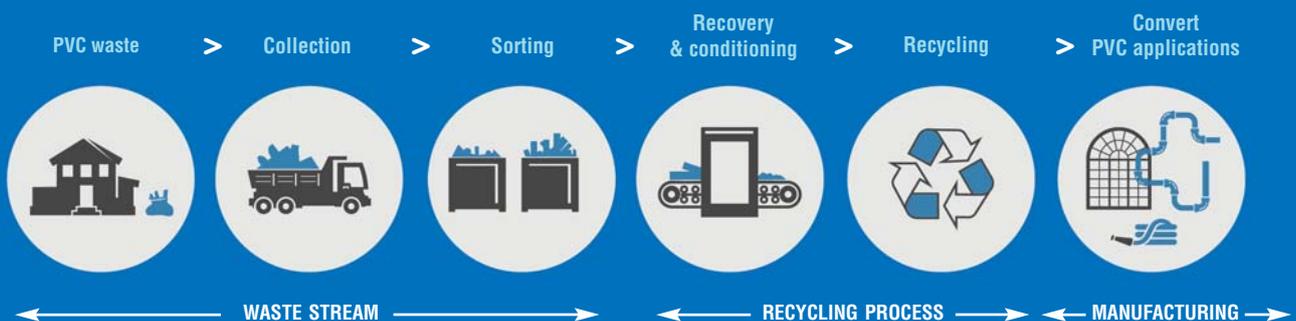
Recovinyl's mission now extends to optimising the resource efficiency of the PVC industry by mediating between recyclers and converters

Its target is to stimulate and certify the use of 800000 tonnes/year of recycled PVC by 2020 as one of the challenges set in the VinylPlus Voluntary Commitment.

Having already established significant volumes of PVC recycling, Recovinyl's new strategy is to consolidate and increase the steady supply of post-consumer and post-industrial PVC waste being recycled in Europe by creating a demand for recycled PVC material from the converting industry. This is known as the "Pull Market Concept".

Recovinyl works in partnership with consumers, businesses, municipalities, waste-management companies, recyclers and converters, as well as the European Commission and national and local governments. The goal is to certify those companies which recycle PVC waste and those accredited converting companies that purchase recyclate from which to manufacture new products and applications.

In 2015, of the 514,913 tonnes of PVC recycled in Europe, the overwhelming majority was registered and certified by Recovinyl using the new accounting system.



PVC recycling methods

A conceptual image showing a grey asphalt road that splits into two paths, forming a Y-shape. The road is set in a lush green field under a clear blue sky with scattered white clouds. Two green rectangular signs with white borders stand on the road. The sign on the left is labeled 'MECHANICAL' and the sign on the right is labeled 'FEEDSTOCK'.

MECHANICAL

FEEDSTOCK

Executive summary

Mechanical and Feedstock recycling are the two existing options for recycling plastic waste. Whilst the first process does not break polymer molecules into small components and requires strict sorting methods, the second usually involves the thermal treatment of the plastic waste stream and is more suitable for unsorted plastic mixtures and composite materials.

Mechanical recycling has been used in Europe for decades. It encompasses two kinds of processes, generally referred to as “conventional” and “non-conventional” technologies. Conventional technologies consist in sorting and shredding separate components within the waste streams, whereas non-conventional technologies precede these steps with a chemical processing or pre-processing in order to remove all non-PVC waste from more complex or contaminated waste streams. In both cases, the excellent thermoplastic nature of PVC enables it to be recycled many times before it loses its technical performance.

Feedstock recycling, on the other hand, recovers the carbon contained in PVC waste from materials that are too complex to be mechanically recycled such as composites. This carbon is then used as feedstock for the production of chemicals. Such processes also yield hydrochloric acid, which is sometimes recycled as such or as calcium chloride. Feedstock recycling encompasses three sorts of processes: gasification, pyrolysis and dehydrochlorination.

The growing complexity of waste streams means both of these methods need constant innovation to keep up with the sustainability challenge, whereas the waste that is not economically and environmentally sustainable to recycle can be incinerated with methods allowing for energy recovery.

There are various methods being used in Europe, and others are being developed.

Mechanical recycling technologies

Improving mechanical recycling can be done in four different manners.

- **A better waste separation**, which is being investigated by [NeidHardt Recycling \(p.28\)](#) (Aluminium-PVC composites), [R-Inversatech \(p.30\)](#) (high speed beating technique), [Jutta Hoser \(p.30\)](#) (production of plastic mats for greenhouse flooring from films and coated fabrics), [Caretta \(p.31\)](#) (shredding and granulation) and [Texyloop® \(p.31\)](#), which requires the dissolving of PVC to separate it from other waste streams.
- **A better treatment of mixed PVC waste** (Conventional mechanical recycling with special features). Solutions being investigated include [AgPR's](#) cryogenic grinding recycling plant [\(p.32\)](#) in Germany and [Rubber Research Elastomerics'](#) technology to mix PVC waste with shredded tyre scrap [\(p.32\)](#).
- The production of **composite recyclates** such as [light concrete \(p.33\)](#) and [composites of PVC and natural materials \(p.33\)](#).
- The **improved recycling of complex waste streams**, which includes [Solvay's VinyLoop \(p.34\)](#) (dissolution, filtration and separation of contaminants).

Feedstock recycling technologies

New technologies are being investigated under two of the three main feedstock recycling processes.

- **Sumitomo Metals (p.36)**, and the **Ebara process (p.37)** are all betting on **gasification** – a high-temperature reaction with restricted amounts of air, oxygen or steam that converts PVC into syngas and carbon dioxide. To this aim, Sumitomo uses iron-making and steel-making technologies to generate a high-energy syngas stream. The Ebara process turns solid residues into a stable granulated slag that can be recycled.
- **Dehydrochlorination** can be done in water or in ionic liquids. The first option is being used under the **Redop process (p.38)**, before it co-injects the resulting product with coal in a furnace in order to produce pig iron, and by **Alzchem (p.39)** which aims to eliminate as much chlorine as possible from the plastics waste with an upstream extruder, before it enters the reactor. A process investigated by the **KU Leuven (p.39)** in Belgium, on the other hand, favours dehydrochlorination in ionic liquid media. The latter allows for the evacuation of the HCl while preventing salt formation.

Incineration with energy recovery and material recycling

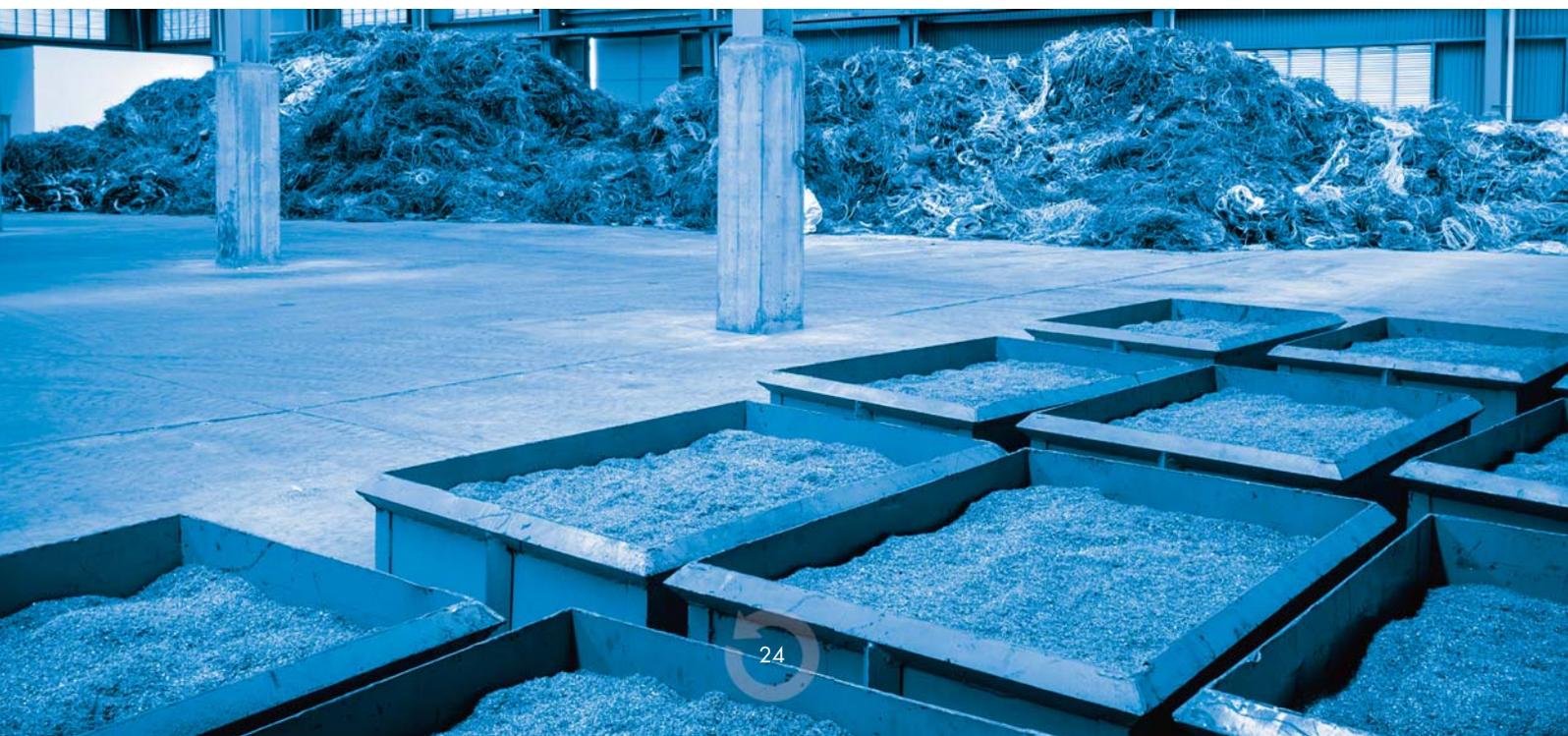
HCl and salt recovery in incineration processes can enable the recycling of part of the waste stream. **SUEZ (p.40)** has used a rotary kiln since 1999 to recover HCl and energy from the likes of PVC waste, contaminated oil, bio-sludge and hazardous solids containing chlorinated substances. This plant has been recently taken over by SUEZ.

MVR (p.41) in Germany was designed to recover HCl from 320000 tonnes of waste per year as a 30% aqueous solution, the purity of which makes it suitable for the chemical sector.

The acid gases generated by incineration of PVC are neutralised by sodium bicarbonate. The obtained sodium chloride is purified and replaces mined sodium chloride to produce sodium carbonate.

HALOSEP® (p.41) and **the SOLVAir® (p.41)**, on the other hand, allow for salt recovery. The first process results in calcium chlorine brine and reduces the amount of neutralisation waste that must be disposed of in landfills, while the second allows for recycling and reusing the sodium bicarbonate used for neutralising gases from the incinerator while reducing the levels of residues resulting from this process.

This section describes each of the above-mentioned technologies in more detail, including their functioning, strengths and possible weaknesses.



PVC recycling: what are the options?

With increasing regulatory pressure to minimise disposal of plastics in landfill, and the obvious desire of the industry to implement sustainable development, improving the scope of recycling technologies for PVC is important. There are two main options for the recycling of PVC waste: **mechanical recycling** and **feedstock recycling**.

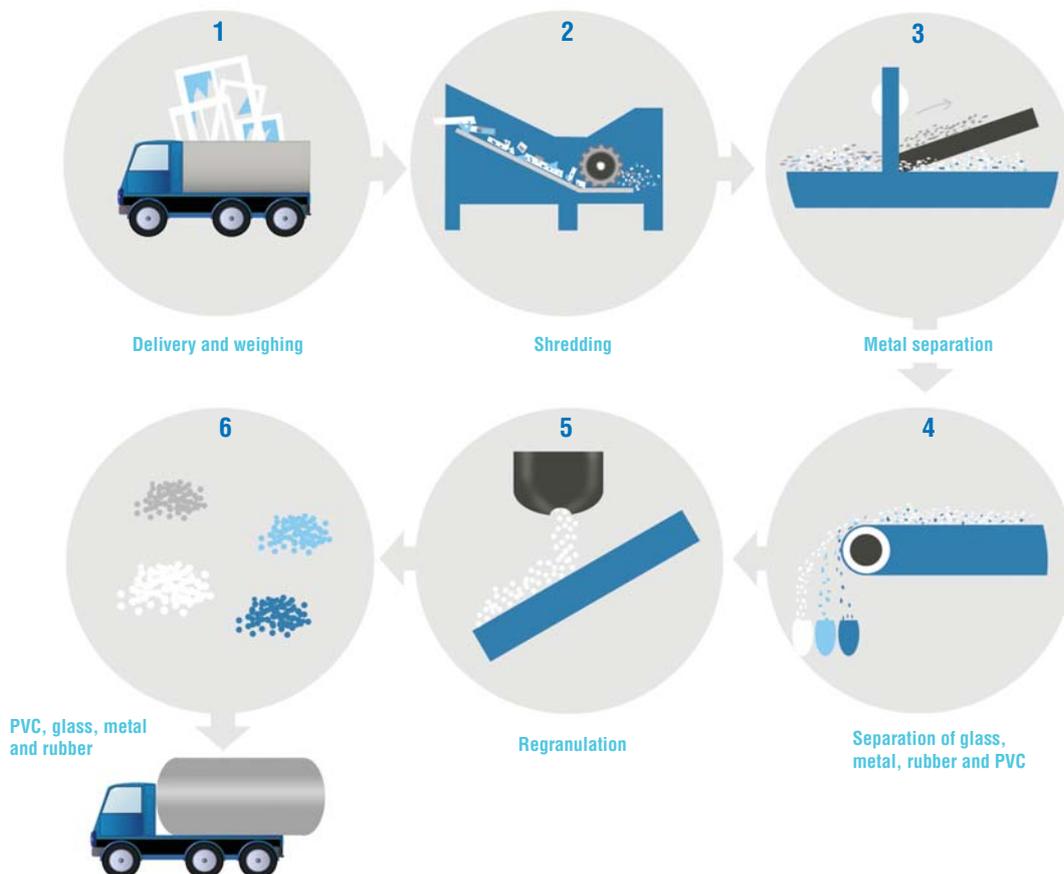
Mechanical recycling

Mechanical recycling covers processes which do not break polymer chains into small components. It is well suited to pre-sorted, single waste-stream waste. Within the mechanical recycling category, two subcategories are defined: conventional and non-conventional technologies.

Conventional technologies describe long-established processes which usually sort, shred

and separate components within the waste stream resulting in pulverised or granulated recycled PVC that can be used in the manufacture of new products.

Non-conventional technologies cover alternative processes that often use solvent based processes or pre-processing to access PVC from more difficult or complex waste streams. The VinylLoop® process is such an example (more details on pages 33-34).



Recycling of PVC windows

> Advantages of mechanical recycling

A waste stream containing a single type of waste or PVC product is the most convenient and straightforward for the recycling operation. It allows for the mechanical recycling of PVC, which essentially involves mechanical grinding of the waste material to produce a granular product that can then be used in the production of new PVC products.

Due to the excellent thermoplastic nature of PVC, it can be heated and moulded or extruded many times to form new products without loss of technical performance.

A degree of pre- or post-processing may be required to remove contaminants, depending on the nature of the original waste material.

> Increasingly complex waste streams

As recycling volumes increase, the available waste streams are likely to become more complex so new processes and technologies capable of successfully handling such waste are required.

VinylPlus is investigating a number of developments that could enhance the scope of conventional mechanical recycling, including:

- Novel or improved waste separation and detection systems such as
 - Sink/float techniques, using gravity, water, brine, or other dense media applied as a separating medium.
 - Idem, using centrifugal forces, as applied in centrifuges or hydrocyclone batteries.
 - Froth flotation, i.e. successive collection of distinct resins after adding collector oils.
 - Electrostatic separation, after corona charging, tribo-electric charging,
 - Optical identification, based on Mid-Infrared, Near-Infrared, Fourier Transformed Infrared, Ultraviolet, various Laser and X-Ray identification Techniques, followed by mechanical or pneumatic separation.
- Conventional mechanical recycling with special features.
- Inclusion of PVC waste within other materials.

Brief descriptions of some potential technologies in these areas are given from page 26 onwards in this document.



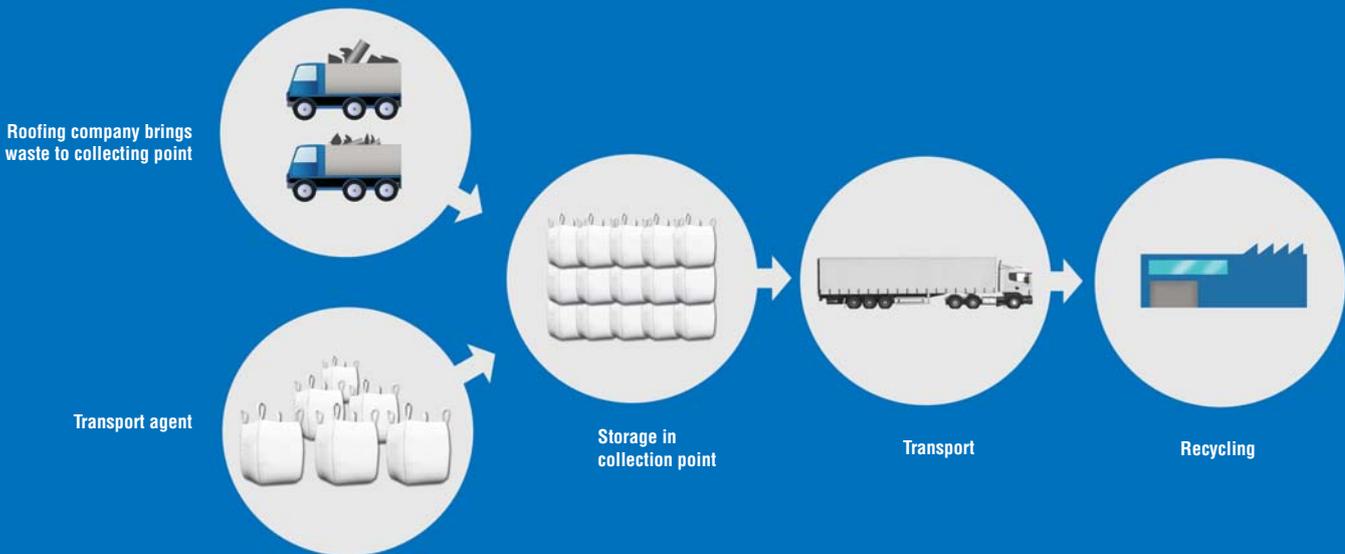
PVC window profiles are fully recyclable
Recycled material can be used in controlled loop

Feedstock recycling

Feedstock recycling is more suitable for unsorted plastic mixtures and waste streams containing composite materials. These processes involve (usually) thermal treatment of the PVC waste stream with recovery of hydrogen chloride that can then be returned to the PVC production process or used in other processes.

The hydrocarbon part of the PVC can be used to generate syngas (or synthesis gas – an industrially useful mixture of hydrogen and carbon monoxide) which can be used as a feedstock for chemicals production.

Recycling of PVC roofing



Recycling methods and technologies

Different PVC recycling techniques and technologies are currently available or are being developed. VinylPlus is focusing on these methods based on their potential for an economically sustainable recycling of “mixed and difficult” PVC waste.

Mechanical Recycling

The first aim of VinylPlus is to stimulate mechanical recycling, taking into account the quality of the waste collected and the requirements of further processing methods and of the final products. Existing methods are being

improved and novel ones developed across Europe in order to obtain:

- Better waste separation;
- Better treatment of mixed plastics waste;
- Composite recyclates;
- Improved recycling of complex waste streams.

Novel or improved waste separation

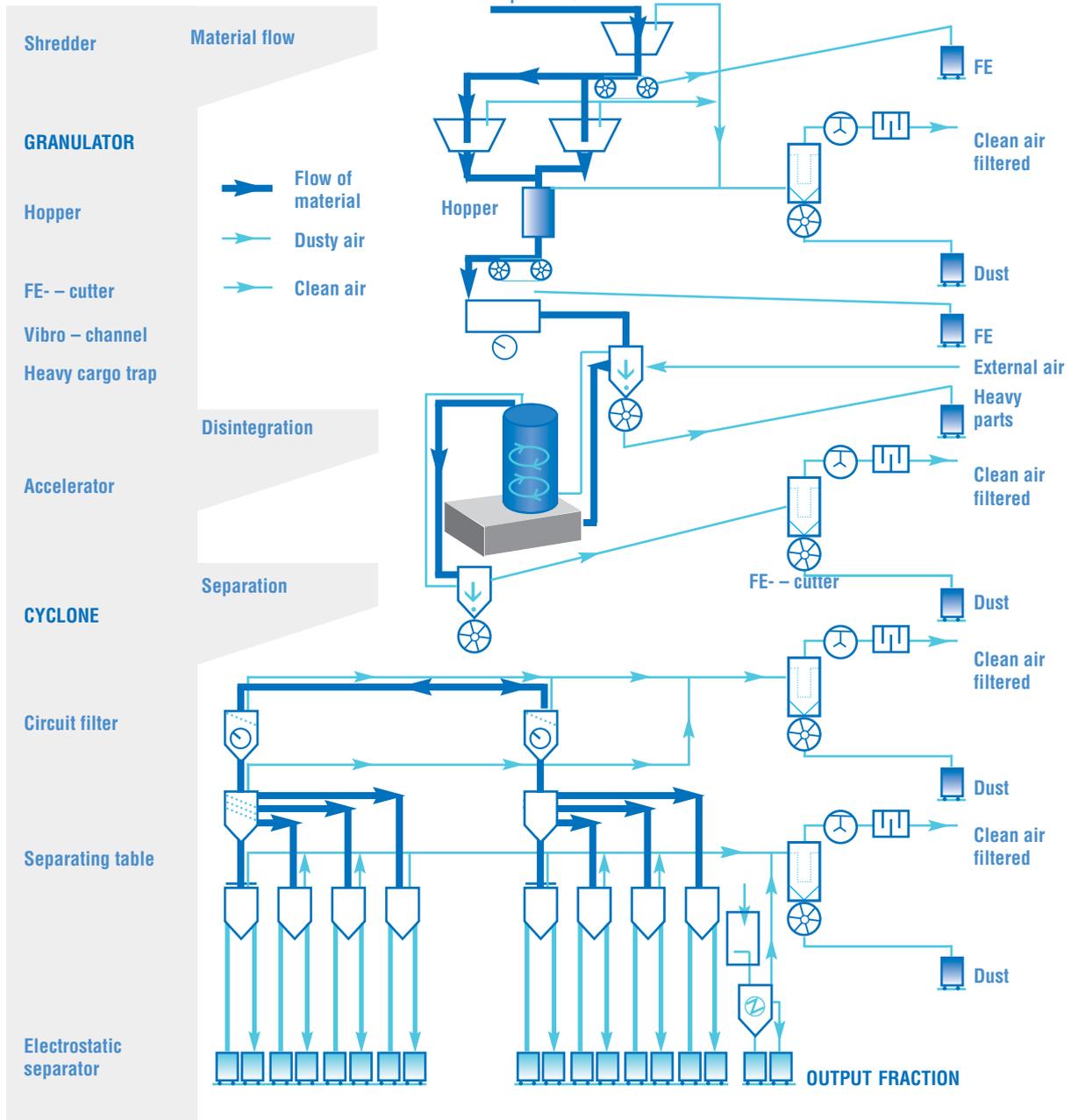
These techniques could separate a mixed or difficult waste stream into streams which can be handled by conventional mechanical recycling.

> Neidhardt Recycling GmbH

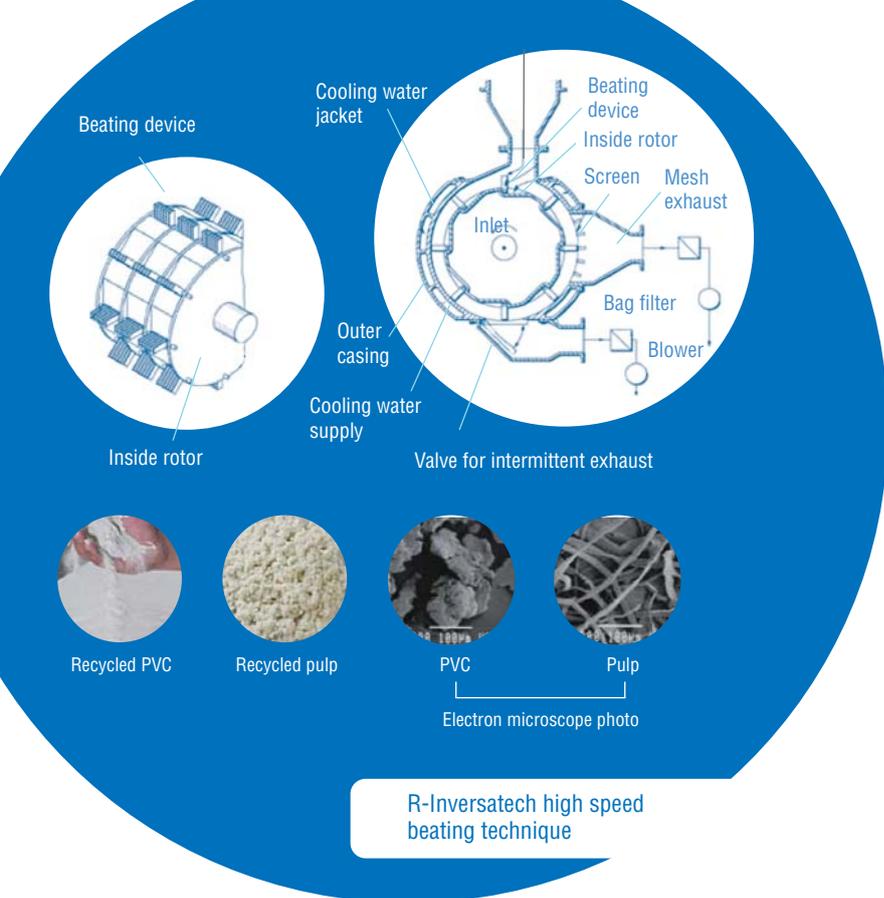
The input material is a PVC - aluminium composite used for blister packaging. The composite, which is supplied as a clean stream, is shredded down to 20 mm. The shredded waste is transported by a conveyor belt to the acceleration rotor and ends up in the air stream between rotor and stator. Aluminium and PVC are separated (delaminated) thanks to the high rotation speed. The process transforms the aluminium sheet into balls, whereas the PVC sheet remains flat.

The delaminated mixture is then sieved on 4 successive sieves, yielding fractions with well-defined granulometry of <0,5mm, 0, 5-0, 7mm, 0, 7-1, 0 mm. Aluminium and PVC are then separated by an electrostatic device. The PVC fraction is supplied to PVC converters manufacturing products such as pipes, separators, etc... The aluminium is also recycled into foundries or for special applications.

Result – process of reconditioning



Result separating technique



> R-Inversatech

This Japanese technology separates fibres from PVC in waste such as tarpaulins, using a high-speed beating technique. The fibres could find potential application in thermal and/or acoustic insulation. The other output is PVC recycle granulate for a broad range of flexible PVC applications.

> Jutta Hoser

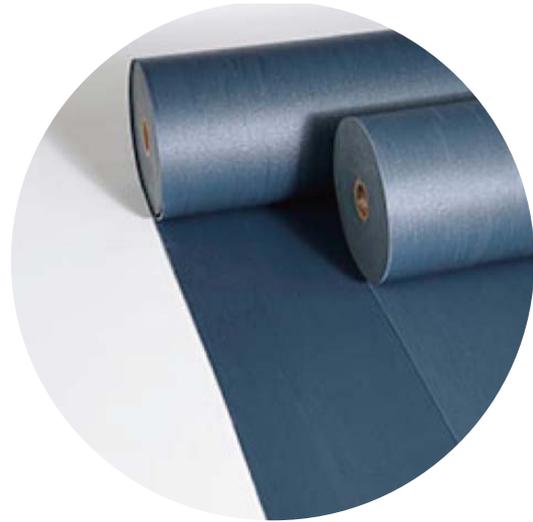
Jutta Hoser produces plastic mats for greenhouse flooring from recycled PVC composite films, plasticised films and coated fabrics. The mat has drainage holes allowing the plants to be watered from below. Once the process is complete, the water is drained away again leaving a clean work surface behind.

The heat insulation property of the mat offers a degree of protection against the plants freezing in their containers. The flooring is suitable for driving on with small machines and it is easy to clean.



> Caretta

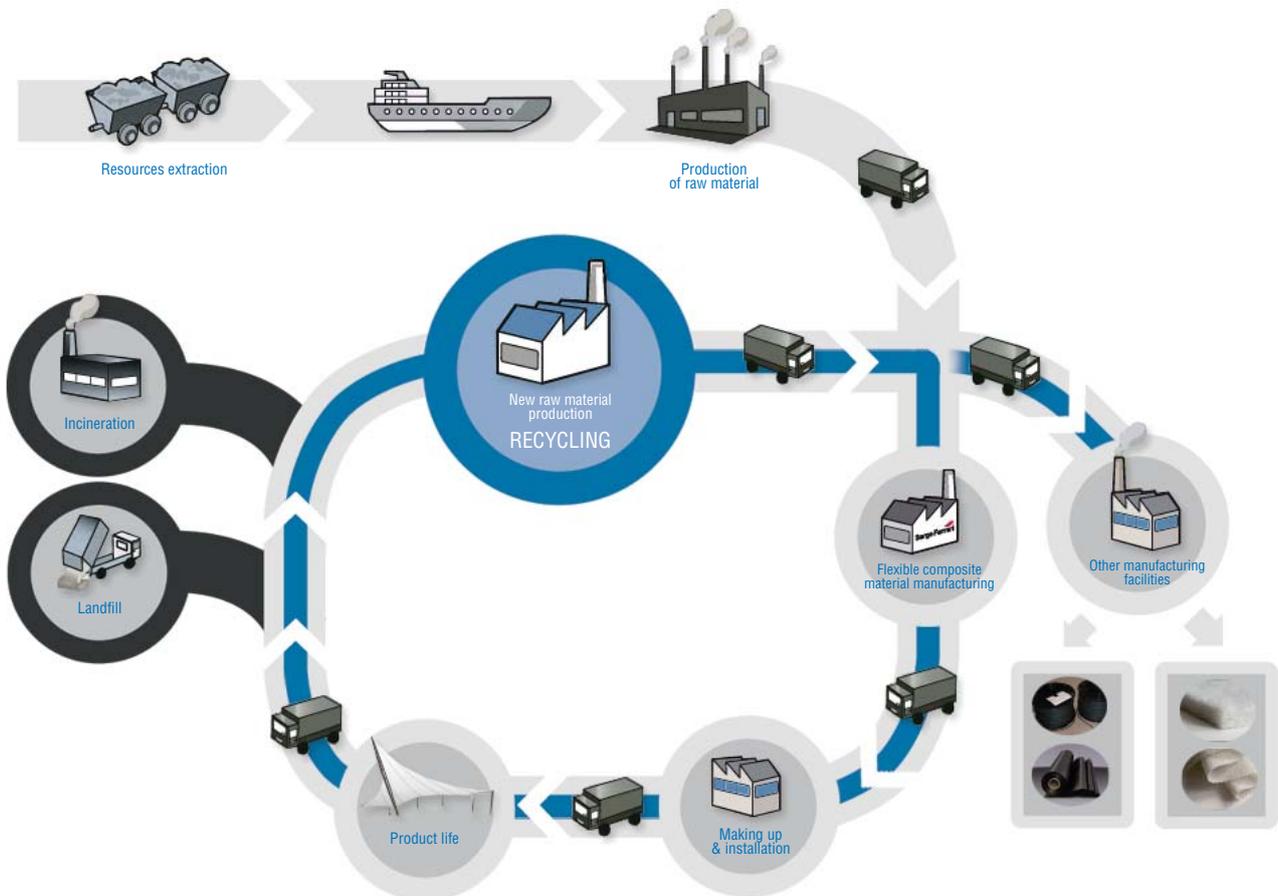
Hemawe/Caretta is a recycling company which has now installed its own recycling equipment in a plant near Erfurt, Germany. It has developed a technique for separating fabric and tissue, etc. from soft PVC foils. Recyclable materials clad with fleece, fabric or textiles are poured into a shredder and chopped into sections approximately 4-6 cm long. The shredded pieces are then granulated and sieved to separate the fibres. The PVC is used to manufacture damp-proof courses, sound-absorbing foils and soundproof mats for pipe insulation.



> Taxyloop®

This processing module is an extension to the VinyLoop plant (see below). It treats coated fabrics with the aim of recycling both the PVC and the polyester fibres. The VinyLoop section dissolves the PVC, allowing separation of the

fibres which are recovered in the Taxyloop module. The PVC is further processed in the VinyLoop plant. A 2000-tonne/year module is installed in the VinyLoop Ferrara plant in Italy.



The Taxyloop process

Conventional mechanical recycling with special features

This typifies mechanical recycling processes (i.e. the PVC chains are not broken down) with some added features.

Production of massive objects from mixed plastic waste: mixed plastic waste is processed by conventional techniques (e.g. extrusion, moulding) into thick-walled objects.

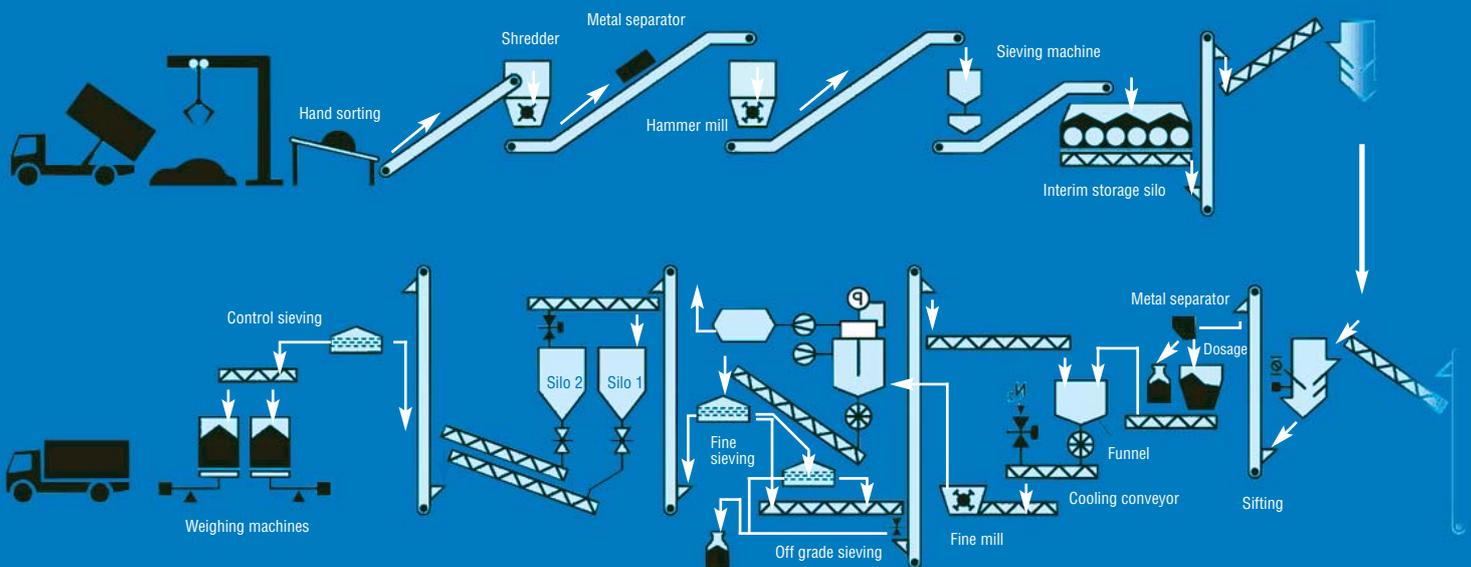
Thick walls are required because mixing a variety of plastics usually yields poor mechanical properties. Typical products are shoe soles and urban furniture (e.g. park benches), traffic controllers and signallers, etc.



> AgPR flooring recycling process

The AgPR cryogenic grinding recycling plant at Troisdorf (Germany) was built in 1993 and

production started in 1994. The theoretical production capacity is around 4000 tonnes/year.



The AgPR process

> Rubber Research Elastomerics

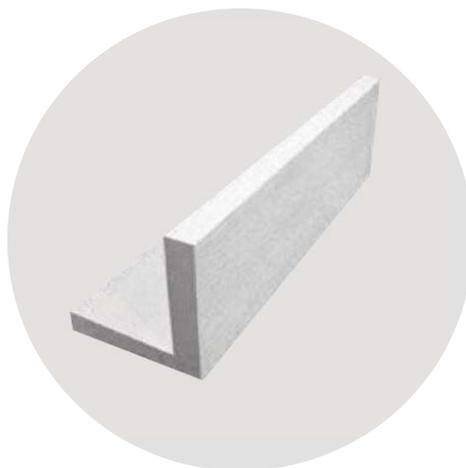
In the USA, this firm uses a patented technology to mix PVC waste (tarpaulins and cable scrap) with shredded tyre scrap combined with a rubber

compatibiliser. 50/50 blends produce harder products and could possibly be used to replace timber in certain construction applications.

Inclusion in other (non-plastic) materials

> Light concrete

PVC waste is mixed into concrete to decrease its density. Such 'light concrete' is currently manufactured using polystyrene. Applications include non-structural elements like roofs, insulation walls and slabs covering gutters. Trials with PVC waste were promising, although flexible waste failed to meet all the stringent migration tests. One advantage of this option is that it can be applied in several small plants.



> Composites of PVC and natural materials

Plastic-wood composites are gaining a share of the decking market. US firms are investigating other applications, for example structural wood lumber and cladding, and there are claims that some decking is manufactured from 95% recycled content, including reclaimed wood, sawdust and plastics. So far, the main plastics recycled in this application are PE and PP, although PVC has been tried, too.

The recycling consortium Resysta® (www.resysta.com/en), produces a wood-like material, based on rice husk and PVC, homogeneously connected in the polymer matrix.

Non-conventional mechanical recycling

Compared to conventional mechanical recycling, non-conventional mechanical recycling methods are often more complex and have been developed to tackle PVC products that are more difficult to recycle at end-of-life. These materials are often composite materials or too contaminated to be accessible to conventional recycling.

Examples of such waste streams include PVC cables where PVC could be contaminated with copper, or tarpaulins in which PVC is combined with polyester fibre.

Research in this area is very important for VinylPlus in order to achieve sustainable solutions to the

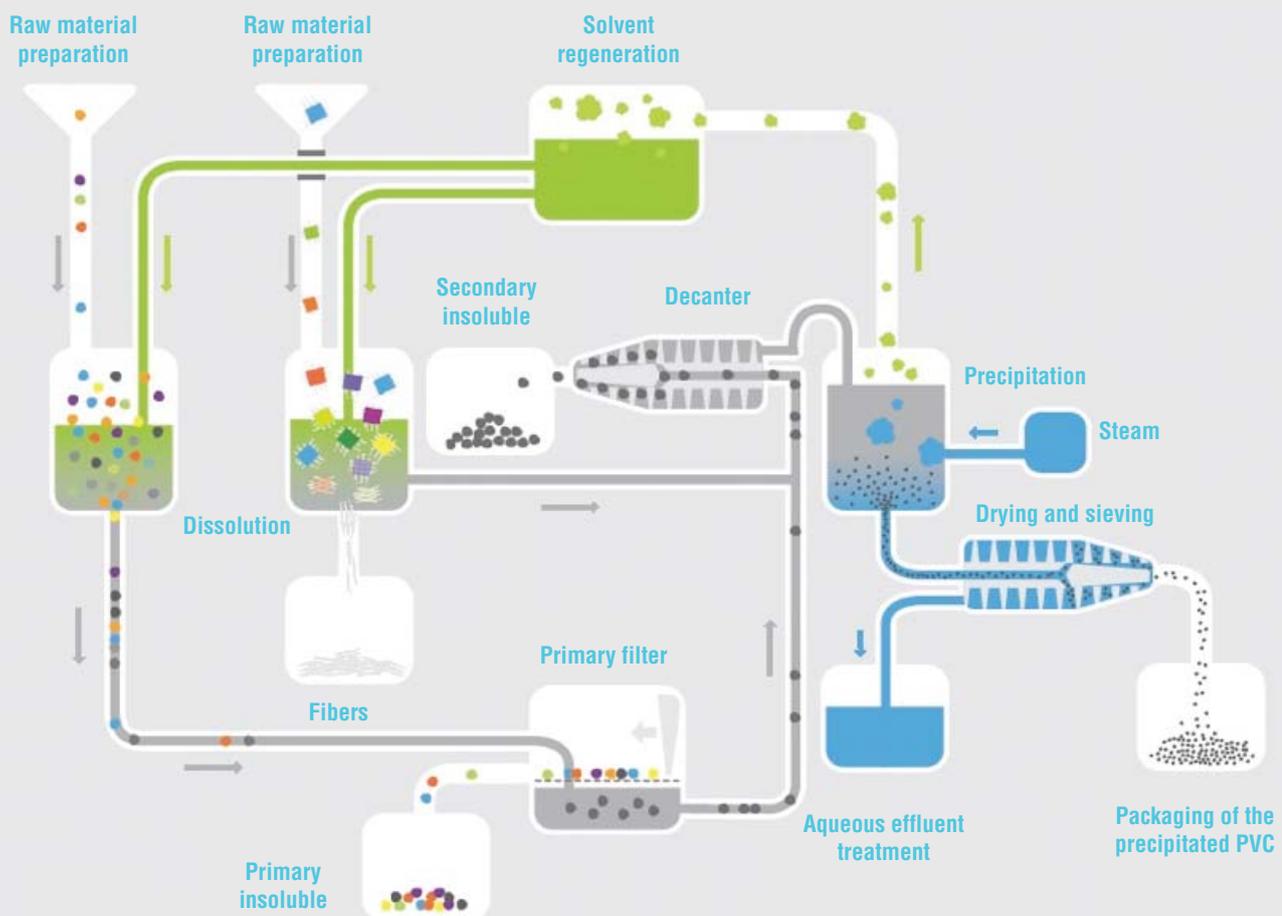
resource efficiency of these PVC composite waste materials.

The most promising technology in this area is undoubtedly VinylLoop®, which is a commercially developed process – see below. Other technologies, such as Poly-Tec, which consists in softening PVC before separating it, are at a relatively early stage of development.

Such processes are still, in effect, 'mechanical recycling' because the PVC molecules are not broken down, but the PVC is separated by processes similar to those used in the chemical industry.

> VinyLoop®

This is a patented process developed by the Solvay Group. The process separates PVC from other materials through a process of dissolution, filtration and separation of contaminants. A solvent is used in a closed loop to dissolve PVC from the waste. This makes it possible to recycle PVC waste from composite materials and recover the solvent, as shown below:



The Vinyloop process

The process comprises five principle steps:

1. Pretreatment

Waste plastics are cleaned, ground and mixed.

2. Dissolution

A specific solvent is used to selectively dissolve the PVC compound in a closed loop – the solvent is continuously regenerated.

3. Filtration and decanting

Impurities are not dissolved. They are separated by primary filtration followed by centrifugal decanting. After separation, the secondary materials are washed with pure solvent to dissolve all remaining PVC compounds.

4. Precipitation of the regenerated PVC

The PVC in solution is recovered in a precipitation tank, where steam is injected to evaporate the solvent and precipitate the PVC.

5. Drying

After recovering the excess water from the slurry, the wet PVC goes to a dryer.

The PVC compound precipitates as micro granules. Possible applications of recycled PVC include coatings for waterproof membranes, pond foils, shoe soles, hoses, diaphragm tunnels, coated fabrics, and PVC sheets. The fully operational commercial plant in Ferrara, Italy is able to handle 10 000 tonnes/year of PVC scrap.

Feedstock recycling

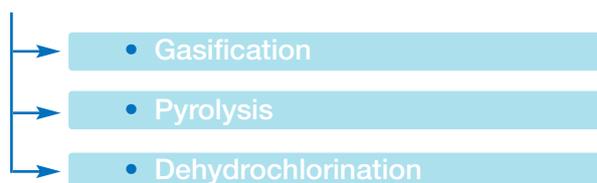
Feedstock recycling processes recover the carbon in PVC, in the form of low molecular weight species (or low molecular weight organic molecules) that can be used as feedstock for chemical processes. Some procedures may also recover hydrogen chloride (HCl) or a neutralised salt.

1. Gasification

Gasification is a high-temperature reaction with restricted amounts of air, oxygen or steam. Part of the PVC waste is converted into carbon dioxide, the rest to 'syngas' which is used to produce chemical feedstock such as methanol, ammonia, oxo-aldehydes, or for making fuels.

An advantage of this process is that the chlorine is almost entirely liberated as water-soluble HCl, which is easily scrubbed out and reclaimed.

There are three classes of process to consider, although there is some overlap between the categories:



Gasification has been successfully applied commercially in large plants processing coal (Sasol in South Africa) or mixed plastic waste, such as the Ebara Ube Industries Processes (EUP), Japan.

The process involves high pressure and a high temperature and therefore requires significant investments and a large scale to operate profitably.

> Sumitomo Metals, Japan

The Sumitomo process is a waste-gasification and secondary-ash melting system for plastic waste using iron-making and steel-making technologies. The process is able to treat both mixed plastics waste and pure PVC waste.

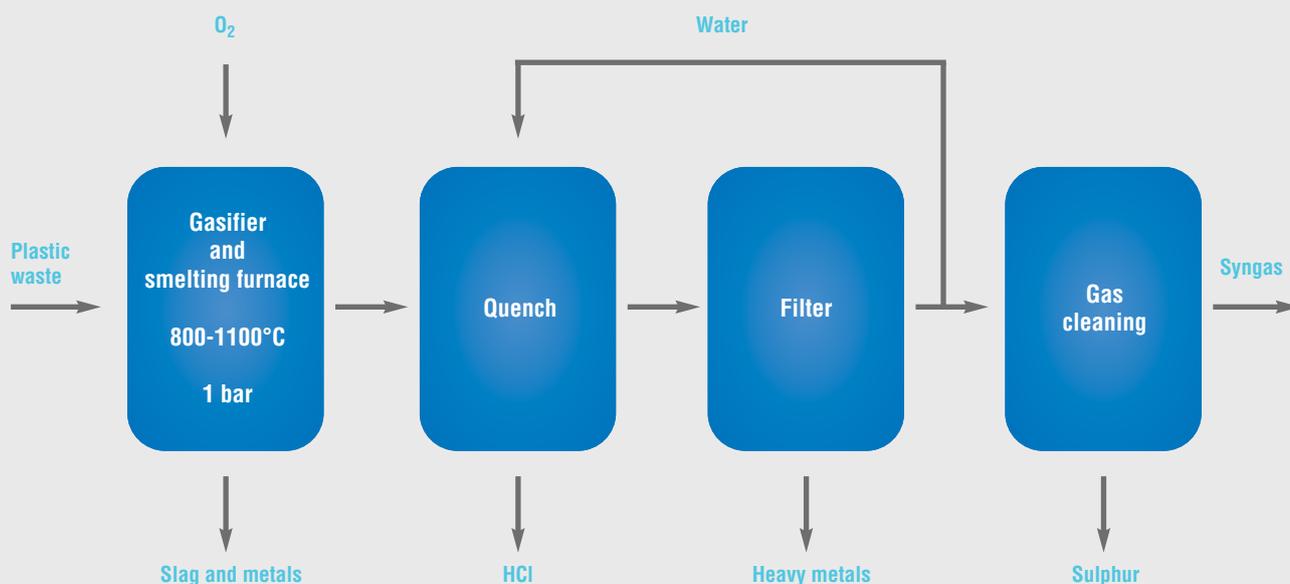
The gasifier consists of a packed ("fixed") bed at a temperature of 2000°C and a fluidised bed at the top of the reactor at a temperature of 800-1100°C. The reactor operates close to atmospheric pressure with a reducing atmosphere to avoid formation of dioxins or furans. The ash residue in the gasifier is melted in the smelting furnace and removed from the bottom of the gasifier. The furnace is equipped with top and sideways oxygen blow lances, ensuring a local temperature above 2000°C.

Plastic waste with low calorific value needs additional coke or wood as a carbon source for steady operation. PVC waste has a low calorific value and therefore needs more additional coke than other plastics waste (7-10% for PVC).

A syngas stream is generated for use in chemical processes. The slag formed in the reactor can be used for roads, and chlorine is recovered as HCl or CaCl₂. The energy recovery rate is >70%.



Sumitomo Metals plant in Japan



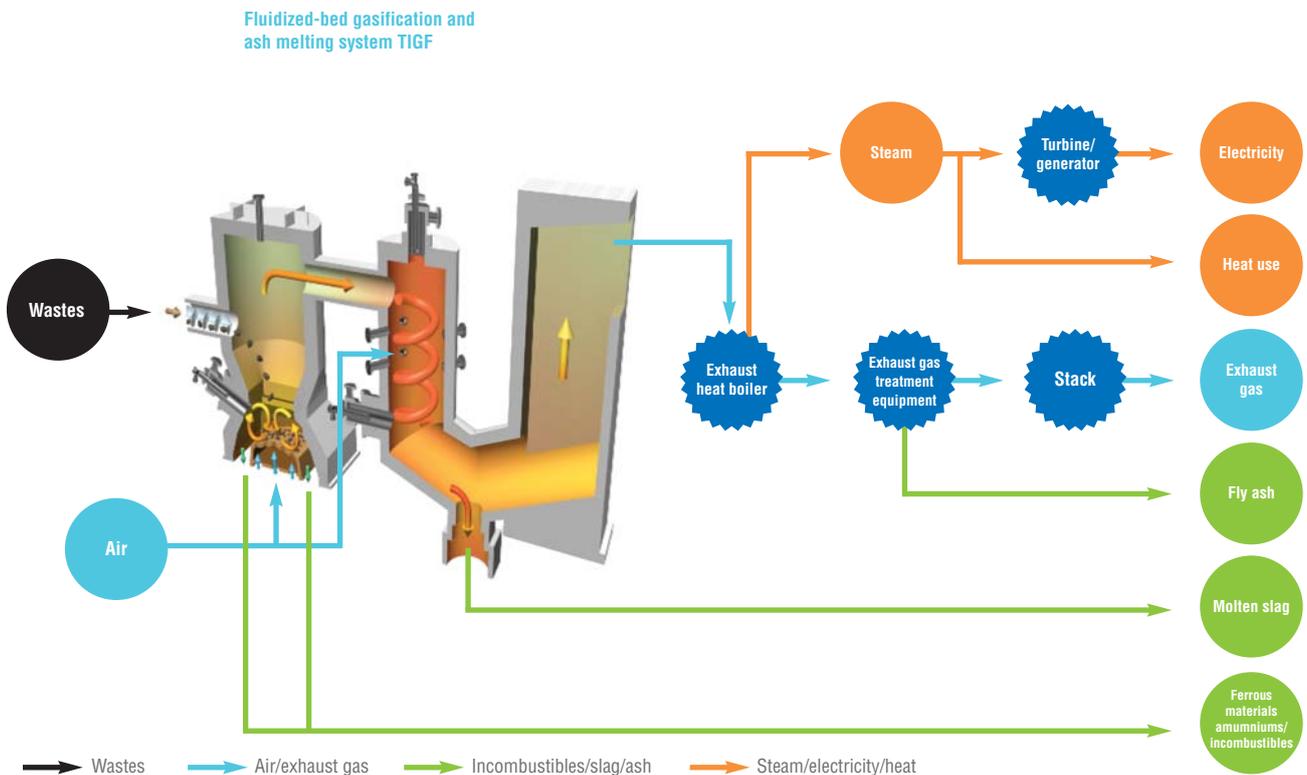
> Ebara process, Japan

Ebara's gasification process, known as 'Twin Internally revolving Fluidized bed Gasifier', is combined with its well-proven technology for ash melting – the 'Meltox' process. This process – known as EUP (Ebara-Ube Process) – uses a cyclonic combustion chamber to turn the solid residues into a stable granulated slag that can be recycled.

The low-temperature gasification takes place at 600-800°C, and the secondary high-temperature gasification at 1350°C. Both reactors are operated at about 10 bars. The process is developed

to treat mixed plastics waste, with a chlorine limit of 5%, although it could probably accept higher chlorine contents with some design adaptations. At the moment, pure PVC cannot be treated in this process.

Two commercial plants are currently operating in Japan. The syngas produced can also be used in other applications, including methanol, H₂, fuel cells and energy production. The chlorine is recovered as NH₄Cl(s), which is used as a fertiliser agent.



2. Pyrolysis

Pyrolysis is high-temperature decomposition normally in the absence of air or oxygen, and yielding a residue of carbon or heavy hydrocarbons. The process is used to convert

non-halogenated plastics, although the presence of chlorine creates specific challenges. We currently do not have any examples of this process in Europe.

3. Dehydrochlorination

This method covers mild degradation processes removing chlorine in a first step, which can then be followed by gasification or pyrolysis.

Dehydrochlorination can take place under pressure in water, in ionic high-boiling liquids, or in dry processes, such as melting, or by hydrogenation.

3.1 Dehydrochlorination in water

> REDOP process

The REDOP process targets the mixed plastic fraction from municipal waste, which usually contains around 1% chlorine, with ranges 0.5 to 5.0 wt.%. The process comprises the following steps:

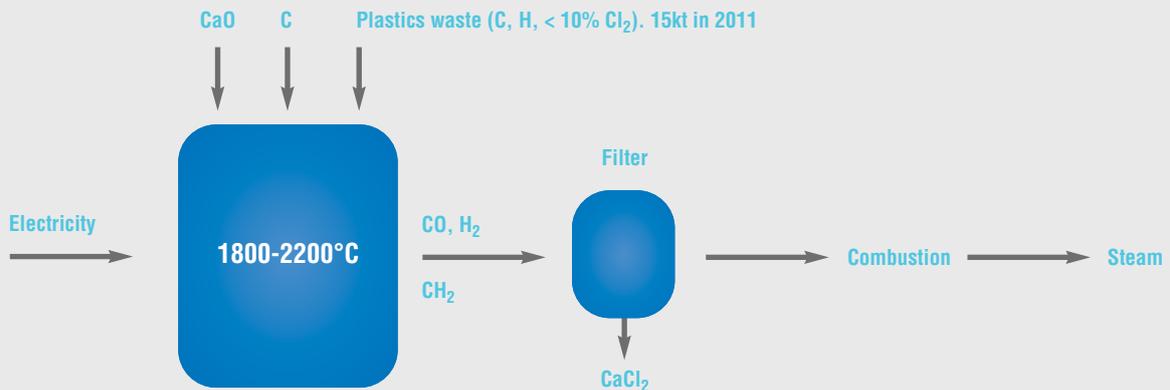
- Post separation of plastic and paper from municipal solid waste;
- Separation of the mixed plastics fraction from the paper fraction;
- Dechlorination of the mixed plastics fraction;
- Co-injection (together with coal) into a blast furnace for the production of pig iron.

Of special interest is the dechlorination step, using a novel process patented by chemical company DSM. Mixed plastics waste is heated batch-wise in a stirred reactor. Degradation products from the cellulose still present act as emulsifiers, helping to stabilise the slurry. The released HCl is neutralised by the addition of a diluted water-soluble base. The non-PVC plastics melt into droplets. When the reactor is cooled down, the plastic droplets solidify and yield granules that only need filtering, washing and drying.

> Alzchem, Germany

The plant capacity is 150000 tonnes/year of calcium carbide production; it strives to use as much plastic waste as possible. A pilot project is ongoing to eliminate as much chlorine as possible

before entering the reactor, with an upstream extruder operating at temperatures which can degrade PVC. The resulting HCl could be sold as a water solution.



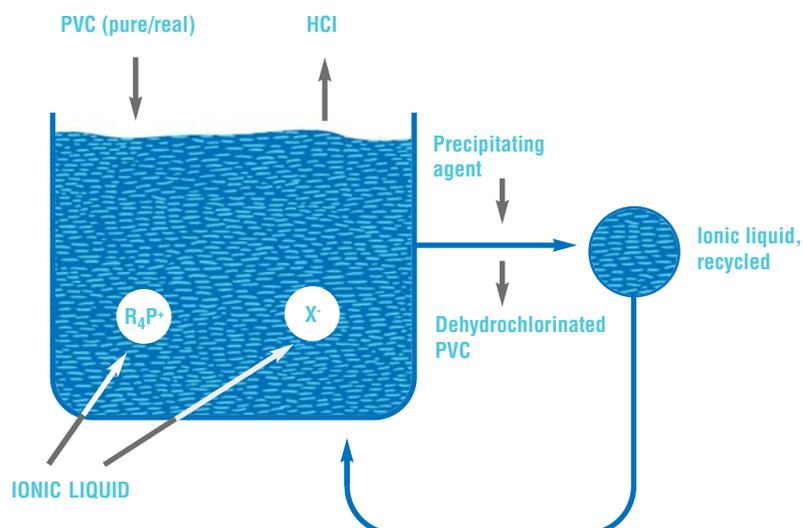
The Alzchem process

3.1 Dehydrochlorination in ionic liquids

> KU Leuven, Belgium

A team at KU Leuven in Belgium is studying dehydrochlorination of PVC in ionic liquid media. These liquids are essentially non-volatile even at elevated temperatures (250°C and more).

This allows for evacuation of the HCl by vacuum or a gas stream, thus avoiding salt formation by reaction of the HCl with caustic soda. The dehydrochlorinated PVC would precipitate out.



The KU Leuven process

Incineration with energy recovery and material recovery

Normal solid-waste incinerators with energy recovery can only tolerate up to 1% chlorine. However, such processes are not accepted as recycling by waste regulation. If HCl and/or its

neutralised salts are recovered and used, then partial recycling may be claimed.

Three processes are highlighted:

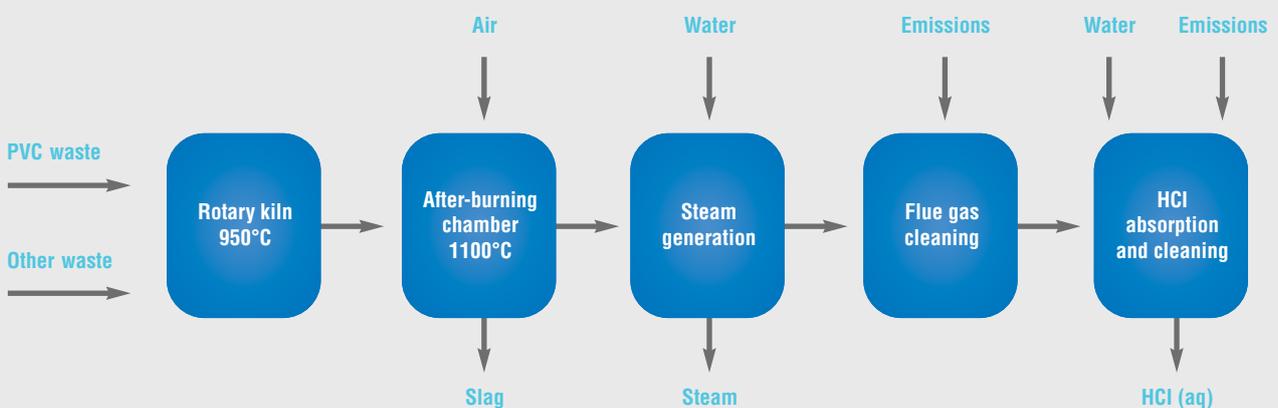
1. HCl recovery

> SUEZ, Germany

This fully commercial plant in Schkopau (Germany), formerly owned by Dow/BSL, uses mixed waste, and has been in operation since 1999. Trials with PVC waste were successfully conducted during January to March 2000 and July 2002 to April 2003. The process can handle mixed PVC waste, contaminated oil, bio-sludge and hazardous solids containing chlorinated substances. HCl and energy are recovered. The annual capacity is 45000 tonnes of waste intake. The process is shown below.

An average of 90% of the chlorine from the PVC input is recovered as 20% HCl (aqueous). The HCl quality is within the specification for use in the on-site chlor-alkali plant via membrane electrolysis. PVC waste has a lower calorific value than other plastic waste due to the high chlorine content. To treat PVC waste in the rotary kiln,

other waste with high calorific value is added to support the combustion. A total energy recovery of 50% is achieved for PVC.



> MVR, Germany

MVR (Müllverwertungsanlage Rugenberger Damm) is an advanced 320 000 tonnes/year energy-recovery plant owned by the City of Hamburg. It was designed to handle much higher hydrochloric-acid levels in its raw gas than most conventional plants to provide more flexibility in waste treatment. The hydrochloric acid was recovered as a 30% aqueous solution, the purity of which made it suitable for the chemical sector. The recovery of HCl has been discontinued for

economic reasons, but the feasibility demonstration remains valid.

Trials with the addition of PVC waste (500 tonnes over five weeks) were extremely successful. No modifications were observed in the composition of the slag or the fly ash, and steam generation was not affected. Hydrochloric acid production increased in proportion to the added PVC waste and the level of dioxins in the gaseous effluent remained extremely low – well below mandatory limits.

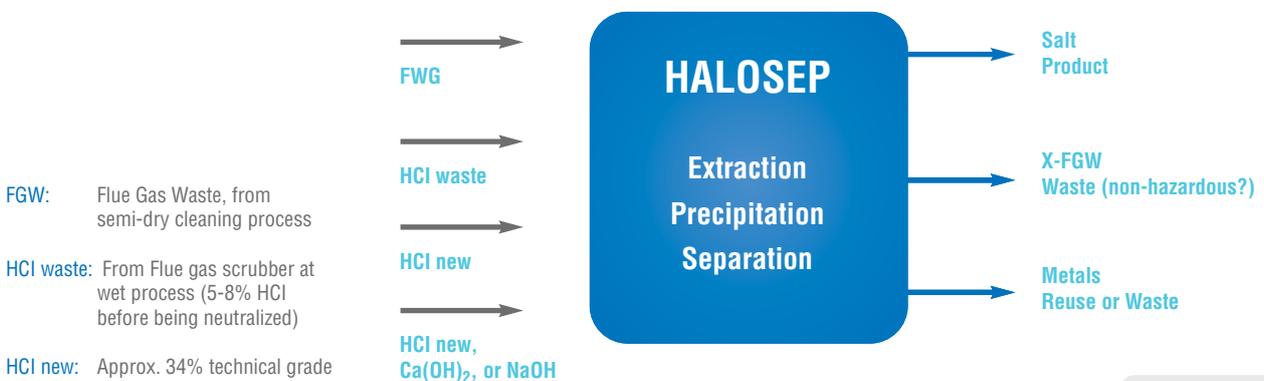
2. Salt recovery

> HALOSEP®

The HALOSEP® process recovers chlorine in the form of salts from incineration waste residues such as flue gas treatment waste (FGW) and HCl scrubber liquid (HCSL). The primary advantage of this process, besides chlorine recovery, is the reduction in the amount of FGW that must be disposed of in landfills. The main product is calcium chloride brine.

Successful pilot trials have been carried out and the process will be further developed in order to licence the technology or build recovery plants.

The process is schematically represented below:



The HALOSEP process

> The SOLVAir® Solution

In waste-to-energy plants, municipal and medical waste incinerators, cement kiln operations, brick and structural clay manufacture, chlorine present in the fuel source will be converted to HCl during combustion. The acid gases can be neutralised by sodium bicarbonate. The obtained Sodium Chloride is recovered by filtration, dissolved in

water, purified and recycled into the production of sodium carbonate. As the process is totally dry, no aqueous effluent is generated which would otherwise have to be treated. This results in a very substantial reduction in the amount of neutralisation residues.

The background of the page is a blue-tinted photograph of various plastic pipes and fittings, including elbows, tees, and straight sections, arranged in a complex network. The lighting is soft, highlighting the textures and curves of the plastic components.

Further information

Glossary

Emerging recycling
technologies

Further information

Organisations

VinylPlus

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Email: info@vinylplus.eu
www.vinylplus.eu

Recovinyl

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1000 Brussels
Belgium
Tel: +32 2 742 9682
Email: info@recovinyl.com
www.recovinyl.com

EuCertPlast certification
www.eucertplast.eu

Further reading

VinylPlus Progress Report 2016
www.vinylplus.eu/documents/42/59/Progress-Report-2016

Selected technologies

Vinyloop
www.vinyloop.com

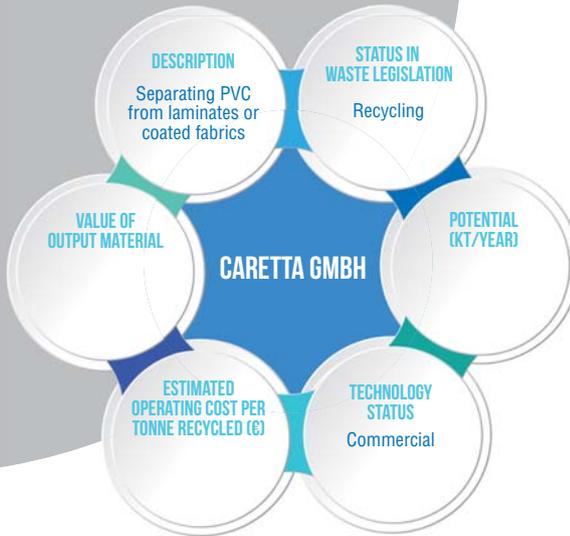
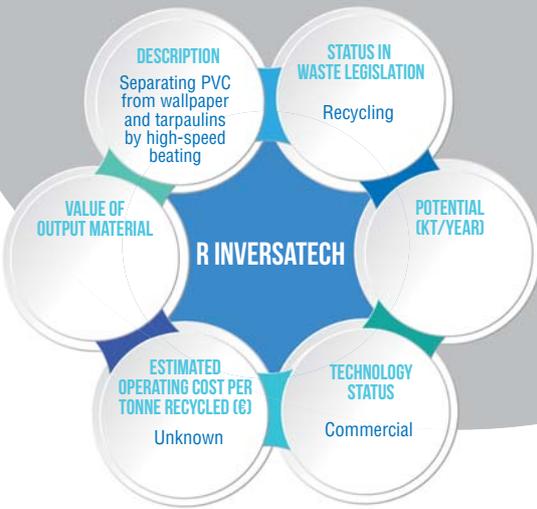
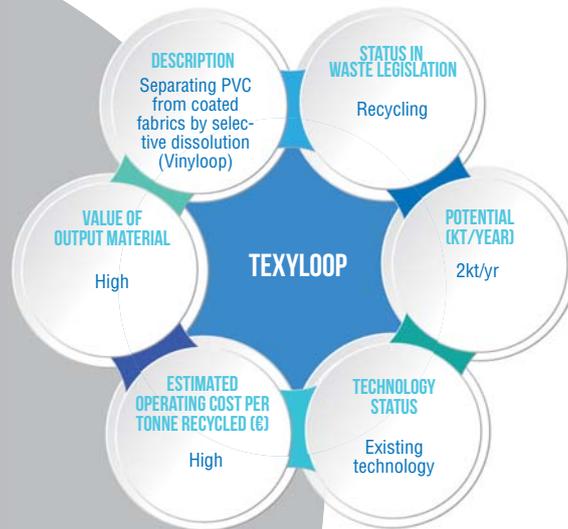
AlzChem
www.alzchem.com

Caretta GmbH
www.caretta-folie.de

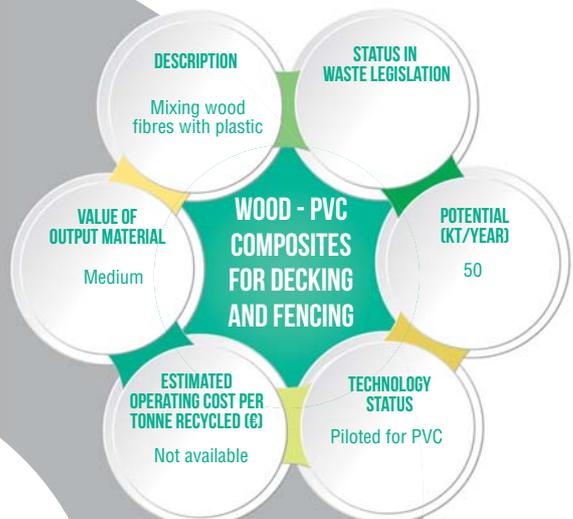
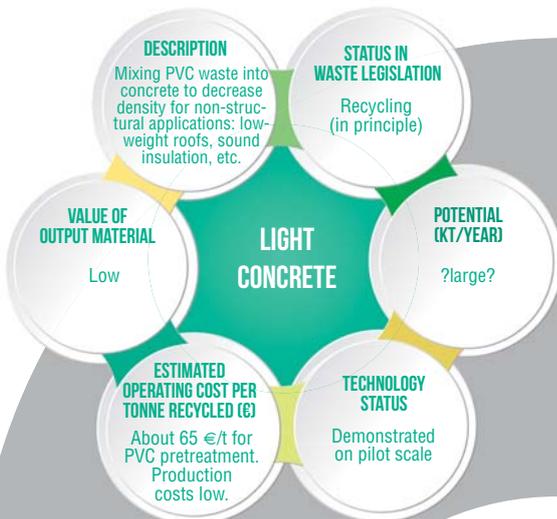
Glossary

CaCl₂	Calcium chloride
ECVM	The European Council of Vinyl Manufacturers
EU	The European Union
HCl	Hydrogen chloride
kT	kilo tonne
LCA	Life Cycle Assessment
NH₄Cl	Ammonium chloride
PE	Polyethylene
PP	Polypropylene
PVC	Polyvinyl chloride
REACH	Registration, Evaluation, Authorisation and restriction of Chemicals
R-PVC	Recycled PVC
SDS(-R)	Safety Data Sheet (for recyclate)
SME	Small and medium-sized enterprise
SHVC	Substances of Very High Concern
Syngas	Synthesis gas (a mixture of hydrogen, carbon monoxide and carbon dioxide, with some methane and nitrogen)

Novel or improved waste separation

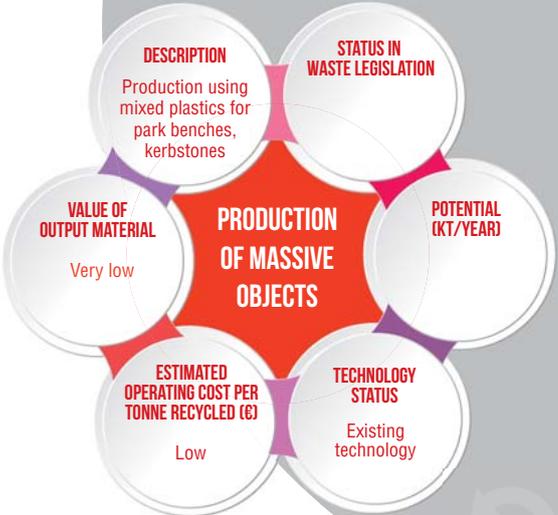
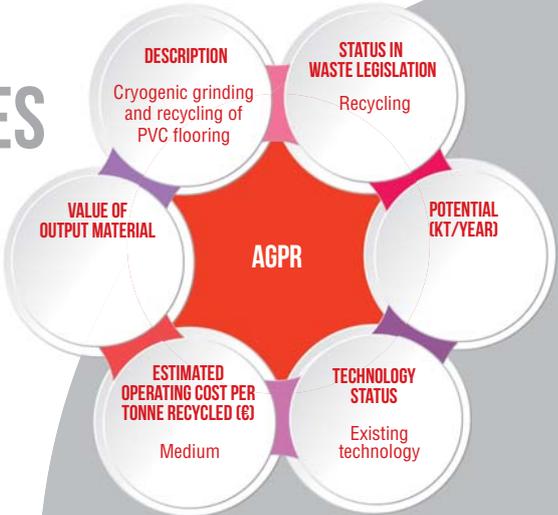
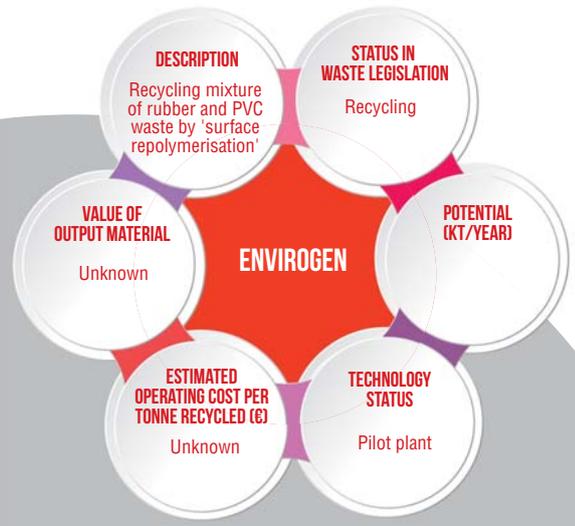
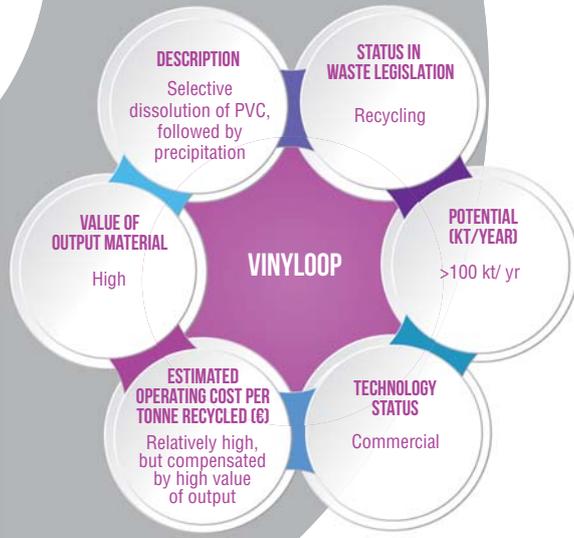
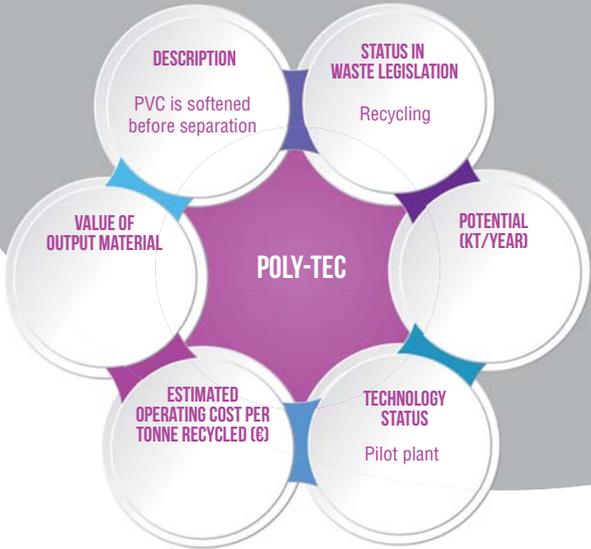


EMERGING RECYCLING



Inclusion in other materials

Non-conventional mechanical recycling



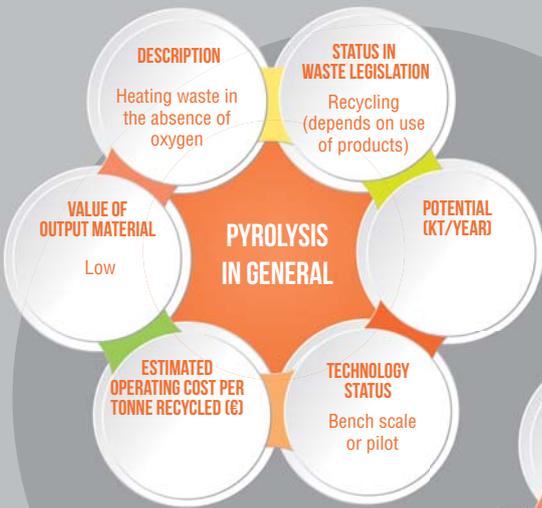
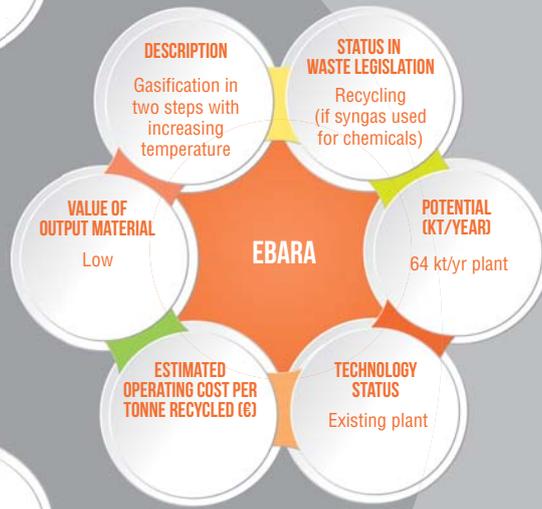
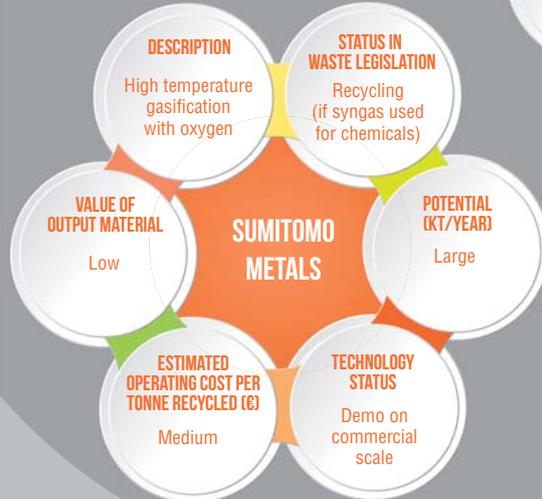
Conventional mechanical recycling with special features

TECHNOLOGIES

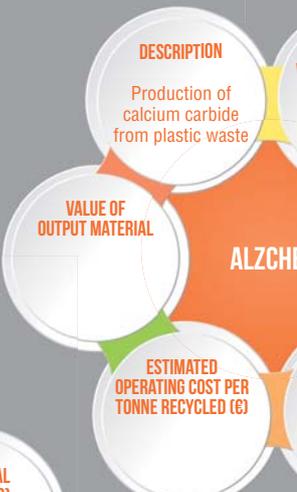
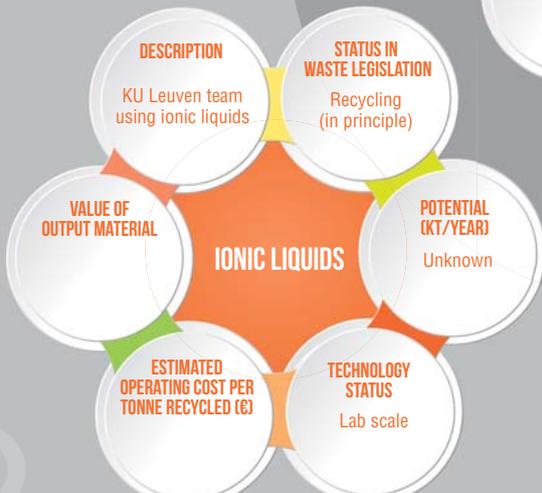
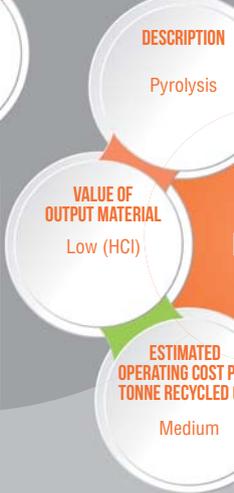
Feedstock recycling



GASIFICATION



PYROLYSIS

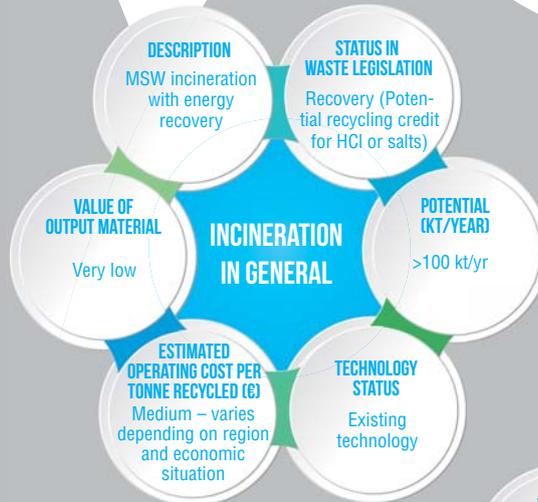


DEHYDROCHLORINATION

EMERGING RECYCLING TECHNOLOGIES

Incineration

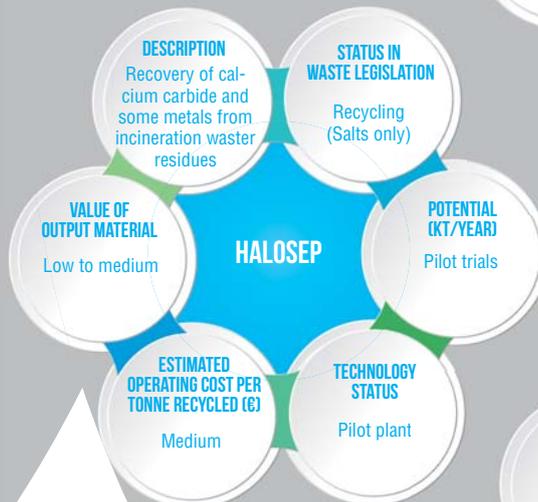
INCINERATION IN GENERAL



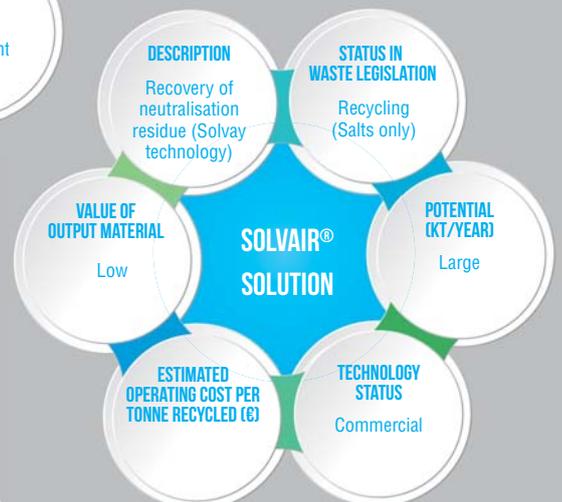
HCl RECOVERY



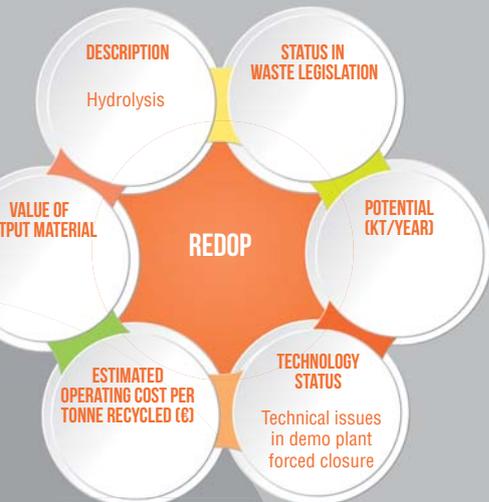
HALOSEP

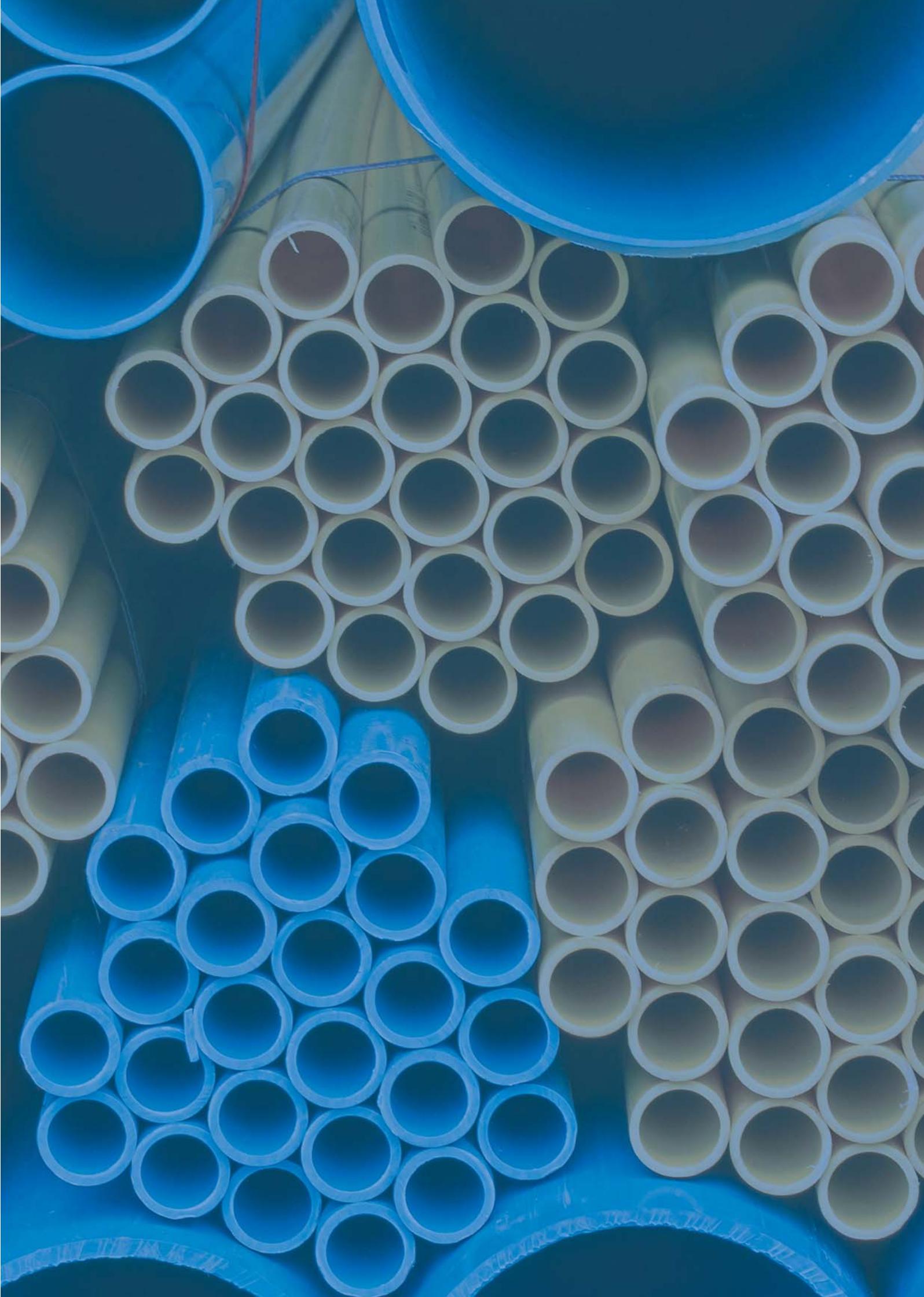


SOLVAIR® SOLUTION



REDOP





VinylPlus – commitment, co-operation, effectiveness

Building on the experience of the Vinyl 2010 Voluntary Commitment to sustainable development, VinylPlus is using the lessons learnt and new knowledge to embed sustainable development across the PVC industry in Europe.

A key element of this initiative is to maximise the safe and sustainable recycling of PVC from a wide range of waste streams to bringing environmental, economic and social benefits to our citizens, customers, industry and the planet.

This brochure outlines some of the challenges and solutions for extending recycling of waste PVC, with an emphasis on the emerging technologies that can access the 'more difficult to recycle' waste streams.

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vinyl plus