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Transforming PVC Waste Through ARCUS Greencycling Technologies' Pyrolysis Technology

JOINT WHITE PAPER

JUNE 2025

EXECUTIVE SUMMARY

- ARCUS Greencycling and VinylPlus® have demonstrated at industrial scale that PVC can be considered as a pyrolysis feedstock when processed by the pyrolysis technology of ARCUS Greencycling Technologies GmbH.
- A pyrolysis oil showing virtually unchanged properties vs. an oil produced from a 100% mixed polyolefin (MPO) feedstock has been produced with a good conversion rate.
- The obtained pyrolysis oil quality is meeting the current petrochemical specification of ARCUS Greencycling's off-takers.
- A bench scale trial has shown that lead-containing cable sheathing waste may be present in the pyrolysis feedstock and will not impact the quality of the oil produced. All tests having shown a good match between bench-scale and industrial-scale processes, ARCUS Greencycling and VinylPlus are confident that this result can be reproduced at industrial scale.
- Prof. Kevin Van Geem (University of Ghent) has confirmed that the pyrolysis oil can be processed in a steam cracker.

INTRODUCTION

Polyvinyl chloride (PVC) is the third most used plastic in Europe. It is a versatile material with many applications in sectors such as construction, healthcare, agriculture, energy, and more. For the past 24 years, the European PVC industry has, under the umbrella of VinylPlus, invested and innovated to make PVC more circular and environmentally sustainable.

In 2024, 724,638 tonnes of PVC waste were recorded as mechanically recycled within the RecoTrace® data collection system, of which 61.4% was pre-consumer and 38.6% post-consumer waste. It is estimated that the amount of PVC waste recycled represents around 35% of the total annual PVC waste generated in the EU-27, Norway, Switzerland, and the UK.[1] Today, PVC waste that is not recycled is either incinerated for energy recovery (around 46%) or landfilled (around 19%).

While mechanical recycling should be the preferred option for economic and environmental impact reasons,[2] the PVC value chain is focused on developing advanced recycling technologies to address PVC waste that presents challenges for conventional mechanical recycling.[3] This includes composites, where PVC is combined with other hard-to-dismantle materials, and waste containing legacy additives. Legacy additives are substances that have been restricted under regulations like REACH during the use phase of PVC articles. Best known example are the lead stabilisers that are regulated in Europe by a REACH restriction.[4]

PYROLYSIS OF PVC WASTE

Pyrolysis is generally considered unsuitable for PVC waste as PVC would lead to pyrolysis oils with too high impurity contents to be fed to a steam-cracker and corrosion issues due to acid emissions.[5] Some pyrolysis technology developers claim that they only allow traces (<0.01%) of PVC in their feedstock. Other developers have, however, announced to be able to produce pyrolysis oils approved by relevant petrochemical players from mixed plastics waste, including significant fractions of PVC waste.

The pyrolysis technology from ARCUS Greencycling has been tested in 2024 on a mixed plastics waste feedstock containing 10% PVC through bench- and industrial-scale trials funded by VinylPlus. A feedstock was prepared by pre-mixing 10% by weight (wt%) of three non-mechanically recyclable PVC waste streams with 90 wt% of a proprietary MPO.

Three PVC waste streams were selected:

- Post-consumer lead-free and lead-containing cable isolation and sheathing waste from Ateco Polimeri (5 wt%)
- Pre-consumer medical waste including DEHP from Raff Plastics (4 wt%)
- Post-consumer floor covering from *Arbeitsgemeinschaft PVC-Bodenbelag Recycling* (1 wt%)

This feedstock was then mixed under nitrogen atmosphere, with an absorbent, granular solid carrier, and other proprietary additives (Figure 1).

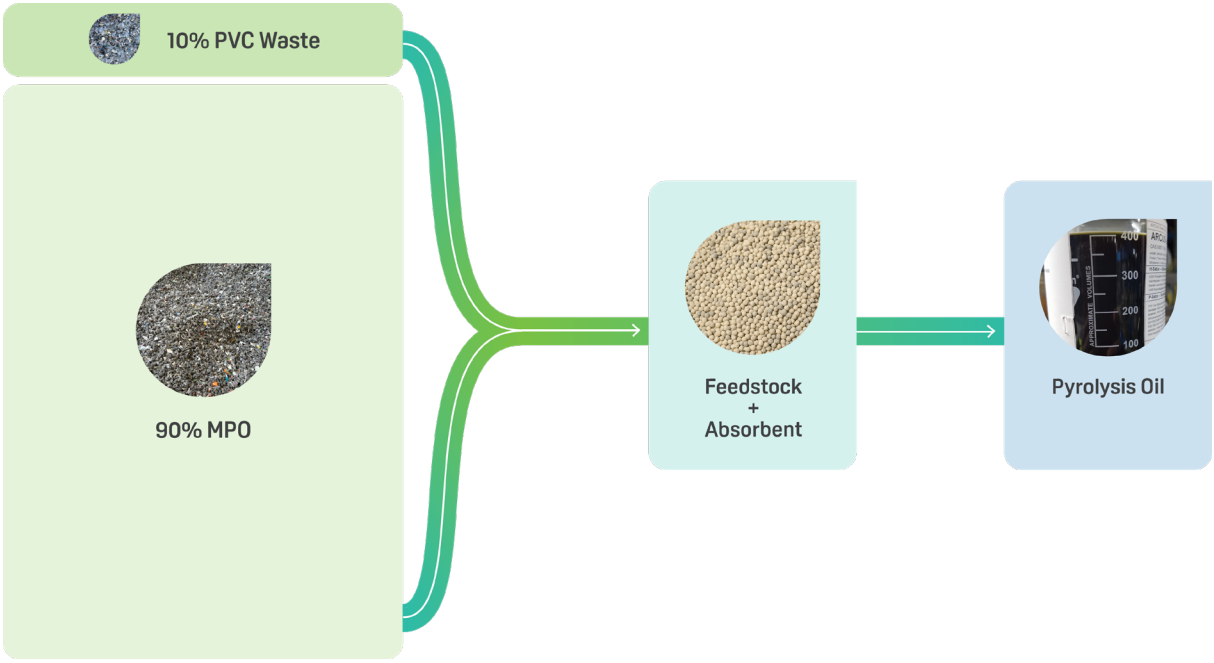

Figure 1: Conversion of PVC waste blended with an MPO feedstock into a pyrolysis oil.

Feedstock based on Extended Producer Responsibility (EPR) schemes typically consists of a mixed, post-consumer waste stream - reflective of real-world consumption patterns - and exhibits broad elemental variability. The oxygen content alone ranges from 5 to 10 wt%, introduced via a range of oxygen-bearing constituents including PET, paper fibers, and residual organic matter. Such oxygen-rich matrices are suboptimal for many thermal or chemical valorisation processes and require highly controlled process environments in pyrolysis.

In addition to oxygen, the waste stream contains a spectrum of heteroatoms and impurities - nitrogen from multilayer packaging and food residues, various metals from inks and coatings, as well as sulphur compounds. These contaminants pose challenges in both process efficiency and downstream product purity, and must be treated efficiently by the ARCUS process.

The above mentioned waste stream is ARCUS Greencycling's daily business and together with VinylPlus a controlled 10 wt% fraction of PVC waste was added, which significantly alters the halogen profile. This addition increases the overall chlorine content of the feedstock to 2–4 wt%, which is comparably high for typical chemical recycling processes. However, the ARCUS process is designed in a way to deal with such high (and higher) amounts of PVC in a safe manner.

It is important to note that all reported values represent real, variable conditions inherent to post-consumer waste streams. Unlike synthetic or single-polymer feedstocks, EPR-derived material is inherently dynamic, and process design must account for this variability to ensure stable operation and consistent output quality.

Bench-Scale Trials

Three test runs were conducted by adding a 10% mass fraction of PVC waste to MPO from German EPRs, using a bench-scale continuous system. Importantly, this bench-scale setup forms the basis for the industrial-scale unit, making the results highly transferable. Two test runs used a mixture of flexible PVC waste. One test run used lead-containing cable sheathing waste.

The mixture contained more than 2 wt% chlorine (Cl) and 400 mg/kg lead (Pb). The content of lead in the pyrolysis oil was found below the measurement limit of 1 mg/kg confirming the ability of the technology in removing legacy additives from the main product.

Industrial-Scale Trials

A successful industrial trial has been run for 60 hours in October 2024 in ARCUS Greencycling's fully authorised and certified demonstration plant located in the Industrial Park Höchst in Frankfurt (Figure 2). The fully electrically powered plant with a 4 kt/y permitted waste capacity has been successfully operated for 4,000 hours. ARCUS Greencycling's plant is engineered at industrial scale and replicable to fast further scale up.

The trial resulted in almost 3 tonnes of pyrolysis oil produced with a conversion rate unchanged by the presence of PVC, and showing virtually unchanged properties and processing cost vs. an oil produced from a 100% MPO feedstock.

As expected, the pyrolysis oil showed residual chlorine and other critical contaminants (nitrogen, calcium, iron, lead) amounts and acidity levels below the limits currently accepted by ARCUS Greencycling's off-takers. The hydrogen chloride (HCl) generated during pyrolysis by the PVC fraction is neutralised directly in the pyrolysis reactor and could be almost fully captured in the pyrolysis coke. Recovery of chlorine from the coke was not within the scope of this study.

With this trial demonstrating the robustness of the ARCUS process in accommodating significant amounts of PVC waste in the feedstock, new opportunities arise for processing more diverse and complex plastic waste streams, enhancing the overall circularity of plastics.

Figure 2: ARCUS Greencycling demonstration plant (Frankfurt, Germany).

CONCLUSIONS

VinylPlus has explored for more than two decades PVC recycling technologies that can further advance the resource efficiency and circular material flow of PVC articles. Mechanical recycling should remain the preferred end-of-life management option as this option leads to the lowest environmental footprint.

In accommodating significant amounts of PVC waste in the plastic waste feedstock, the pyrolysis process from ARCUS Greencycling provides a complementary technology to existing mechanical, dissolution, gasification, chlorine recovery, and dehydrochlorination recycling methods for processing more diverse and complex plastic waste streams, enhancing the overall circularity of plastics and offering the PVC industry an additional avenue to address end-of-life PVC, contribute to sustainability targets.

REVIEW STATEMENT

Professor Kevin Van Geem
University of Ghent

Our comprehensive GC×GC-FID and GC×GC-AED analysis of the ARCUS pyrolysis oil, derived from PVC-rich waste, has yielded promising results. We've identified primarily paraffins and olefins in the feed with a carbon range up to C45, confirming its potential as a steam cracker feedstock. The oil has a lower chlorine content than typical pyrolysis oils. Nevertheless, the presence of oxygenated compounds (3,836 ppmw) and chlorinated species (91 ppmw) necessitates dilution, suggesting a feasible 3 wt% addition based on chlorine and 2 wt% based on oxygen. Similar to pyrolysis oils produced from traditional, polyolefinic-rich waste, hydrotreatment could effectively reduce these contaminants, paving the way for its direct, undiluted use in a steam cracker. This marks a significant step towards sustainable PVC waste valorisation."

– Ghent, Belgium, 25 May 2025

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Jointly published by:

ARCUS Greencycling Technologies GmbH, founded in 2016 and based in Ludwigsburg, Germany, is a greentech company specialising in chemical recycling of mixed plastic waste. Their proprietary pyrolysis process converts non-recyclable plastics into high-quality pyrolysis oil and gas, which can be used in the petrochemical industry. In 2022, ARCUS commissioned Germany's first industrial-scale pyrolysis plant at Industriepark Höchst in Frankfurt, with a capacity of 4,000 tons per year. The company has secured certifications including REACH, ISCC+, RedCert2, and EfB, ensuring compliance with environmental and quality standards.

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VinylPlus® is the European PVC industry's commitment to sustainable development. Through VinylPlus, the European PVC industry is creating a long-term sustainability framework for the entire PVC value chain, improving PVC products' sustainability and circularity and their contribution to a sustainable society. It covers the EU-27, Norway, Switzerland and the UK. VinylPlus represents around 200 companies of PVC resin and additives producers and converters and coordinates a network of about 150 recyclers. Since 2000, VinylPlus has invested close to €140 million in sustainability in Europe.

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