From waste to worth:

High-quality recycled plastics through advanced mechanical recycling

beyond the obvious

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Introduction

For decades, industries using plastics in their production have relied on primary materials, as recycled plastics were unsuitable for demanding applications. Until recently, the processes required to produce high-quality recycled plastics at scale were not widely available. As a result, the proportion of plastics made from both mechanically and chemically recycled plastics combined has remained at under ten percent worldwide.[1]

However, the landscape is changing rapidly. Regulatory demands, market expectations for sustainability and the data needed for digital product passports are pushing the plastics recycling and processing industry to produce high-quality recycled polymers with a fully traceable production process.

Advanced rheology control, developed by VTT, is an automated quality-adjustment system that provides industry operators with confidence in both the quality and desired properties of recycled plastics.

For mechanical and chemical recyclers, extrusion companies and the compounding industry, this technological advancement unlocks new product possibilities. High recycled content content can be used in even the most demanding applications, such as automotive dashboards and food packaging. Compliance, safety and certification requirements can be met with confidence. Waste is reduced and resources are used more efficiently.

This whitepaper, supported by case examples, shows how shifts in the regulatory and technological domains are driving the transition to a circular plastics economy and creating new opportunities for value creation.

1 https://plasticseurope.org/knowledge-hub/plastics-the-fast-facts-2025/

Europe sets ambitious targets for recycled plastics

The European Union is reshaping the plastics industry through regulation. The Directive on End-of-Life Vehicles (ELV) sets mandatory targets for recycled plastic content in cars. A typical car can contain a couple of hundred kilograms of plastic, which makes automotive recycling a key part of the circular economy. Yet, recycled plastic accounts for only about 3% of the plastic used in manufacturing new vehicles.

The ELV directive proposes the following phased plan for introducing minimum recycled plastic content in vehicles:

15%	by **6 years** after the entry into force of the regulation
20%	by **8 years** after the entry into force of the regulation
25%	by **10 years** after the entry into force of the regulation

Alongside ELV, the EU Packaging and packaging waste regulation (PPWR) imposes similar stipulations for packaging, driving the need for high-quality recycled polymers and transparent production processes across multiple sectors.

The PPWR aims to reduce the use of primary materials in packaging, ensure all packaging placed on the EU market is recyclable in an economically viable way by 2030 and minimise substances of concern (SoC) and substances of very high concern (SVHC). This also includes imposing restrictions, for example, on PFAS when they exceed certain thresholds. These measures reinforce the shift towards circularity and underscore the need for advanced recycling technologies that can deliver consistent quality and compliance.

These regulations are not just compliance measures; they are reshaping how companies create value and secure a competitive advantage. Businesses that can demonstrate the origin and quality of their materials will stand out in a market where transparency is becoming a baseline expectation.

Meanwhile, brand owners and end customers are increasingly shaping the industry. Their commitment and expectations are driving higher standards for recyclers and compounders. The use of recycled materials is shifting from an optional practice to an industry norm. Companies that adapt and deliver high-quality, certified recycled plastics will be well-positioned to meet growing demand and build stronger relationships with brands from various industries.

Those who invest in advanced recycling technologies can turn this shift into an opportunity for growth and differentiation.

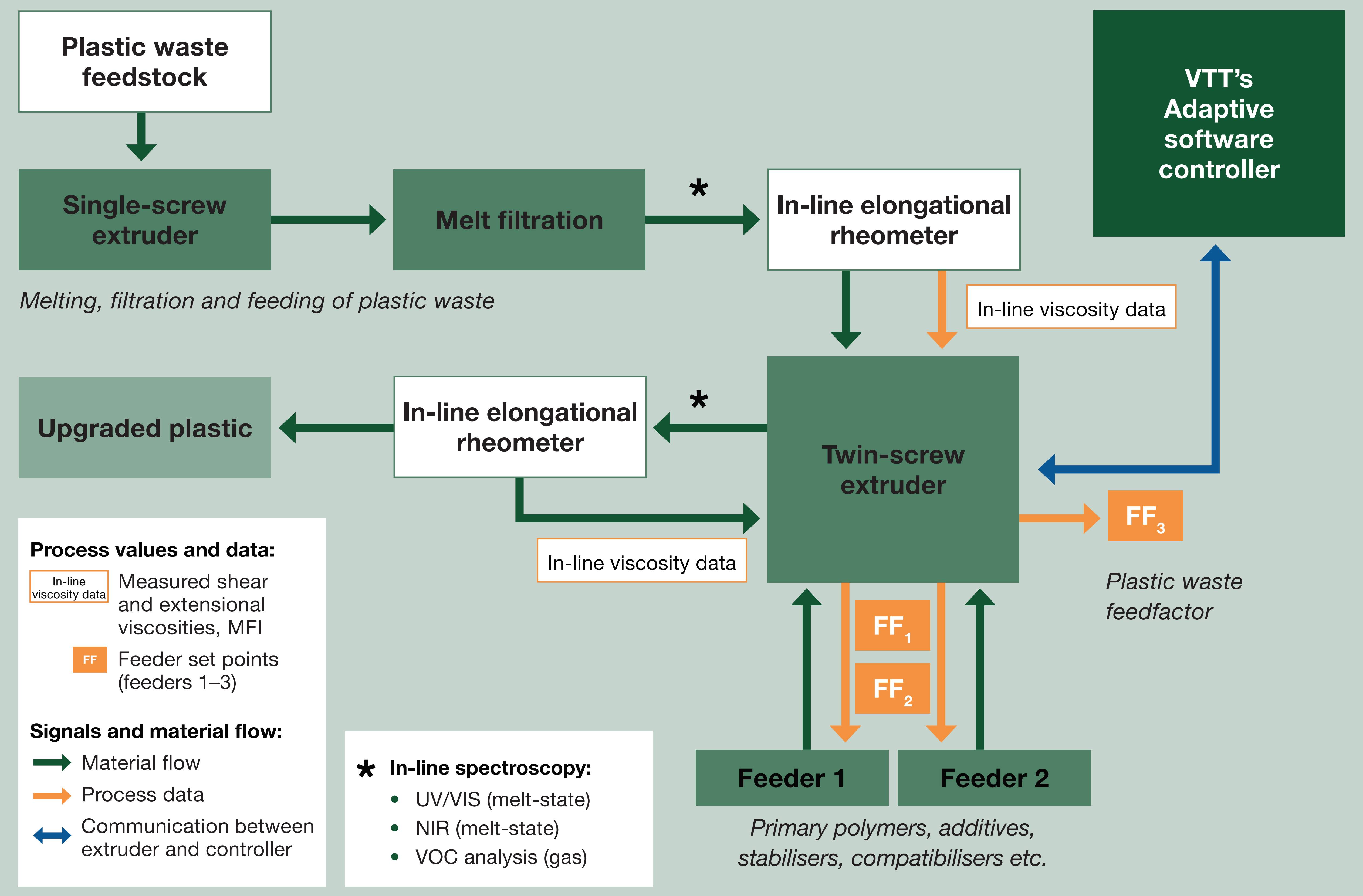
How to reach a higher recycled content without compromising quality?

For years, mechanical recycling has been hindered by limitations that reduce its impact. Variability in feedstock, inconsistent quality and safety concerns have made it difficult to use recycled plastics in high-value applications. These issues have created uncertainty for recyclers, compounders and plastics converting companies, who need reliable solutions to meet growing market and regulatory demands.

VTT addresses these challenges with an advanced mechanical recycling approach that combines in-line quality monitoring and adaptive process control in extrusion. Instead of relying on offline sampling and manual adjustments, the system continuously measures critical properties during processing and uses this data to stabilise and upgrade material quality automatically. This approach transforms conventional extrusion processing from a passive process into a controlled, data-driven operation.

With VTT's approach, it is possible to monitor key attributes such as melt viscosity, melt flow index, colour, homogeneity and volatile organic compounds in real time, improving material quality, processing safety and sustainability. By integrating these measurements into smart process control, it eliminates batch variability and ensures consistent performance. This capability is essential for meeting the requirements of digital product passports and certification schemes, which demand detailed, traceable data for every batch.

These benefits translate into tangible value for the industry. Companies can achieve higher recycled content without compromising quality, reduce waste by catching deviations early and build trust with customers through verified data. The result is a more efficient, sustainable and competitive recycling process that holds up to the toughest standards.



Adaptive in-line rheology control. The adaptive software controller responds to melt-flow variations in the plastic-waste feedstock by automatically adjusting the additive dosing, ensuring stable output viscosity despite fluctuations in recycled material properties.

Case

A circular approach to recycling end-of-life multilayer films

Each year, nearly three million tonnes of multilayer films are incinerated or landfilled after use in consumer and industrial applications. This represents a major environmental challenge and a significant loss of economic value. The Circular Multilayer Plastic Approach project (CIMPA)[2] addressed this challenge by introducing advanced rheology upgrading techniques to enhance the future potential of mechanically and physically recycled multilayer plastics, while also pursuing other objectives to enhance the recyclability of multilayer films.

Traditionally, recycled multilayer feedstocks have suffered from wide variations in melt flow properties, making them unpredictable and difficult to process into high-quality products. This variability has been a major barrier to reintroducing recycled materials into demanding applications, such as film production for food and agriculture.

During the project, CIMPA addressed processing problems in real time, resulting in higher quality PE/PA and PE/EVOH recyclates and reduced material waste. The approach used twin screw extrusion combined with embedding selected primary materials and additives, narrowing the range of rheological properties.

For recyclers and plastics converter companies, this ensures greater confidence in the quality of recycled inputs, fewer production stoppages and the ability to meet stringent standards for agricultural and food contact applications.

The benefits extend beyond the factory floor. CIMPA's results showed that its approach could keep hundreds of millions of euros worth of plastic materials in use and cut approximately 2.1 million tonnes of CO_2 equivalent per year – roughly the same as 0.15% of all emissions in the EU.

2 https://cordis.europa.eu/project/id/101003864/reporting

Case

Turning municipal solid waste into high-quality film

VTT has demonstrated that even plastics from mixed municipal solid waste (MSW) collected in Finland can be successfully recycled into high-quality products.[3] From this stream, polyethylene (PE) plastics were separated, washed and processed through a sequence of steps: material feeding, single-screw extrusion, melt filtration with in-line viscosity measurement and twin-screw compounding with degassing. The upgraded material was then extruded, cooled and granulated.

Despite the low initial quality of the feedstock, VTT produced thin film prototypes from the recycled PE. The upgraded r-PE showed good processability with mechanical properties close to those of primary resins. This shows that plastics previously considered unsuitable for mechanical recycling can be refined to meet the requirements of film production when advanced processing and quality control are applied.

For recyclers and converters, this opens new possibilities for recovering value from waste streams previously destined for incineration or landfill.

3 https://cris.vtt.fi/en/publications/recycling-plastics-from-residual-municipal-solid-waste-final-repo/

From variability to predictability: In-line monitoring is evolving rapidly

Variations in colour, chemical composition or melt flow can lead to off-spec batches, wasted material and lost revenue. In addition to advanced rheology control, VTT is developing adaptive processing control solutions based on in-line spectroscopy to overcome production variability. These solutions enable real-time monitoring and dynamic adjustments during manufacturing.

For many applications, aesthetics and performance are non-negotiable. Even if recycled plastics meet mechanical requirements, inconsistent colour or unpredictable flow properties can make them unsuitable for high-value uses. Traditionally, these issues are detected only after production, resulting in costly rework or disposal.

In-line spectroscopy[4] provides a window into the material as it is processed:

- **UV/VIS spectroscopy** monitors colour properties, helping maintain visual consistency.
- **NIR spectroscopy** tracks chemical composition, ensuring the right blend of components.
- **FTIR analysis** detects volatile organic compounds (VOCs), supporting safety and compliance.

Continuous monitoring of these critical quality attributes allows operators to identify fluctuations early and take corrective action before defects occur. In the future, advanced process control algorithms based on machine learning will compensate automatically for colour variations, reducing reliance on heavy pigment dosing and cutting costs.

Equally important is the ability to gather data on critical quality attributes, such as melt viscosity, composition and colour, which can support initiatives like digital product passports or provide proof of batch quality.

Looking ahead, VTT is exploring how this approach could go further. For example, polymer manufacturers, compounders or recyclers often need to produce materials with different melt flow index (MFI) values. Once property modelling is established, VTT's system allows setting a target MFI and automatically adjusting feed rates of different components to achieve that specification. This would not only minimise fluctuations but also enable manufacturers to refine products to meet precise requirements. In the future, VTT aims to extend this control beyond melt flow properties to other critical parameters as well. Moreover, in-line process control will be integrated into downstream processing.

4 VTT's advanced mechanical recycling line is equipped with in-line UV/VIS and NIR spectrophotometer systems by ColVisTec AG, enabling in-line extrusion process control.

Conclusion

Advanced process control and in-line quality monitoring are transforming plastics recycling from a reactive process into a data-driven, reliable industry. These innovations enable recyclers and manufacturers to consistently produce high-quality, traceable recycled plastics that meet strict regulatory and market demands.

Case examples show that even challenging waste streams can become valuable resources with the right technology. Companies that invest in digitalisation and adaptive control will be best positioned to lead in a market where transparency, quality and sustainability are essential.

Authors / contact

Jani Pelto
Principal Scientist
jani.pelto@vtt.fi
+358 40 821 2258

Ilkka Rytöluoto
Senior Scientist
ilkka.rytoluoto@vtt.fi
+358 40 197 5501

Ville Roininen
Customer Account Lead
ville.roininen@vtt.fi
+358 40 752 5289

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