DRIVING THE FUTURE OF SUSTAINABLE MOBILITY:

# Engineering plastics circularity

## The need

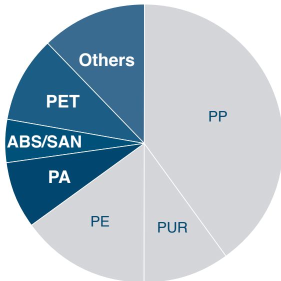
To address today's climate and plastic waste crises, we need to make the plastics used in vehicles more sustainable.

This drive for circular, low-carbon automotive plastics is reinforced by ambitious targets set by OEMs, including the amount of recycled content that cars must contain.

This applies to the high-performance engineering plastics used to produce a huge range of vehicle parts – from engine covers and electrical connectors to interior lighting, consoles and trims.

These materials include:

- **Polyamide (PA) / Nylon**
- **Polyester (PET, PBT)**
- **Acrylonitrile Butadiene Styrene (ABS)**
- **Polycarbonate (PC)**
- **and blends of the above**

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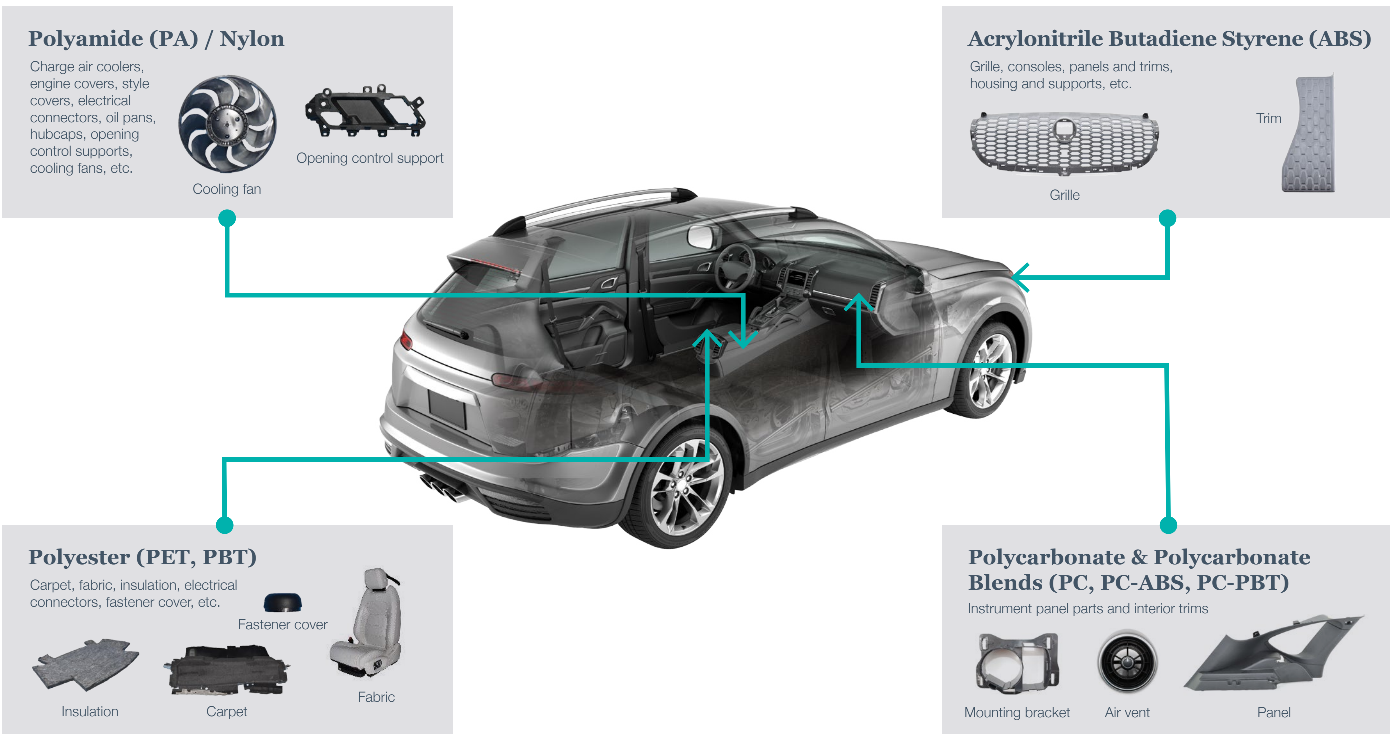


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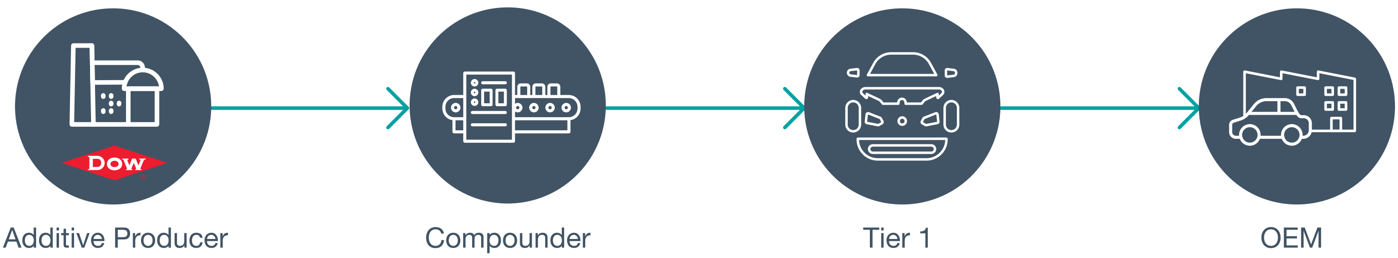



Making engineering plastics more sustainable requires the collaboration of players across the automotive plastics value chain.

## The challenge

### 1

**Loss of properties**

Polymers' properties degrade over time, due to their exposure to UV, humidity and high temperature. This makes end-of-life engineering plastics unsuitable for recycling into high performance applications, since they have lower mechanical properties.

In addition to this, the recycling process damages the molecular chains – which affects viscosity, mechanical properties and surface appearance (increase or decrease in viscosity, change in gloss, and more).

**The solution**
**Impact/Rheology Modification**

### 2

**Cross-polymer contamination**

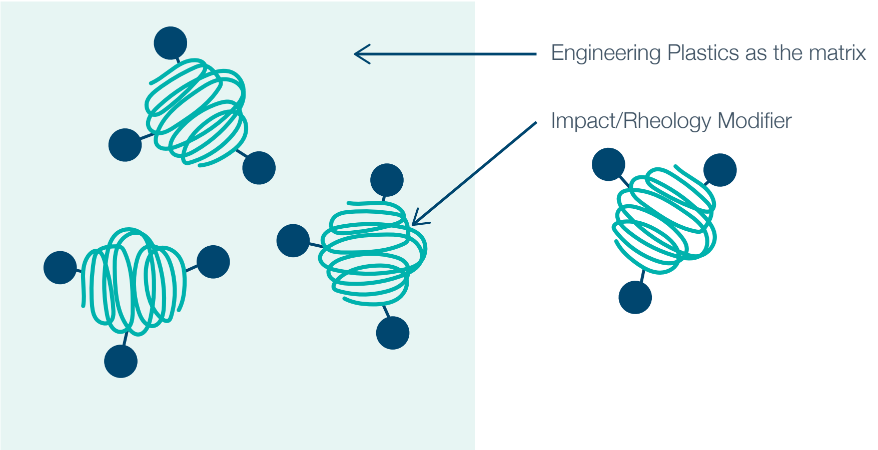
Commercially available plastic waste streams may contain a mix of different polymers. This impurity makes it difficult to turn end-of-life engineering plastics into the high-performance materials required for automotive applications.

**The solution**
**Compatibilization**

## The solution

### 1. Impact/Rheology Modification

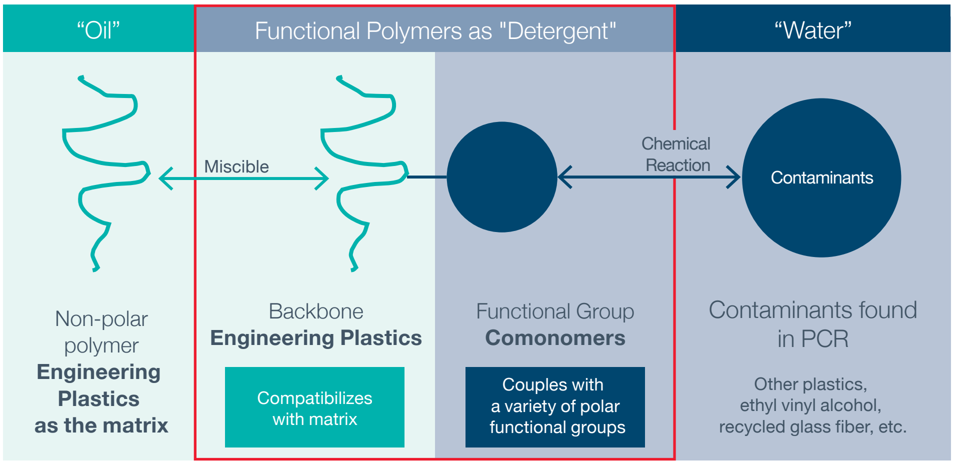
Adding impact modifiers – rubbery polymers – to end-of-life plastics improves their impact strength and flexibility, increasing their value by transforming them from a brittle material to a tough one.




### 2. Compatibilization

Compatibilizers help to blend mixed plastic waste by improving the adhesion between incompatible polymers – much as a detergent allows oil and water to mix.

Reactive and/or non-reactive compatibilizers can help synergistically combine the components present in the recycling stream. This produces a more uniform mixture, which enhances the mechanical properties of the recyclate.



## A. Polyamide (PA) / Nylon

**FUSABOND™ Functional Polymers** and **SURLYN™ Ionomers** enable compounders to incorporate contaminants when recycling PA. They also restore properties lost during the recycling process, like impact resistance and aesthetics.

Fusabond functional polymers

Surlyn ionomers

### FUSABOND™ Functional Polymers

**Impact Resistance:** offers a wide range of impact resistances, including high-performance toughness at low temperatures.

**Compatibilization:** homogenizes recyclate with contaminants.

**Processability:** improves the flow of recyclates by reducing its melt viscosity. This makes them easier to process – reducing injection molding cycle times and improving mold filling.

**High affinity to glass and mineral fillers**

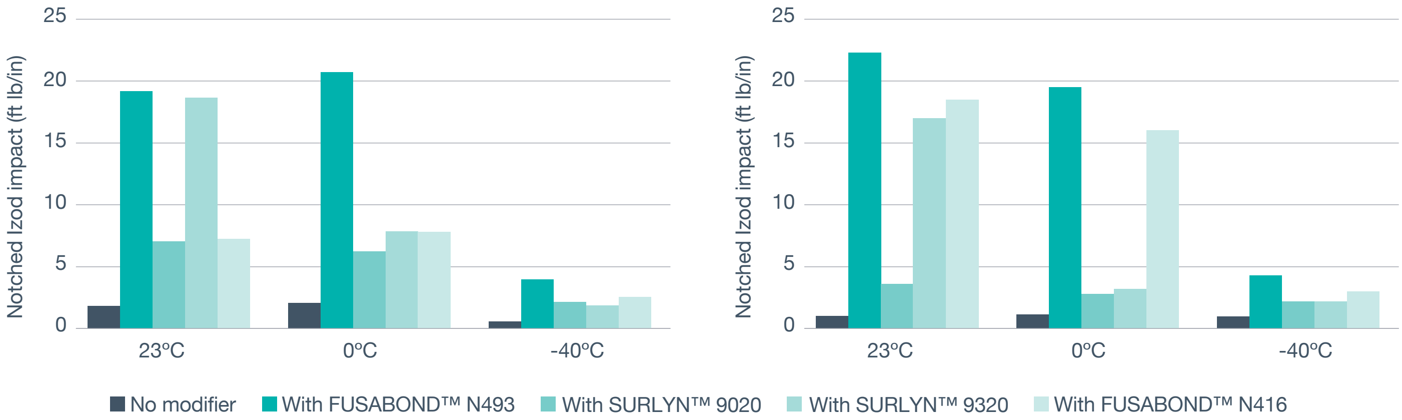
### SURLYN™ Ionomers

Retains **flexular modulus** (stiffness) and **melt strength** (elasticity).

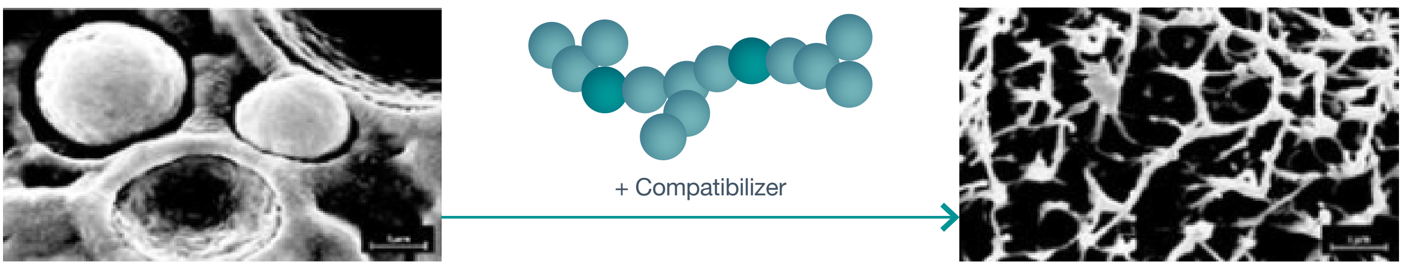
**Aesthetics** of vehicle parts: produces a **high-gloss** surface finish.

## 1. Impact/Rheology Modification

Our impact modifiers offer a range of performance options to address specific needs.




## 2. Compatibilization




**PA with PE contamination**

**With 10% FUSABOND™ Functional Polymers**

- FUSABOND™ Functional Polymers lead to finer dispersion of blend components and better bonding
- Influencing interfacial energy through polarity or reaction
- Improved processability and mechanical properties

*Typical values, not to be construed as specifications. Users should confirm results by their own tests.

## B. Polyester (PET, PBT)

**ELVALOY™** and **ELVALOY™ AC Copolymers** are a family of polymers that help compounders to incorporate contaminants when recycling polyesters.

The combination of both can improve the flow and melt strength (elasticity) of the recyclate, which makes it easier to process, and restore mechanical properties lost during recycling, like impact resistance and tensile strength.

Elvaloy copolymers for alloys

Elvaloy AC acrylate copolymers

**Impact Resistance**: offers a wide range of impact resistances, including high performance toughness at low temperature.

**Ductility**: significantly increases elongation at break.

**Hydrolysis resistance**: retains tensile strength and other mechanical properties damaged by hydrolysis during processing and aging.

**Compatibilization**: homogenizes recyclates with contaminants.

Increases the **melt strength** of recycled waste streams through reactivity.

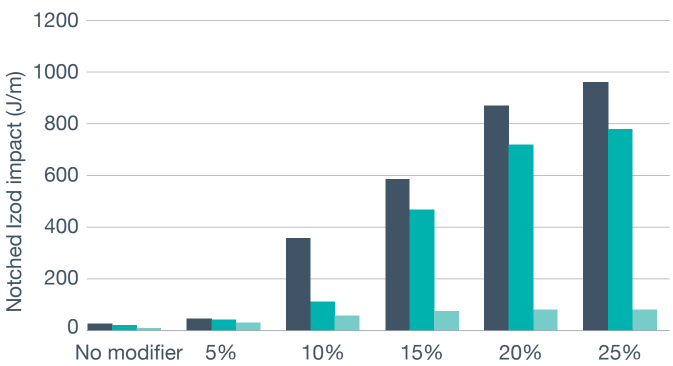
**Processability:** improves the flow of recyclates by reducing its melt viscosity. This makes them easier to process – reducing injection molding cycle times and improving mold filling.

**Aesthetics** of vehicle parts: produces a **high-gloss** surface finish, improves chemical resistance to **stress cracking**, and has excellent **UV stability**.

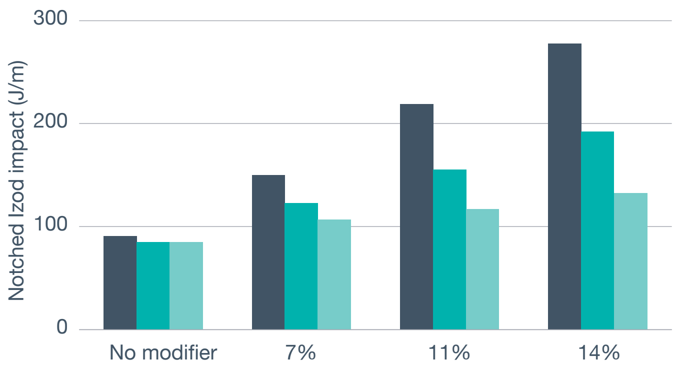
**High affinity to glass and mineral fillers** – ensuring the high performance of recyclate containing these materials.

### 1. Impact/Rheology Modification

**Incorporating ELVALOY™ PTW into PBT**

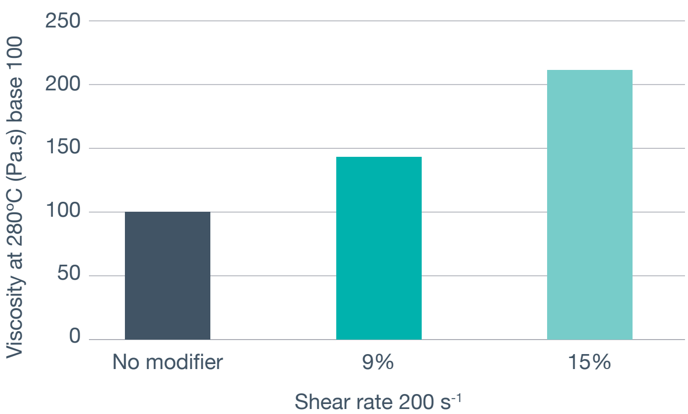



**Incorporating ELVALOY™ PTW into PBT (filled with 30% Glass Fiber)**




23°C 0°C -40°C

**Incorporating ELVALOY™ Copolymers into recycled PET**




**Viscosity increase with ELVALOY™ Copolymers in thermoformed PET waste**

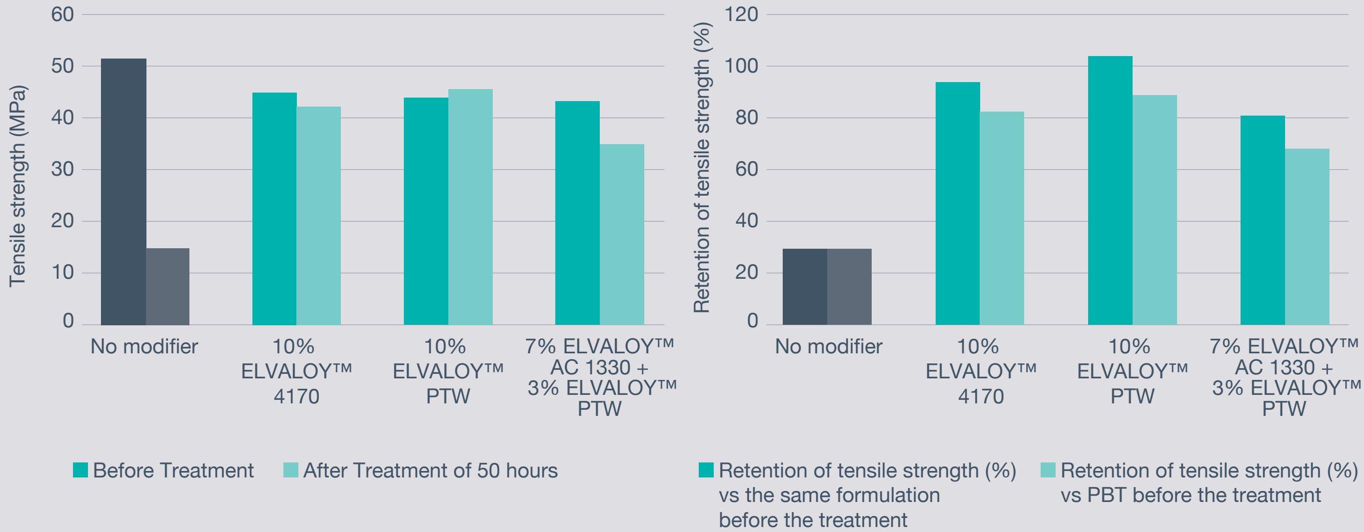
- Adding ELVALOY™ Copolymers increases the melt viscosity/strength of recycled PET, by acting as a reactive "hook" for PET chains
- By boosting the viscosity to the required level, ELVALOY™ Copolymers make it possible to incorporate a higher percentage of recycled PET in the compound

*Typical values, not to be construed as specifications.
Users should confirm results by their own tests.

**Exposure to hot and humid environments**, not only throughout a product's use phase but also at the end of its life as a waste stream, poses **challenges in recycling polyester**. Such exposure causes hydrolysis, which compromises the tensile strength of the material. The humidity needs to be removed during recycling, and with polyester's typically low molecular weight, it would require solid-stating before use.

**ELVALOY™ PTW Copolymers** perform as a chain extender in extrusion to help increase molecular weight and thus improve mechanicals like **impact resistance, low-temperature flexibility, drawability, and stress crack resistance**.

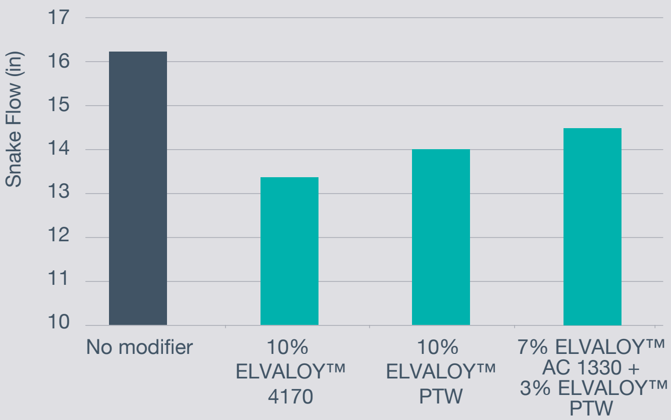
**Incorporating ELVALOY™ and ELVALOY™ AC Copolymers into PBT:**
**Tensile strength before and after 50 hours of treatment in hot and humid conditions**

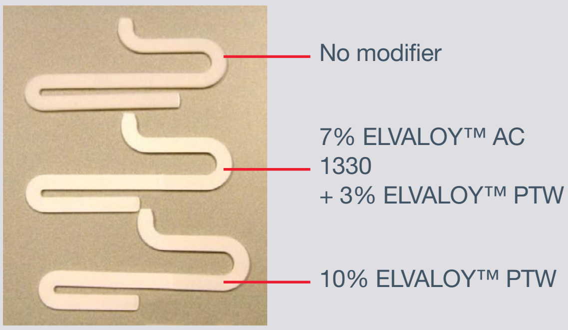



The tensile strength data above demonstrate how ELVALOY™ grades can help retain performance after hours of exposure in hot and humid conditions with the hydrolytic resistance the modifiers bring.

However, chain extenders can also increase viscosity and thus hamper flow. To balance this effect, ELVALOY™ PTW can be combined with **ELVALOY™ AC Copolymers to improve flowability**.

**Incorporating ELVALOY™ and ELVALOY™ AC Copolymers into PBT: Snake flow**




Note: the color in this picture does not reflect the true color of the samples.

The snake flow test shows the improved flowability with the addition of ELVALOY™ AC Copolymers, for the balance of the properties needed to recycle polyesters.

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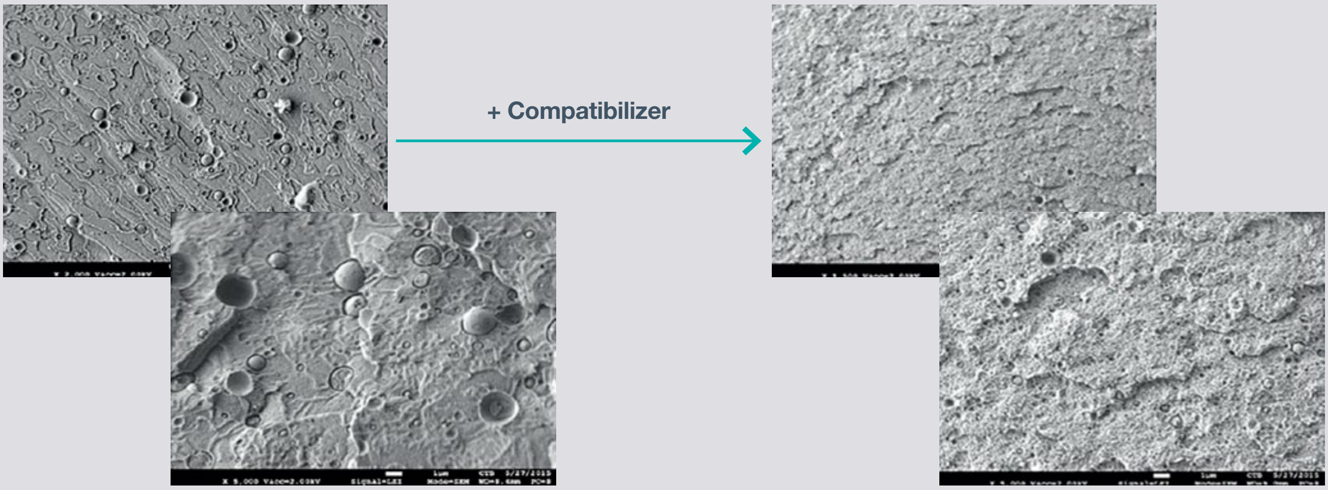
## 2. Compatibilization




PET with PE contamination

With ELVALOY™ PTW Copolymers

Image source: A2MAC1

- Blend of PET-PE (92.5%-7.5%) shows a much more homogeneous structure with the blend containing ELVALOY™ PTW Copolymers.

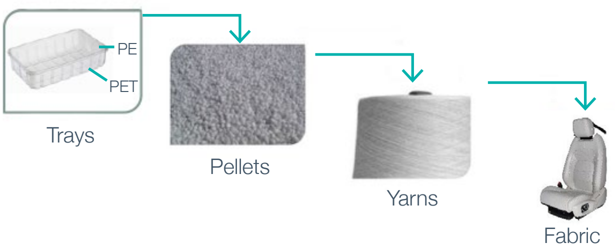
### Recycling PET-PE to produce new, high performance fabrics

The addition of **ELVALOY™ PTW** supports the recycling of PET blends contaminated by polyethylene (PE) – for example from PET trays – to produce fibers, even at high draw ratios. It also significantly improves these fibers' tenacity.

ELVALOY™ PTW works as a coupling agent and compatibilizer for the contaminants, and as an impact modifier and chain extender for the polyester matrix. This makes it possible to turn polyester-rich waste into high value applications, like seating fabrics.

### Alternative Second Life of a PET-PE Tray

PET-PE waste **made suitable** for high-performance **fiber applications**

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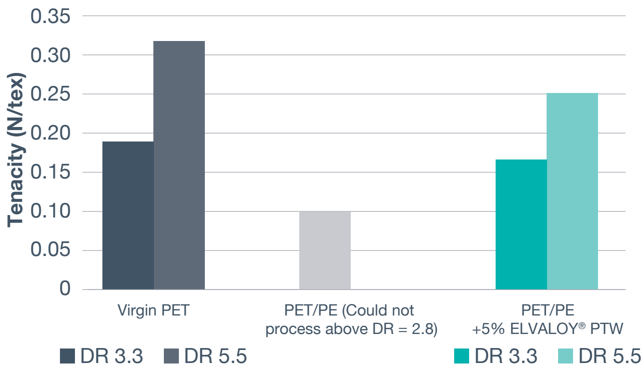



*DR = Draw Ratio

→ **Without compatibilizer:** no stable extrusion process due to PE contamination

→ **With compatibilizer:** increase in fiber tenacity, close to virgin PET

→ Supports **processability** of PET-PE waste for new fabric production

*Typical values, not to be construed as specifications. Users should confirm results by their own tests.

## C. Acrylonitrile Butadiene Styrene (ABS)

**ELVALOY™ AC Copolymers** have a high performance range and a heterogeneous molecular structure for modifying the impact strength of recycled ABS streams and improving their processability.

Elvaloy AC acrylate copolymers

**Impact Resistance:** offers a wide range of impact resistances, including high-performance toughness at low temperatures.

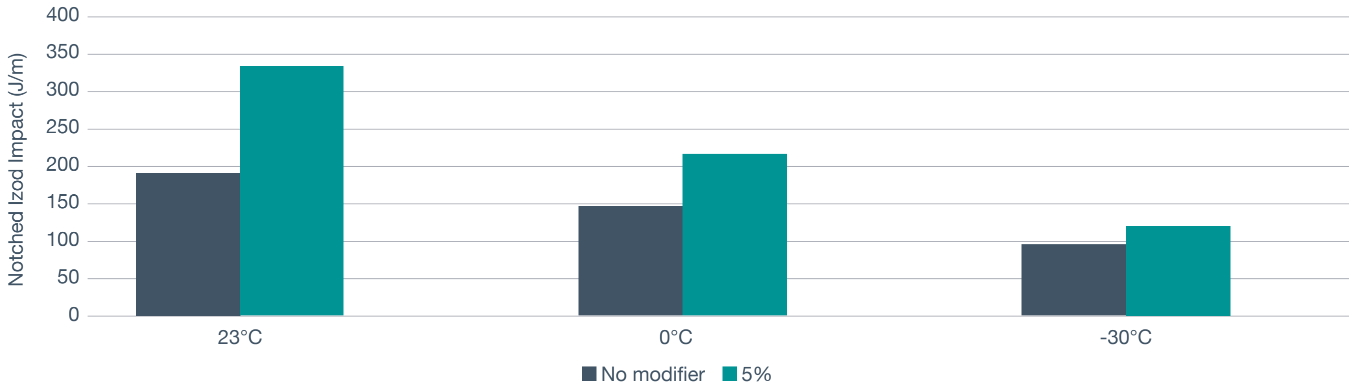
**Processability:** improves the flow of recyclates by reducing its melt viscosity. This makes them easier to process – reducing injection molding cycle times and improving mold filling.

**Aesthetics** of vehicle parts: produces a **high-gloss** surface finish, improves chemical resistance to **stress cracking**, and has excellent **UV stability**.

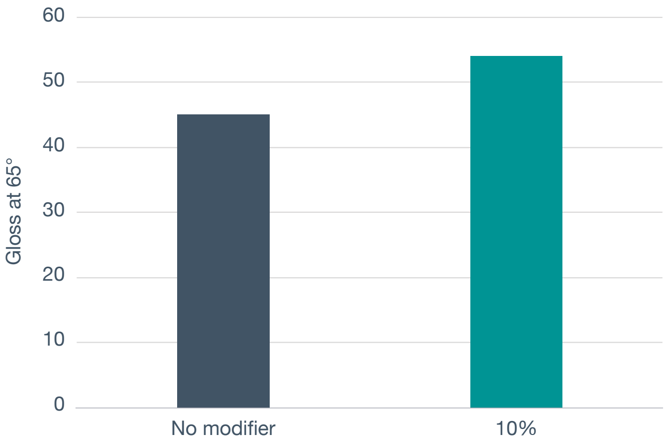
### 1. Impact/Rheology modification

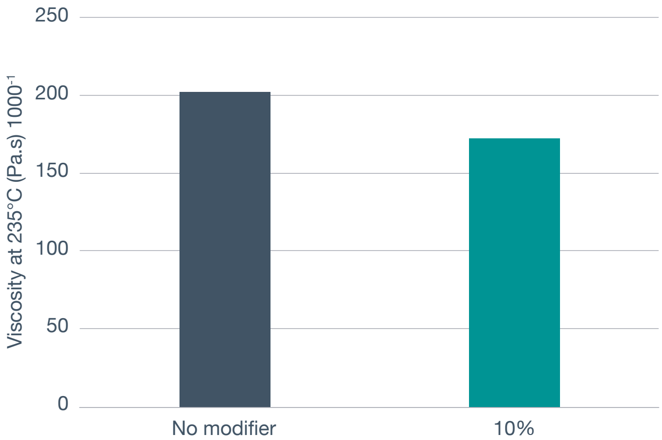
**Incorporating ELVALOY™ AC Copolymers into ABS**

ABS impact performance significantly improves at only 5% incorporation of ELVALOY™ AC Copolymers even at low temperatures.




**Incorporating ELVALOY™ AC Copolymers into recycled ABS**




**25% improvement in gloss** and **15% reduction in viscosity** versus control.

*Typical values, not to be construed as specifications.
Users should confirm results by their own tests.

## D. Polycarbonate & Polycarbonate Blends (PC, PC-ABS, PC-PBT)

An excellent engineering polymer, polycarbonate is very tough at room temperature. However, its toughness deteriorates at low temperatures and if fillers are added.

Adding elastomeric modifiers like **ELVALOY™** and **ELVALOY™ AC Copolymers** can not only boost these properties, but also restore those impacted by the recycling process, or by the presence of unwanted contaminants in the recyclate. It also improves the processing of PC blends by reducing melt viscosity and improving flow. This leads to shorter cycle times, lower melt fracture, and therefore smoother surfaces.

**Impact Resistance:** offers a wide range of impact resistances, including high-performance toughness at low temperatures.

**Ductility:** significantly increases elongation at break.

**Processability:** improves the flow of recyclates by reducing its melt viscosity. This makes them easier to process – reducing injection molding cycle times and improving mold filling.

**Aesthetics** of vehicle parts: produces a **high-gloss** surface finish, improves chemical resistance to **stress cracking**, and has excellent **UV stability** (not suitable for transparent PC applications).

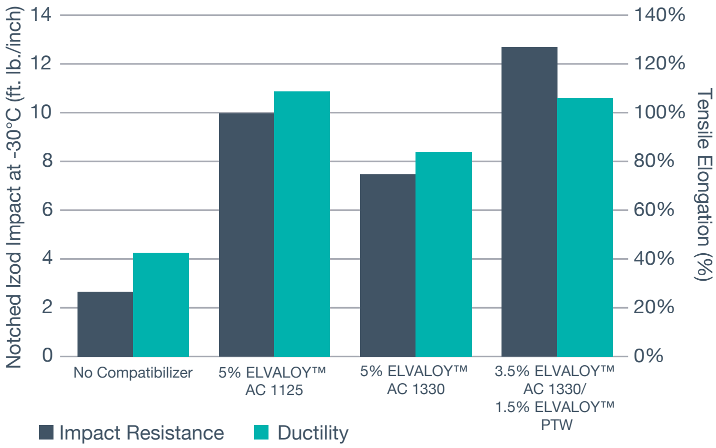
Elvaloy™ copolymers for alloys

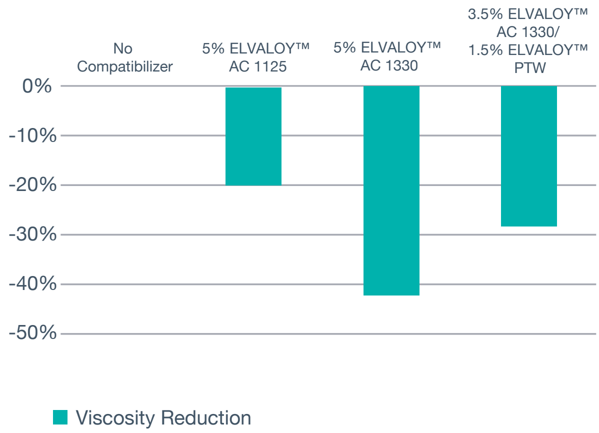
Elvaloy™ AC acrylate copolymers

| PC Attribute | Good to Excellent | Need to Improve |
|---|---|---|
| **High temperature (>-10°C) toughness** | X | |
| **Low temperature toughness (<-10°C)** | | X |
| **Heat deflection temperature (HDT)** | X | |
| **Stiffness** | X | |
| **Electrical properties** | X | |
| **Weatherability** | X | |
| **Flame resistance (FR)** | X | |
| **Toughness with filler** | | X |
| **Chemical resistance** | | X |

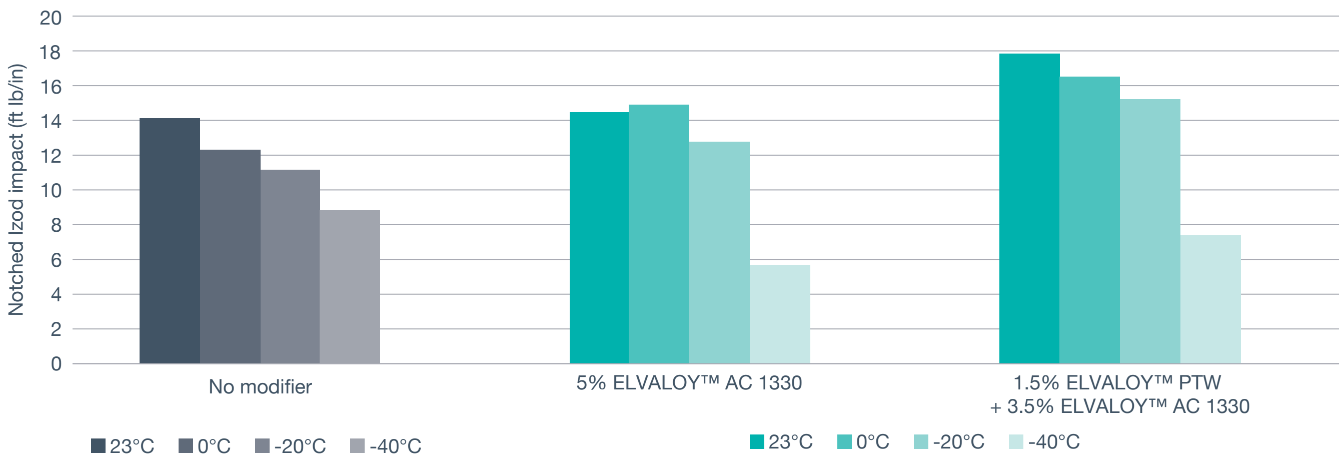
## 1. Impact/Rheology Modification

### Incorporating ELVALOY™ AC Copolymers into PC




### Incorporating ELVALOY™ AC Copolymers into PC-ABS (70%-30%)




**Our wider MobilityScience™ sustainability strategy**

Helping enable the circularity of engineering plastics is just one of the ways that we're helping to build a sustainable future that supports resilient, low-carbon mobility.

Innovating across the full spectrum of automotive plastics, and the full range of mobility challenges, we're committed to driving sustainability in three key areas: **climate protection, safer materials,** and **circular economy**.


*Typical values, not to be construed as specifications. Users should confirm results by their own tests.

## Dow's circular technologies

Zooming in on circularity from our three sustainability goals, we are investing in innovations and collaborations across the value chain, to help build a circular ecosystem for all types of automotive plastic.

### 1 Design

We help design for longer life and end-of-life by bringing in-depth experience and innovative materials that make vehicle parts easier to recover, reuse and recycle, while offering properties needed both for production and for performance during the vehicle's life.

Circulibrium

### 2 Mechanical Recycling

Coupled with our experience in automotive requirements for safety and aesthetics, our technologies support mechanical recycling into new vehicles not just with our PCR offering, but also a wide range of boosters and binders for diverse recyclates.

### 3 Waste to Intermediates Recycling

We give a second life to hard-to-recycle materials like thermosets, by converting them back into monomers, significantly reducing overall product carbon footprint and our reliance on fossil feedstocks.

### 4 Waste to Feedstock Recycling

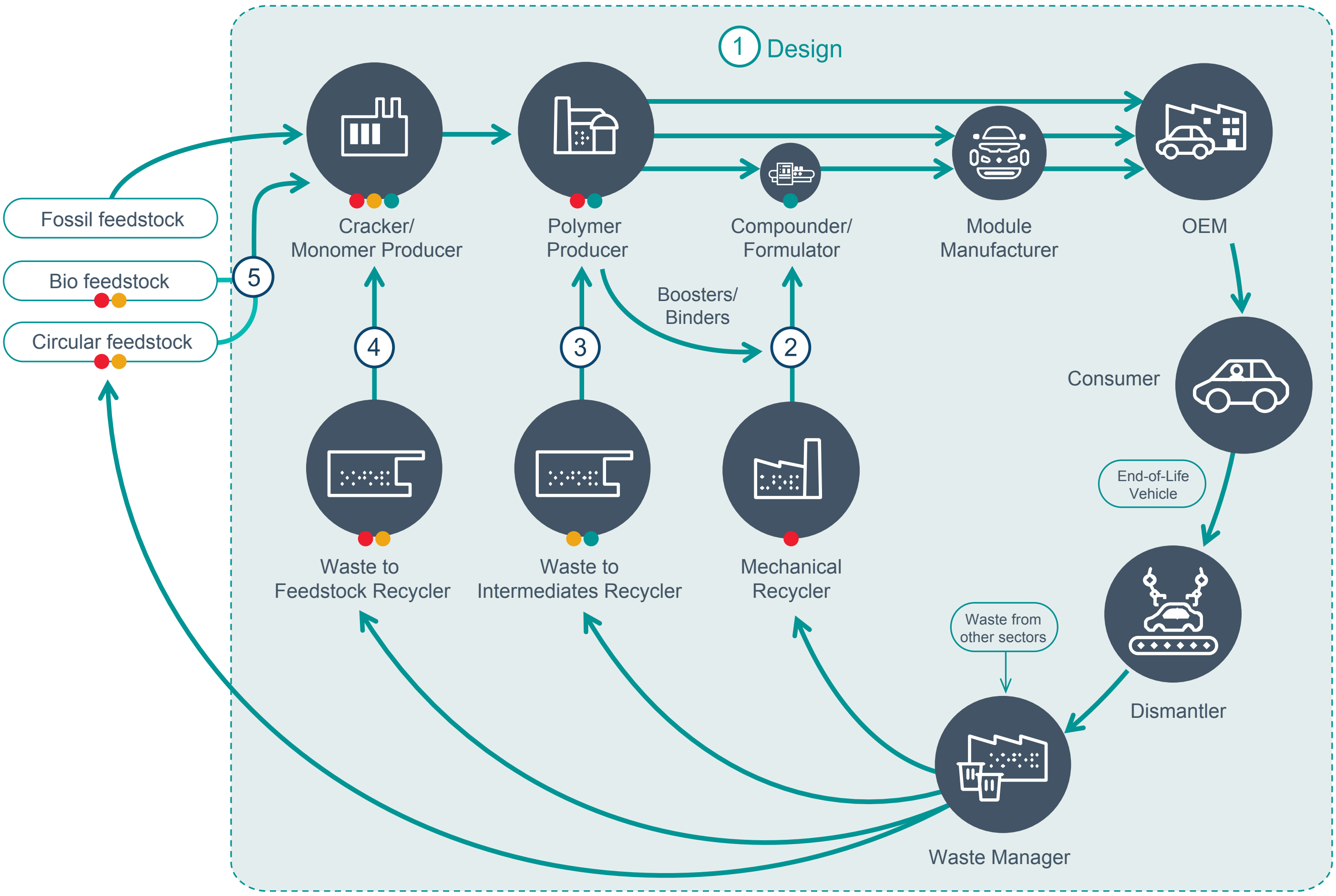
We contribute to the circularity of even harder to recycle streams by converting plastics back into feedstock, producing new materials with identical performance and reducing the plastic waste going into landfilling or incineration.

Renuva

### 5 Bio or Circular Feedstocks

We help the industry realize further decarbonization and circularity with our products made from bio-circular and circular feedstocks. These come from non-food/feed-compete sources and have virgin-identical properties.

Renuva Ecolibrium




| Technologies for Automotive Circularity from Dow & Dow Partners | | |
|---|---|---|
| Polyolefins | Boosters for PP (TPO), PA, PET, PBT, ABS, PC & PC Blends | Exterior (bumpers, etc.), Interior (panels, skins, airbag covers, etc.), Under-the-Hood |
| | EPDM | Weatherseal, Under-the-Hood, Tires |
| | PE | Under-the-Hood (air ducts, windshield water tanks) |
| Polyurethanes | PU (PUR) | Interior (seats, skins, etc.), Acoustics, Battery Systems, Tires |
| Silicones | Silicone Composites, VMQ | Battery Systems, Interior (skins, airbags), Power Electronics/ADAS, Under-the-Hood, Cables & Connectors, Lighting Systems, Tires |

## ② Mechanical Recycling

Dow's innovations in circularity of engineering plastics is part of a wider portfolio of technologies supporting the incorporation of PCR into automotive applications.

| Recycled Polymers | Mechanical Recycling | New Vehicles |
|---|---|---|

### Recycled Polymers

**Polypropylene (TPO/PP-EPDM)**

Bumpers, frames, fenders, door panels, instrument panels, skins, trims

**Polyamide (PA) / Nylon**

Charge air coolers, engine covers, style covers, electrical connectors, oil pans, hubcaps, opening control supports, cooling fans, etc.

**Polyester (PET, PBT)**

Carpet, fabric, insulation, electrical connectors, fastener covers, etc.

**Acrylonitrile Butadiene Styrene (ABS)**

Grille, consoles, panels and trims, housing and supports, etc.

**Polycarbonate & Polycarbonate Blends (PC, PC-ABS, PC-PBT)**

Instrument panel parts and interior trims

Source: A2MAC1

### Mechanical Recycling

**Challenges of recycling polymers into new vehicles**

**1**

**Loss of properties**

Mechanical recycling alters the properties of the plastic, thus creating the need for **impact/ rheology modification**.

**2**

**Cross-polymer contamination**

Commercially available PCR may contain a mix of different polymers. This impurity would require **compatibilization** to produce new plastic compounds.

### New Vehicles

Engage™ 11000 series polyolefin elastomers

Fusabond™ functional polymers

Surlyn™ ionomers

Elvaloy™ copolymers for alloys

Elvaloy™ AC acrylate copolymers

| | Impact Modifier | Compatibilizer | Coupling Agent |
|---|---|---|---|
| Polypropylene (TPO/ PP-EPDM) | ENGAGE™ | FUSABOND™ | FUSABOND™ |
| Polyamide (PA) / Nylon | FUSABOND™ SURLYN™ | FUSABOND™ RETAIN™ | FUSABOND™ |
| Polyester (PET, PBT) | ELVALOY™ ELVALOY™ AC SURLYN™ | ELVALOY™ ELVALOY™ AC | ELVALOY™ ELVALOY™ AC |
| Acrylonitrile Butadiene Styrene (ABS) | ELVALOY™ AC | ELVALOY™ AC | |
| Polycarbonate (PC) & PC Blends (PC-ABS, PC-PBT) | ELVALOY™ ELVALOY™ AC | ELVALOY™ ELVALOY™ AC | FUSABOND™ |

| Binder | |
|---|---|
| Polyurethane (PU) | VORAMER™ |

④ Waste to Feedstock Recycling

⑤ Bio or Circular Feedstocks

**More options for sustainability**
To further help our customers produce materials with circular content, we've developed two special versions of the polymers. More sustainable than standard options, they offer exactly the same performance, so there's no need for requalification.

**CIR**

Polymers with circular content produced using recycled materials – reducing the use of virgin fossil-based resources. This production process is ISCC+ certified on a mass balance basis.

Fusabond CIR functional polymers

Surlyn CIR ionomers

Elvaloy CIR copolymers for alloys

Elvaloy AC-CIR acrylate copolymers

**REN**

Polymers with bio-circular content made using other industries' plant residues as raw materials – which significantly reduces its carbon footprint.

Fusabond REN functional polymers

Surlyn REN ionomers

Elvaloy REN copolymers for alloys

Elvaloy AC-REN acrylate copolymers

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**Recycled Polymers / Circular Feedstocks**

CIR

**Circular option**

**Bio Feedstocks**

REN

**Bio option**

Polymers made with bio-circular feedstocks produced from residues of other industries, reducing the use of virgin fossil resources

- No food/feed competition
- Certified sustainable forestry/farming
- Plant-based resins are ISCC+ certified
- Identical performance to virgin material: **No requalification needed**
- Supporting $CO_2$ reduction versus fossil fuel-based equivalent

**New Vehicles**

**Modifiers and Compatibilizers for Engineering Plastics** in interior, exterior and under-the-hood applications

- Polyamide (PA) / Nylon
- Polyester (PET, PBT)
- Acrylonitrile Butadiene Styrene (ABS)
- Polycarbonate & Polycarbonate Blends (PC, PC-ABS, PC-PBT)

Image Source: A2MAC1

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