

# Compatibilizers: Creating New Opportunity for Mixed Plastics

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Compatibilizers have long been used as a tool in the prime resin industry to create special resin blends that yield desired performance and properties that could only be obtained by a co-polymer blend of resins that would otherwise not be compatible. In layman's terms, compatibilizer additives allow resins that would not neatly blend together to "talk to each other" and bond in a way that creates enhanced performance when compared to either polymer alone. Incompatible polymers prevent their practical use, such as in injection molding parts, because they delaminate during melt processing, causing rejects.

Also, virgin polymers are chain scissored during melt processing and the resultant recycle resin has lesser mechanical properties when compared to the starting virgin resin due to the reduced molecular weight. The use of compatibilizers is being explored increasingly in the recycling industry as a way to create value in mixed feed streams that cannot be further segregated by resin type, either due to technical challenges related to collecting, cleaning and sorting, or economic infeasibility.

## THE OPPORTUNITY

Unfortunately the situation that recyclers are seeing increasingly is a decrease in bale quality and yields. The residual materials that are left over after a bale has been processed are often sold for a few pennies per pound, if they can be sold at all, which is far less than the recyclers actually paid for the material as part of the bale. Recent findings suggest HDPE recyclers are suffering a 20-percent yield loss, while their PET recycling counterparts are experiencing upwards of 40-percent yield loss.<sup>1</sup> This rate of material loss can quickly change the economics of an operation from black to red. Similarly, in bales of material where the resin types are inherently highly mixed, such as bales of plastics from electronics, the most desirable resin types like ABS and HIPS might only make up 60-percent of the bale. What is a recycler to do with the other 40-percent mixed-fraction that might not be separable, again because of technical or economic infeasibility? If that yield loss could be put to use as another valuable feed stream, it can dramatically change the economics of an operation, as well as further divert valuable plastics from the landfill.

In some cases, recyclers are finding that compatibilizers are key to recycling multi-resin products, such as flexible packaging. Without the use of compatibilizers, recovery of some packaging and products would not be possible. These layers of otherwise incompatible resins can be blended and then used in varying levels to make panels and parts for durable goods, creating a true upcycling story. A list of compatibilizers and the materials suppliers that offer them can be found in Appendix A.

## HOW DIFFERENT COMPATIBILIZERS WORK

1. **Bipolar copolymer compatibilizers:** A polymer can be incompatible with another polymer for a number of chemical reasons, including the fact that their polarities are different. Polymers with dissimilar polarities can be made compatible by using bipolar copolymer compatibilizers that bridge the polarities. For example, Santoprene® TPV (see data table) is a block copolymer of polar aromatic styrene monomer and non-polar aliphatic butadiene monomer. When the butadiene styrene block copolymer is added, its built-in bipolarity acts to attract the dissimilar polar polymers creating a compatibility effect. This approach works well with known segregated streams — such as a non-polar polyolefin with a polar polymer such as Nylon (PA) — but is of limited value in post-consumer recycle streams containing a multiplicity of polymers that vary from batch to batch and within a given batch of recycle.
2. **Maleated copolymer compatibilizers:** Bond formation between maleic anhydride-g-polypropylene

<sup>1</sup> Verespej, Mike. Kicking out Contamination, Resource Recycling, August 2014.

(PPg) and polyamide 6 (PA) by in situ block copolymer formation can be called Fusion Bonding. Maleated polymers can be prepared directly by polymerization or by modification during compounding via the reactive extrusion process. Their anhydride groups can react with amine, epoxy and alcohol groups. For example, Fusabond® M603 Resin (see data sheet) is a random ethylene copolymer, incorporating a monomer which is classified as being a maleic anhydride equivalent for application uses. The exact composition is considered to be proprietary information.

Also, styrene maleic anhydride, also known as SMA or SMA<sub>nh</sub>, is a synthetic polymer that is built-up of styrene and is another suitable agent for compatibilizing normally incompatible polymers such as PA/ABS blends. The limitation of this class of additives is their specificity requiring known chemistry and of the polymers to be compatibilized. In addition, maleic anhydride depolymerizes condensation polymers such as PET and PC, thus obviating their use in mixed streams such as PCR containing olefins, PET and assorted other polymers.

3. ***In Situ Macromolecule Catalysts:*** Since monomers become polymers (macromolecules) in the presence of catalysts — and all polymers are catalyzed — in situ macromolecular copolymerization of two or more dissimilar polymers in the melt via in situ catalysis using thermally stable organometallics holds the possibility of allowing the use of high levels of PCR in consumer goods.

A brief study of the history of polymer catalysis using Ziegler-Natta and Metallocene catalysts defines a path for future development.

- Ziegler-Natta catalyst:  
<http://www.britannica.com/EBchecked/topic/657096/Ziegler-Natta-catalyst>
- Metallocene as Olefin Polymerization catalysts:  
[http://www.cobalt.chem.ucalgary.ca/group/met\\_intro.html](http://www.cobalt.chem.ucalgary.ca/group/met_intro.html)

Ester forms of organometallics known as titanates, zirconates, aluminates and zirco-aluminates provide possible chemistries for R&D programs in making high levels of PCR in consumer goods a reality since they are used as esterification catalysts for PET and single-site metallocenes catalysts for polyolefins. In addition, it is possible that this class of catalysts is synergistic with maleated copolymers. The disadvantage of this class of additive is its use is not as yet well known to the recycling industry and recyclers in general are not R&D chemists and require the offering of simple additive systems and processes that can be replicated easily in a practical manner at a reasonable cost. For example, recyclers will have to become more familiar with reactive compounding techniques to optimize the catalysis effects, and will need to have the capability to monitor and adjust melt process conditions to optimize the Work Energy imparted to the interface of the dissimilar polymers (work energy being defined as the area under the plot of polymer melt torque vs. melt screw residence time).

## THE CHALLENGES

Despite the opportunities that compatibilizers may offer in realizing new value in previously overlooked recycle streams, there are some challenges presented when using them with recycled feed streams. One of the main challenges with recycled material is the aforementioned generally inconsistent nature of the resin mix. In many cases, it is very hard to predict the exact mix of resins in any feed stream, let alone the residual of that stream which is usually the remainder from a positive sort of the desired materials. As is demonstrated in Appendix A, compatibilizers specifically target two or more resin types. No “one-size-fits-all” compatibilizer exists on the market today for any mix of materials. For compatibilizers to work consistently, the recycle feed stream itself has to be fairly consistent in resin composition.

On the other hand, where there are varied recycle streams, the use of organometallic esters has to be investigated more thoroughly and its efficacy established. Also, as with any new chemistry, food contact approval for their use has to be obtained.

## HOW TO USE THE GUIDE

Information about the commercially-available compatibilizers and the materials suppliers can be found in Appendix A. A list of the targeted resins that each compatibilizer is designed to affect is also outlined. Those recyclers seeking to test the use of a compatibilizer need to fully understand the make-up of the target feed stream and potential for viability of that stream over time. Also, the recycler has to become more like a custom compounder with a better knowledge of material science and a better understanding of the principles of mixing dissimilar materials such as those faced by seasoned processors in the rubber, color concentrate and thermoplastic industries.

It is the intent of the Recycling Committee of SPI for this document to serve as an initial introduction to how compatibilizer additives can be used to create value out of otherwise no-, or low-value mixed recycle streams. This document serves as the foundation for further demonstration work in this area. It is the ultimate goal of the Committee to provide as much information as possible to highlight the possibilities of this material and facilitate the use of compatibilizers as a solution for residual and mixed feed streams where possible.

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## APPENDIX A: COMPATIBILIZER GUIDE

Material Supplier Company Name	Compatibilizer Brand Name	Target resins for blending (ie, PP and PE)	Website with product information
PolyGroup Inc.	Propolder® MPP2020 20 Micron Powder	PP, Copolymers, Others	<a href="http://www.polygroupinc.com">www.polygroupinc.com</a>
PolyGroup Inc.	Propolder® MPP2040 40 Micron Powder	PP, Copolymers, Others	<a href="http://www.polygroupinc.com">www.polygroupinc.com</a>
PolyGroup Inc.	Novacom® HFS2100 P 150 Micron Powder	PE, Copolymers, Others	<a href="http://www.polygroupinc.com">www.polygroupinc.com</a>
PolyGroup Inc.	Novacom® HFS2100 Pellet	PE, Copolymers, Others	<a href="http://www.polygroupinc.com">www.polygroupinc.com</a>
Kenrich Petrochemicals, Inc.	Ken-React® CAPS® L® 12/L (20% active pellet)	HDPE/PP Blends, Post-Consumer Recycle, Comm./Eng. Thermoplastics	<a href="http://www.4kenrich.com">www.4kenrich.com</a>
Kenrich Petrochemicals, Inc.	Ken-React® CAPOW® L® 12/H (65% active powder)	HDPE/PP Blends, Post-Consumer Recycle, Comm./Eng. Thermoplastics	<a href="http://www.4kenrich.com">www.4kenrich.com</a>
Kenrich Petrochemicals, Inc.	Ken-React® LICA® 12 (100% active liquid)	HDPE/PP Blends, Post-Consumer Recycle, Comm./Eng. Thermoplastics	<a href="http://www.4kenrich.com">www.4kenrich.com</a>
Kenrich Petrochemicals, Inc.	Ken-React® CAPS® KPR® 12/LV (20% active pellet)	HDPE/PP Blends, Post-Consumer Recycle, Comm./Eng. Thermoplastics	<a href="http://www.4kenrich.com">www.4kenrich.com</a>
Kenrich Petrochemicals, Inc.	Ken-React® CAPOW® KPR® 12/H (65% active powder)	HDPE/PP Blends, Post-Consumer Recycle, Comm./Eng. Thermoplastics	<a href="http://www.4kenrich.com">www.4kenrich.com</a>
Kenrich Petrochemicals, Inc.	Ken-React® Titanates & Zirconates	HDPE/PP Blends, PCR, Blends of Two or More Polymers	<a href="http://www.4kenrich.com">www.4kenrich.com</a>
Exxon	Vistamaxx® propylene-based elastomer	polyisobutylene (PIB), styrene isoprene styrene (SIS), polyvinyl chloride (PVC)	<a href="http://www.exxonmobilchemical.com/Chem-English/brands/vistamaxx-propylene-based-elastomers.aspx?ln=productservices">http://www.exxonmobilchemical.com/Chem-English/brands/vistamaxx-propylene-based-elastomers.aspx?ln=productservices</a>
Exxon	Santoprene® TPV		<a href="http://www.exxonmobilchemical.com/Chem-English/brands/santoprene-the-moplastic-vulcanizate-tpv.aspx?ln=productservices">http://www.exxonmobilchemical.com/Chem-English/brands/santoprene-the-moplastic-vulcanizate-tpv.aspx?ln=productservices</a>
Exxon	Vistalon® EPDM Rubber		<a href="http://www.exxonmobilchemical.com/Chem-English/brands/vistalon-ethylene-propylene-diene-epdm-rubber.aspx?ln=productservices">http://www.exxonmobilchemical.com/Chem-English/brands/vistalon-ethylene-propylene-diene-epdm-rubber.aspx?ln=productservices</a>
Exxon	Exact plastomers		
Exxon	Exxelor polymer resins	"most commonly used polar polymers and polyolefins"	<a href="http://www.exxonmobilchemical.com/Chem-English/brands/exxelor-polymer-resins.aspx?ln=productservices">www.exxonmobilchemical.com/Chem-English/brands/exxelor-polymer-resins.aspx?ln=productservices</a>

Material Supplier Company Name	Compatibilizer Brand Name	Target resins for blending (ie, PP and PE)	Website with product information
Dupont	Fusabond® M603	(Recycle Stream) PE/ PA, PE/ EVOH, PA/ EVOH/ PE	<a href="http://www2.dupont.com/Fusabond/en_US/assets/downloads/fusabond_m603.pdf">www2.dupont.com/Fusabond/en_US/assets/downloads/fusabond_m603.pdf</a> <a href="http://www2.dupont.com/Polymer_Modifiers/en_US/functions/polymer-compatibilizer.html">www2.dupont.com/Polymer_Modifiers/en_US/functions/polymer-compatibilizer.html</a>
Dupont	Fusabond® E226	(Recycle Stream) PE/PA, Surllyn EVOH or PA	<a href="http://www2.dupont.com/Fusabond/en_US/assets/downloads/fusabond_e226.pdf">www2.dupont.com/Fusabond/en_US/assets/downloads/fusabond_e226.pdf</a>
Dupont	Bynel® 41E710	(Recycle Stream) PE/EVOH or PA/EVOH/PE	<a href="http://www2.dupont.com/Bynel/en_US/assets/downloads/bynel_41e710.pdf">www2.dupont.com/Bynel/en_US/assets/downloads/bynel_41e710.pdf</a>
Dupont	Surllyn® 1650	(Recycle Stream) Surllyn EVOH or PA	<a href="http://www2.dupont.com/Surllyn/en_US/assets/downloads/surllyn_1650.pdf">www2.dupont.com/Surllyn/en_US/assets/downloads/surllyn_1650.pdf</a>
Dupont	Fusabond® P353	(Recycle Stream) PP/PA or PP/EVOH/PP	<a href="http://www2.dupont.com/Fusabond/en_US/assets/downloads/fusabond_p353.pdf">www2.dupont.com/Fusabond/en_US/assets/downloads/fusabond_p353.pdf</a>
Dupont	Elvaloy® PTW	(Recycle Stream) Polysters/ PE	<a href="http://www2.dupont.com/Elvaloy/en_US/assets/downloads/elvaloy_ptw.pdf">www2.dupont.com/Elvaloy/en_US/assets/downloads/elvaloy_ptw.pdf</a>
Dupont	Elvaloy® 3427AC	(Recycle Stream) Polysters/ PE	<a href="http://www2.dupont.com/Elvaloy/en_US/assets/downloads/elvaloy_ac_3427.pdf">www2.dupont.com/Elvaloy/en_US/assets/downloads/elvaloy_ac_3427.pdf</a>
Arkema	Lotader® AX8840	PET, PBT, PPS, Metal, Paper, Glass	<a href="http://www.arkema.com/export/shared/content/media/downloads/products-documentations/ceca/pof/lotader/tds-lotader-ax8840.pdf">www.arkema.com/export/shared/content/media/downloads/products-documentations/ceca/pof/lotader/tds-lotader-ax8840.pdf</a>
Arkema	Lotader® 3210	Polyamide/polyolefin	<a href="http://www.arkema.com/export/shared/content/media/downloads/products-documentations/ceca/pof/lotader/tds-lotader-3210.pdf">www.arkema.com/export/shared/content/media/downloads/products-documentations/ceca/pof/lotader/tds-lotader-3210.pdf</a>
Arkema	Lotader® 3410	Polyamide/polyolefin	<a href="http://www.arkema.com/export/shared/content/media/downloads/products-documentations/ceca/pof/lotader/tds-lotader-3410.pdf">www.arkema.com/export/shared/content/media/downloads/products-documentations/ceca/pof/lotader/tds-lotader-3410.pdf</a>
Arkema	Lotader® 3430	Polyamide/polyolefin	<a href="http://www.arkema.com/export/shared/content/media/downloads/products-documentations/ceca/pof/lotader/tds-lotader-3430.pdf">www.arkema.com/export/shared/content/media/downloads/products-documentations/ceca/pof/lotader/tds-lotader-3430.pdf</a>
Arkema	Lotader® 4700	Polyamide/polyolefin	<a href="http://www.arkema.com/export/shared/content/media/downloads/products-documentations/ceca/pof/lotader/tds-lotader-4700.pdf">www.arkema.com/export/shared/content/media/downloads/products-documentations/ceca/pof/lotader/tds-lotader-4700.pdf</a>

Material Supplier Company Name	Compatibilizer Brand Name	Target resins for blending (ie, PP and PE)	Website with product information
Arkema	Lotader® AX8900	PBT, PET, PPS	<a href="http://www.arkema.com/export/shared/.content/media/downloads/products-documentations/ceca/pof/lotader/tds-lotader-ax8900.pdf">www.arkema.com/export/shared/.content/media/downloads/products-documentations/ceca/pof/lotader/tds-lotader-ax8900.pdf</a>
Arkema	Lotader® 4720	Polyamide/polyolefin	<a href="http://www.arkema.com/export/shared/.content/media/downloads/products-documentations/ceca/pof/lotader/tds-lotader-er-4720.pdf">www.arkema.com/export/shared/.content/media/downloads/products-documentations/ceca/pof/lotader/tds-lotader-er-4720.pdf</a>
Poly Ad	Does not list compatibilizers	PA, PC, PBT, POM, TPE, TPO, TPV, ABS, PS, PE, PP	<a href="http://www.polyadservices.com/pas_polyad-brochure.pdf">www.polyadservices.com/pas_polyad-brochure.pdf</a>
Chemtura			<a href="http://www.adiprene.com/corporate-view/2/v/index.jsp?vgnextoid=2fd-f3a147007c310VgnVCM1000002b36c-cadRCRD">www.adiprene.com/corporate-view/2/v/index.jsp?vgnextoid=2fd-f3a147007c310VgnVCM1000002b36c-cadRCRD</a>
BASF	Baxxodur® EC 301	Cross Linking agent for epoxy resin systems	<a href="http://www.basf.com/group/corporate/en/brand/BAXXODUR_EC_301">www.basf.com/group/corporate/en/brand/BAXXODUR_EC_301</a>
BASF	Baxxodur® EC 311	Cross Linking agent for epoxy resin systems	<a href="http://www.basf.com/group/corporate/en/brand/BAXXODUR_EC_311">www.basf.com/group/corporate/en/brand/BAXXODUR_EC_311</a>
BASF	Baxxodur® EC 303	Cross Linking agent for epoxy resin systems	<a href="http://www.basf.com/group/corporate/en/brand/BAXXODUR_EC_303">www.basf.com/group/corporate/en/brand/BAXXODUR_EC_303</a>
BASF	Baxxodur® EC 280	Cross Linking agent for epoxy resin systems	<a href="http://www.basf.com/group/corporate/en/brand/BAXXODUR_EC_280">www.basf.com/group/corporate/en/brand/BAXXODUR_EC_280</a>
BASF	Baxxodur® EC 201	Cross Linking agent for epoxy resin systems	<a href="http://www.basf.com/group/corporate/en/brand/BAXXODUR_EC_201">www.basf.com/group/corporate/en/brand/BAXXODUR_EC_201</a>
BASF	Baxxodur® EC 130	Cross Linking agent for epoxy resin systems	<a href="http://www.basf.com/group/corporate/en/brand/BAXXODUR_EC_130">www.basf.com/group/corporate/en/brand/BAXXODUR_EC_130</a>
BASF	Baxxodur® EC 110	Cross Linking agent for epoxy resin systems	<a href="http://www.basf.com/group/corporate/en/brand/BAXXODUR_EC_110">www.basf.com/group/corporate/en/brand/BAXXODUR_EC_110</a>
Summa Industrial Polymers Recovered		PP/PE	<a href="http://www.summapolimeros.com.br/english.html">http://www.summapolimeros.com.br/english.html</a>
Kraton Polymers	Styrennics	Polypropylene / Polystyrene or PPE, Nylon / Polyethylene or Nylon / Polypropylene, Nylon / Polystyrene or PPE, Polypropylene / Polyethylene	<a href="http://www.kraton.com/products/modification/polymer_modification.php">http://www.kraton.com/products/modification/polymer_modification.php</a>

Material Supplier Company Name	Compatibilizer Brand Name	Target resins for blending (ie, PP and PE)	Website with product information
Kraton Polymers	Polypropylene	Polypropylene / Polystyrene or PPE, Nylon / Polyethylene or Nylon / Polypropylene, Nylon / Polystyrene or PPE, Polypropylene / Polyethylene	<a href="http://www.kraton.com/products/modification/polymer_modification.php">http://www.kraton.com/products/modification/polymer_modification.php</a>
Kraton Polymers	Polyamides	Polypropylene / Polystyrene or PPE, Nylon / Polyethylene or Nylon / Polypropylene, Nylon / Polystyrene or PPE, Polypropylene / Polyethylene	<a href="http://www.kraton.com/products/modification/polymer_modification.php">http://www.kraton.com/products/modification/polymer_modification.php</a>
Kraton Polymers	Polycarbonate	Polypropylene / Polystyrene or PPE, Nylon / Polyethylene or Nylon / Polypropylene, Nylon / Polystyrene or PPE, Polypropylene / Polyethylene	<a href="http://www.kraton.com/products/modification/polymer_modification.php">http://www.kraton.com/products/modification/polymer_modification.php</a>
Eastman	Eastman G-3003 Polymer		<a href="http://www.eastman.com/Pages/ProductHome.aspx?product=71000983">www.eastman.com/Pages/ProductHome.aspx?product=71000983</a>
Byk	ZAC	Ionic cross linking agent with carboxyl functional polymers	<a href="http://www.byk.com/fileadmin/byk/additives/highlights/usa_wax_emulsions/25_Oktober_2013/TDS_ZAC_US.pdf">www.byk.com/fileadmin/byk/additives/highlights/usa_wax_emulsions/25_Oktober_2013/TDS_ZAC_US.pdf</a>
Dow	RETAIN™	PE/EVOH or PA/EVOH/PE (Recycle Stream Compatibilizer)	<a href="http://plastics.ulprospector.com/data-sheet/e234765/retain-3000">http://plastics.ulprospector.com/data-sheet/e234765/retain-3000</a>
Dow	AMPLIFY TY™	PE/EVOH or PA/EVOH/PE (Recycle Stream Compatibilizer)	<a href="http://www.dow.com/packaging/solutions/amplify-ty.htm">http://www.dow.com/packaging/solutions/amplify-ty.htm</a>
Dow	INTUNE™	PE/PP Compatibilizer	<a href="http://www.dow.com/elastomers/news/2013/20131017a.htm">http://www.dow.com/elastomers/news/2013/20131017a.htm</a>

## MATERIAL SUPPLIERS

Company name	Contact	Email	Webpages
Poly Ad	Dan Lee	<a href="mailto:dan.lee@polyadservices.com">dan.lee@polyadservices.com</a>	
BASF	Arthur Finkle	<a href="mailto:arthur.finkle@basf.com">arthur.finkle@basf.com</a>	
Michigan Molecular Institute(MMI)	Adrian Merrington	<a href="mailto:merrington@mmi.org">merrington@mmi.org</a>	<a href="http://www.mmi.org/merrington.html">www.mmi.org/merrington.html</a>
Green Line Polymers		<a href="mailto:theber@greenlinepolymers.com">theber@greenlinepolymers.com</a>	<a href="http://www.greenlinepolymers.com/industries_served.asp">www.greenlinepolymers.com/industries_served.asp</a>
Summa Industrial Polymers Recovered		<a href="mailto:lucas@summapolimeros.com.br">lucas@summapolimeros.com.br</a>	
Greening Eco (Brazil)		<a href="mailto:chicko@greening.eco.br">chicko@greening.eco.br</a>	
Sun Chemicals		<a href="mailto:Leonard.Davis@sunchemical.com">Leonard.Davis@sunchemical.com</a>	
Arkema		<a href="mailto:mark.lavach@arkema.com">mark.lavach@arkema.com</a>	
Dupont		<a href="mailto:Carole.A.Davies@dupont.com">Carole.A.Davies@dupont.com</a>	
Exxon		<a href="mailto:donna.s.davis@exxonmobil.com">donna.s.davis@exxonmobil.com</a>	
Poly Group			<a href="http://www.polygroupinc.com/Pages/Compatibilizers.aspx">www.polygroupinc.com/Pages/Compatibilizers.aspx</a>
Kenrich Petrochemicals	Sal Monte	<a href="mailto:sjmonte@4kenrich.com">sjmonte@4kenrich.com</a>	<a href="http://www.4kenrich.com">www.4kenrich.com</a>
Byk (Altana)			<a href="http://www.byk.com/en/contact.html">www.byk.com/en/contact.html</a>
Kraton® Polymers			<a href="http://www.kraton.com/products/modification/polymer_modification.php">www.kraton.com/products/modification/polymer_modification.php</a>
Eastman			<a href="http://www.eastman.com/Pages/ProductHome.aspx?product=71000983">www.eastman.com/Pages/ProductHome.aspx?product=71000983</a>
Metabolix		<a href="mailto:makhthar@metabolix.com">makhthar@metabolix.com</a>	
Dow Chemical	Brian Walther	<a href="mailto:bwwalther@dow.com">bwwalther@dow.com</a>	<a href="http://www.dowpackaging.com">www.dowpackaging.com</a>



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