

Plastics Recycling and the Circular Economy: Catalytic and Compatibilization Solutions

Multi-Client Study Presentation

June 2020



Plastics Recycling and the Circular Economy: Catalytic and Compatibilization Solutions

This TCGR multi-client study was launched in December 2019 and completed in June 2020. The study's scope, and specific contents (as depicted in the ToFC beginning on page 11 of this presentation), reflect the inputs from a group of "charter" subscribers who indicated their priorities for coverage, areas to be expanded/deepened and focal points for emphasis in opportunity identification. These are leading industrial developers, suppliers, and end-users of technologies and plastics resins addressing recycling and the circular economy.

I. ABSTRACT

There is an intense R&D effort being undertaken by plastics producers, industry consortia and academia globally to understand and appreciate the hurdles to be overcome and to economically resolve a serious improvement in the recyclability of plastics, which has taken a center stage in a global debate (Circular Economy Action Plan, 2018). It is hoped that this will transform the way plastic products are designed, used, produced and recycled in the EU and other industrial countries. China, the U.S. and Western Europe and other regions are pressing for sustainable solutions to plastic recycling and a drastic reduction of plastic waste to the marine environment. (Azocleantech, 2017). This study is designed to assist the plastics and polyolefin industries to identify new pipeline technologies and strategic commercial directions which will help speed up their resolutions to these challenges in an economical way. It addresses current state-of-art (SoA) in technology and commercial development, identifies and addresses progress towards viability in two (2) promising approaches – notably catalytic and compatibilization – and provides strategic guidance on the competitive landscape and future investment. It is a "must have," industrially-sourced assessment for addressing the current industry need from resin producers, process licensors and catalyst/compatibilizer suppliers from a practical perspective.

II. BACKGROUND

All open literature and related studies to date do an adequate job of defining "the challenge" from both a market statistical basis, as well as defining the current plastics industry recycling status, i.e. the state-of art (SoA) in recycling technologies. What is clearly missing is a visionary industrial oriented Technology Roadmap for the next 5-10 years that concentrates R&D and commercial development efforts to speed up deployment, improving both efficiency and effectiveness of implementation, particularly in mixed plastics waste.

The missing factors to be addressed more fully are:

- What new pipeline technologies for different segments, e.g. PET, polyolefins, mixed plastics, etc., are likely to be the best directions for producers and industry to pursue economically?
- What do plastic producers currently think about this challenge, and what are their plans to address the issue? Without their support and input, the process will undoubtedly be slower.
- What likely country, regional and global regulations will impact each company's decision making?

No one disputes this is a decade long challenge! The issues to be resolved go beyond technical to include economic ones, based on the commercial understanding that currently the collection, separation of physical plastics streams, and the conversion back to monomers or recyclable technologies as they stand to date, are not yet ready for “prime time.” In this multiclient study, TCGR takes a lead in providing viable technological directions from both pipeline R&D and commercial strategy perspectives.

Our leading networks from within the plastics industries, as well as from our Dialog Group®, industrially and from academia, provide us with unique resources to interface on a global basis, to provide insights that would not be readily available elsewhere. We are also very operations focused; therefore we can include production insights unavailable from others.

The challenge is, of course, currently diverse and fragmented, so in this visionary report we offer a consolidation of current knowledge, along with direct field interviews with the developers of next generation solutions. We believe the timeliness and vision will assist resin producers, process licensors, catalyst manufacturers and the logistics systems in improving the rate of recycling in a faster manner. There is much rhetoric and confusion that needs to be uncoiled to create a solid pathway forward. If we are to collectively resolve this issue together, then some sound thinking and minds must prevail. By consolidating this global information, with the best scientific and commercial minds, we have the opportunity to make some better investment and R&D investment decisions.

Industry has taken significant steps recently:

- On January 16, 2019 **The Alliance to End Plastic Waste (AEPW)** was launched, which has committed over \$1BIL, with the goal of investing \$1.5 BIL over the next five years. The founding members of this consortium include; BASF, Berry Global, Braskem, Chevron Phillips, Clariant, Covestro, Dow, DSM, ExxonMobil, Formosa Plastics, Henkel, LyondellBasell, Mitsubishi Chemical, Mitsui Chemical, NOVA Chemicals, Oxychem, Polyone, Procter & Gamble, Reliance, SABIC, Suez, Shell, SCG Chemicals, Sumitomo Chemical, TOTAL, Veolia, and Versalis (ENI).

As of July 10, 2019 this consists of 12 new companies; Equate Petrochemical, Gemini, Grupo Phenix, Mondi, Novolex, Pepsi Co, Sealed Air Corporation, Sinopec, SKC, Storopak, TOMRA and Westlake. In announcing this expansion, AEPW stated by advancing a global coordinated effort focused on recovering, recycling and reusing plastics, we will develop a global business model that creates value from waste.

- In the polystyrene segment “**Styrenics Circular Solutions (SCS)**” was formed in December, 2018 with four founding members INEOS Styrolution, TOTAL, Trinseo, and Versalis (Eni); in June, 2019 Repsol joined. This consortium has teamed up with Agilyx to develop depolymerization back to monomers.

B. New Advanced Compatibilizer Solutions

Many industry papers have summarized commercially available compatibilizers including those from The Society of Plastics Industry or SPI (SPI, 2015). The current challenge is not available solutions but rather cost/performance ones for commercial recyclers. Also, one of the challenges is that each batch of mixed plastics has a different composition and most recyclers are not sophisticated to be able to understand the chemistry to adjust to these moving targets within the field. No “one-size-fits-all” is a common phrase within the industry.

In block copolymer (BCP) compatibilizers, the blocks can be chemically identical or similar to the blend components to be compatibilized. BCPs comprised of iPP-miscible and PE-miscible blocks are thus viable compatibilizers for PE/iPP blends, since BCPs are thermodynamically driven to immiscible interfaces. The copolymer helps to weld commercial PE and PP together, enables morphological control, and transforms brittle materials into mechanically tough blends (Figure 2)

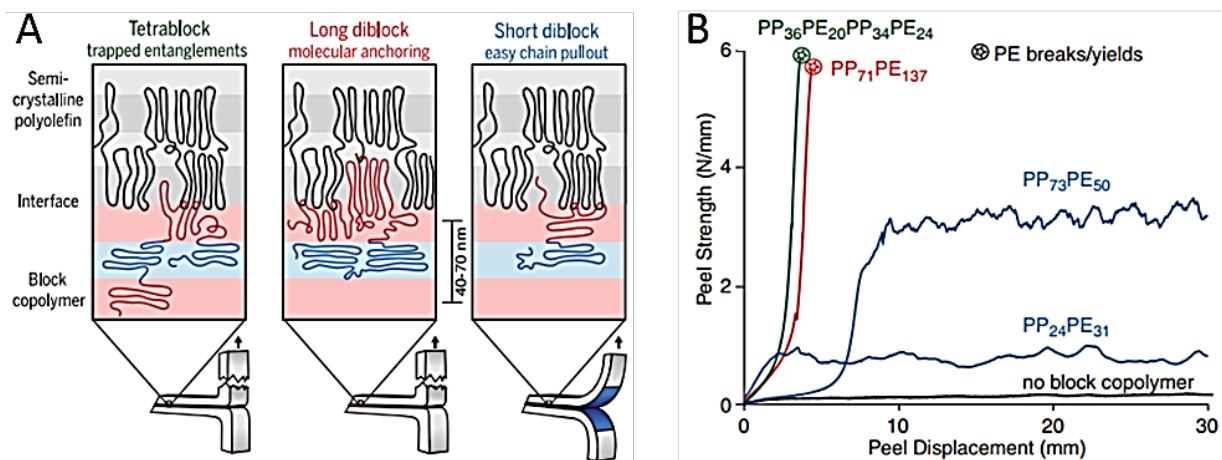


Figure 2. Block copolymers as non-reactive compatibilizers for PE/iPP blends. A) Proposed models to explain the adhesive differences between (left) tetrablock, (middle) high Mn diblock, and (right) low Mn diblock copolymers. B) Peel strength of PE/iPP blends in the presence of different block copolymer compatibilizers.

Source: Eagan et al., 2017

One of the objectives of this study is to provide industry guidance to resin producers, technology developers and ultimately to recyclers on how to better anticipate these mix changes, to reduce rejected waste. We have encouraged subscribers to support the education needs in the marketplace, needed to bridge these gaps.

In order to focus the content of this well researched document, we have also included more involvement of our project team. Specifically, with sufficient “charter subscriber” ToFC inputs (a practice always followed by TCGR multi-clients), we have been able to tailor the scope/content for subscribers to make it a study, “by the industry, for the industry.” This is a unique hallmark of our operations.

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III. THE NEED FOR THIS STUDY

The case for choosing this subject has never been clearer. Due to increasing environmental drivers, the need for such a study has never been more timely. Major plastics producers are now committed to significant reductions in plastic landfill, and the reduction of waste plastics finding their way into our oceans. The older methods of disposal like incineration or even pyrolysis are no longer acceptable due to tightening emissions and CO₂ regulations.

One of the key issues is that different plastics waste streams do not mix when thermally heated, like oil and water. So new compatibilizer technologies are an R&D direction that needs to be better explored. It is also clear that pyrolysis approaches are not an economic solution. This study will reveal more advanced approaches being undertaken on a global basis. There are opportunities in catalysis, in determining the molecular structure of the resin (including co-monomer incorporation containing functional groups) to design-in re-use/recycle functionality.

The benefits of aggregating the multiple approaches into one study creates an opportunity to extract and determine which approaches or pathways are most beneficial given the local circumstances, providing value to chemical (olefins and other monomer) producers and suppliers of different types of plastics.

Critical topics this study addresses include:

1. State-of Art (SoA) in industry investments and partnerships in existence.
2. New pipeline technologies in for the next 5-10 years, including benchmarking economics where available, key players, pilots and R&D investments.
3. Regional outlooks based on market opportunities and regulatory drivers.
4. Strategies for implementation.

This study also complements other studies undertaken by The Catalyst Group Resources, demonstrating TCGR's unique capability and resources to deliver exceptional insight. Recent multi-client studies can be seen on <http://www.catalystgrp.com> for more detail.

- ***Polyolefin (PO) Catalysts and Processes: Competitive Implications of Industry Consolidation*** (completed in July 2018)
- ***Polyolefin (PO) Catalysts & Processes: Technological and Commercial Impacts on PE and PP, 2015-2025*** (completed in May 2017)
- ***Progress in Technology for Polyolefin Production: Quantifying the Value-Added of Advanced Catalysts, Co-catalysts/Activators and Stereoregulators*** (completed in December 2011)

IV. SCOPE AND METHODOLOGY

As seen in the report's actual Table of Contents (TofC) beginning on page 11, which has been revised/expanded to reflect the inputs/feedback of "charter" subscribers who signed up prior to study launch, TCGR's recently completed study focuses on new technologies in pilot and in the R&D pipeline that enhance the economics through catalysis and compatibilizers which retain or enhance virgin resin properties, so that we can find pathways beyond lower value reuses such as road asphalt and park benches. There is already considerable work being undertaken by Borealis Everminds™ and LyondellBasell in these directions. At the latest Society of Plastics Engineers (SPE) "Polyolefins Conference" in Houston (February 2019), we also conducted interviews with a number of companies developing interesting new compatibilization technologies.

SECTION III summarizes the current State-of-Art (SOA) and emerging technologies for all key resins including PET, Styrenics, Polyolefins and Thermoplastics in general.

SECTION IV and SECTION V document pipeline technologies from patent analyses, literature reviews, and field interviews with producers and pilot companies, first in the area of catalysts, then in the area of compatibilizers.

SECTION VI examines early stage technologies by analysis of the patent and technical literature, with a goal of providing plastics producers a peek into the competitive direction and potential promising technologies being promoted within the industry.

SECTION VII presents the view of resin producers, converters, users, and trade groups to obtain a better clarity on the industry needs and wants moving forward during the next 5-10 years.

SECTION VIII documents existing and pending regulations globally, and the potential impact those regulations have on the plastics and plastics recycling value chains.

SECTION IX presents TCGR's strategies and recommendations.

V. QUALIFICATIONS

The Catalyst Group Resources, a member of The Catalyst Group, works with clients to develop sustainable competitive advantage in technology-driven industries such as chemicals, refining, petrochemicals, polymers, specialty/fine chemicals, biotechnology, pharmaceuticals, and environmental protection. We provide concrete proven solutions based on our understanding of how technology impacts business.

Using our in-depth knowledge of molecular structures, process systems, and commercial applications, we offer a unique combination of business solutions and technology skills through a range of client-focused services. Often working as a member of our clients' planning teams, we combine our knowledge of cutting-edge technology with commercial expertise to:

- Define the business and commercial impacts of leading-edge technologies
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- Assess technology options through strategy development, including:
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- Lead and/or manage client-sponsored R&D programs targeted through our opportunity identification process.
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 - Timely technical publications

The client-confidential assignments conducted by The Catalyst Group include projects in:

- Reinventing R&D pipelines
- Technology alliances
- Technology acquisition
- Market strategy

We have built our consulting practice on long-term client relationships, dedication, and integrity. Our philosophy is clear and focused:

***We Provide the "Catalysts" for Business Growth by Linking Technology
and Leading-Edge Business Practices to Market Opportunities***

VI. DELIVERABLES AND PRICING

This report is timely and strategically important to those industry participants and observers both monitoring and investing in the development and implementation of technologies for the conversion of waste mixed plastics recycling. TCGR’s report, based on technology evaluations, commercial/market assessments and interviews with key players goes beyond public domain information. As a result, subscribers are requested to complete and sign the “Order Form and Secrecy Agreement” on the following page.

The study, “***Plastics Recycling and the Circular Economy: Catalytic and Compatibilization Solutions***” was completed in June 2020.

<u>Post-production subscribers*</u>	<u>after publication</u>	US\$21,000
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Plastics Recycling and the Circular Economy: Catalytic and Compatibilization Solutions

Report in PDF format, in addition to subscription price	US\$1,000
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** Charter subscribers (those who signed up for the study before its launch) had the opportunity to work with TCGR to further refine the scope of the report by nominating specific voice of customer and/or study content as well as delineating areas of particular interest for inclusion in the assessment.*

ORDER FORM AND SECRECY AGREEMENT

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Please enter our order for **“Plastics Recycling and the Circular Economy: Catalytic and Compatibilization Solutions”** completed in June 2020, as follows:

_____ **“Plastics Recycling and the Circular Economy: Catalytic and Compatibilization Solutions,”** as a “post-production” subscriber for US\$21,000.

_____ Please enter our order for the study to be delivered in PDF (Adobe Acrobat) format for use across our sites/locations (i.e., site license) for an additional \$1,000.

_____ Please send us _____ additional printed copies @ \$250 each.

In signing this order form, our company agrees to hold this report confidential and not make it available to subsidiaries unless a controlling interest (>50%) exists.

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Plastics Recycling and the Circular Economy: Catalytic and Compatibilization Solutions

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