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, LyonndelBasell, 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.
In the PET segment, commercial operations are already underway, to depolymerize using hydrolysis or glycolysis processes. Eastman just announced conversion of their Kingsport, TN to recycle waste PET into new products. Others, including Dow, Shell and even Kodak have chosen directions, as PET is already the most recycled plastic globally, enhanced by the ability to convert PET into yarns and fabrics for the clothing industries. These processes are enhanced using Zn acetate (and other) catalysts. We will benchmark these alternatives.

Because Styrenics and PET are so well documented (although we have cameo developments), we have focused on the largest challenge involving polyolefins (PO) and mixed plastics wastes (PET/PO, PVC, nylon and other mixtures) which represent about 75-80% of this report, where a better and deeper understanding is needed.

A. New Advanced Catalytic Solutions

A group at Waste Technologies reported the conversion of waste HDPE to liquid hydrocarbon fuel by pyrolysis-catalytic cracking using CuCO$_3$ at 390 °C (Singh et al., 2018). The deconstruction mechanisms are summarized in Figure 1. Conversion of HDPE to liquid hydrocarbon fuel increased in the presence of CuCO$_3$, which is converted to CuO at the elevated reaction temperature. Basic sites in CuO may generate carbenium ions, resulting in an increase in the olefin yield. Carbenium ions derived from lower hydrocarbons may combine to give higher cyclic or aromatic hydrocarbons.

![Figure 1. Mechanisms of waste HD-PE plastic using pyrolysis-catalytic cracking over CuCO$_3$. Source: Singh et al., 2018](image-url)
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](image)

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” ToC 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.
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)
- **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 (ToC) 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
- Develop technology strategies that support business objectives.
- Assess technology options through strategy development, including:
  - Independent appraisals and valuations of technology/potential
  - Acquisition consulting, planning and due diligence
- Provide leading-edge financial methodology for shareholder value creation
- Lead and/or manage client-sponsored R&D programs targeted through our opportunity identification process.
- Provide leading information and knowledge through:
  - World-class seminars, conferences and courses
  - 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.

Post-production subscribers* after publication US$21,000

Plastics Recycling and the Circular Economy: Catalytic and Compatibilization Solutions

Report in PDF format, in addition to subscription price US$1,000

* 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:

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CONTENTS

SECTION I. INTRODUCTION/BACKGROUND .............................................................................. 1
   A. BACKGROUND .................................................................................................................... 1
   B. SCOPE AND OBJECTIVES ............................................................................................... 2
   C. THE STUDY TEAM .......................................................................................................... 3
   D. COMMON ABBREVIATIONS USED .................................................................................. 4
   E. REFERENCES .................................................................................................................... 5

SECTION II. EXECUTIVE SUMMARY ..................................................................................... 7
   A. OVERVIEW OF THE CHALLENGES .................................................................................. 7
   B. PLASTICS RECYCLING ..................................................................................................... 8
   C. SUBSTAINABILITY AND CIRCULARITY ........................................................................... 12
   D. REGULATORY APPROACHES .......................................................................................... 13
   E. REFERENCES ................................................................................................................... 14

SECTION III. RECYCLING OF PLASTICS: STATE OF THE ART AND EMERGING TECHNOLOGIES ......................................................................................... 15
   A. POLYOLEFIN', PET, STYRENICS, AND MIXED PLASTICS RECYCLING MARKET .......... 15
      1. Introduction .................................................................................................................. 15
      2. Post-Consumer Recycling (PCR) ................................................................................. 18
      3. Post-Industrial Recycling (PIR) ................................................................................. 20
   B. RECYCLING TECHNOLOGIES ....................................................................................... 22
      1. Reuse/Repurposing/Upcycling .................................................................................... 22
      2. Mechanical Recycling (MR) ..................................................................................... 23
      3. Gasification ................................................................................................................ 25
   C. LIMITATIONS TO CURRENT PRACTICE ...................................................................... 26
      1. Scalability ..................................................................................................................... 26
      2. Segregation and Sorting ............................................................................................ 28
      3. Performance Gaps ..................................................................................................... 29
      4. Life Cycle Analysis (or Assessment) – LCA ............................................................... 30
   D. EMERGING TECHNOLOGIES BY PROVIDER ............................................................... 31
      1. Loop Industries .......................................................................................................... 32
      2. PureCycle Technology ............................................................................................... 33
3. BP .................................................................................................................................... 34
4. Agilyx .................................................................................................................................. 35
5. Frauenhofer Polystyrene Loop .......................................................................................... 37
6. Polystyvert .......................................................................................................................... 38
7. Unilever CreaSolv .................................................................................................................. 39
8. APK Newcycling .................................................................................................................... 39
9. IBM VolCat ............................................................................................................................ 40
10. Carbios .................................................................................................................................. 42
11. SABIC .................................................................................................................................. 42
12. Demeto Project ....................................................................................................................... 43
13. Pyrowave ................................................................................................................................ 43
14. BioCellection ......................................................................................................................... 44
E. REFERENCES ......................................................................................................................... 45

SECTION IV. CHEMICAL RECYCLING/UPCYCLING OF POLYOLEFINS .......... 49
A. CATALYTIC DEPOLYMERIZATION ...................................................................................... 50
   1. Catalytic Pyrolysis ................................................................................................................ 51
   2. Hydrocracking ...................................................................................................................... 55
   3. Alkane Metathesis ................................................................................................................. 56
   4. Oxidative Depolymerization ............................................................................................... 57
B. UPCYCLING TO NOVEL PRODUCTS ................................................................................. 58
C. POST-FUNCTIONALIZATION OF POLYOLEFINS ......................................................... 59
D. COMPATIBILIZER: BLENDING/INJECTION ....................................................................... 60
   1. Reactive Compatibilization ............................................................................................... 60
   2. Non-Reactive Compatibilization ......................................................................................... 62
E. NOVEL POLYMERS ............................................................................................................. 64
F. REFERENCES ......................................................................................................................... 66

SECTION V. NEW COMPATIBILIZATION TECHNOLOGIES ............................................. 73
A. INTRODUCTION ..................................................................................................................... 73
   1. Why Blend Polymers? ......................................................................................................... 73
   2. Blend Morphologies ............................................................................................................. 74
   3. Types of Compatibilizers ..................................................................................................... 75
B. COMPATIBILIZERS FOR BLENDS WITH POLYOLEFINS ............................................. 75
   1. Existing Compatibilizer Solutions ....................................................................................... 75
2. Polyolefin Copolymers ........................................................................................................ 76
3. Functionalized Polyolefins .............................................................................................. 80
4. Newer Commercialized Compatibilizer Technologies ................................................... 87
5. Other Commercial Compatibilizer Technologies ............................................................ 90
6. New Technologies ........................................................................................................... 90
C. REFERENCES ............................................................................................................... 94

SECTION VI. R&D PIPELINES AND DIRECTIONAL INVESTMENT FOR
THE NEXT 5-10 YEARS ........................................................................................................... 99
A. COMMERCIAL STRATEGIES AND PATENT ANALYSIS BY PRODUCER ........ 99
   1. Pyrolysis and Cracking ............................................................................................ 99
   2. Compatibilizers ...................................................................................................... 104
   3. Bio-Conversion ..................................................................................................... 107
   4. Novel Materials ................................................................................................... 107
B. EARLY STAGE (TRL 1-3) R&D ................................................................................. 109
   1. Catalytic Depolymerization ................................................................................. 109
      a. Catalytic Pyrolysis ............................................................................................ 109
      b. Alkane Metathesis ......................................................................................... 110
   2. Upcycling to Novel Products ............................................................................... 111
   3. Post-Functionalization of Polyolefins ................................................................. 111
   4. Compatibilizer: Blending/Injection ....................................................................... 111
   5. New Polymers .................................................................................................... 112
C. REFERENCES ............................................................................................................. 112

SECTION VII. VOICE OF CUSTOMER − WHAT PRODUCERS ARE SAYING
AND DOING ............................................................................................................................. 117
A. PRODUCER POINT OF VIEW .................................................................................. 118
B. RECYCLER POINT OF VIEW .................................................................................. 125
C. EXPECTATIONS FOR PRACTICAL SOLUTIONS AND TIMING ............................ 128
D. REFERENCES ............................................................................................................. 131

SECTION VIII. REGULATORY ACTIONS ........................................................................ 135
A. GLOBAL REGULATORY ACTIONS ........................................................................ 135
   1. European Regulatory Actions ............................................................................. 139
   2. USA Regulatory Actions ...................................................................................... 140
   3. China and South East Asia Regulatory Actions .................................................. 141
B. ACTIONS FROM CONSUMER GOODS PRODUCERS AND CONSUMER INTENTIONS ................................................................. 142

C. PENDING ISSUES/IMPACTS .................................................................................................................................................. 146
1. Regulation Impact on Polyolefins Consumptions and Profitability ................................................................. 146
2. Regulation Impact on Biopolymers Development/Use ........................................................................... 147
3. Developing a Robust PCR Market ......................................................................................................................... 148
4. A Future of Wastes to Chemicals? ......................................................................................................................... 149

D. REFERENCES .............................................................................................................................................................. 150

SECTION IX. RECOMMENDATIONS AND CONCLUSIONS ................................................................................................. 153

REFERENCES ........................................................................................................................................................................ 156

FIGURES

Figure II-ES-1 Mechanisms of waste HD-PE plastic using pyrolysis-catalytic cracking over CuCO₃ .............................................................. 9
Figure II-ES-2 PE/PP blend compatibilized with alternating PE/PP block copolymer has smaller discrete phases and improved tensile strength and elongation ....... 10
Figure II-ES-3 SABIC’s process for converting plastic waste to olefins and aromatics ....... 11
Figure II-ES-4 Countries with the worst management of plastic waste ................................................................. 13
Figure III-A-1 Comparison of plastic produced, and plastic waste generated ......................................................... 15
Figure III-A-2 Percentage of plastic waste recycled in selected developed nations ................................................................. 16
Figure III-B-1 Operations in Mechanical Recycling (MR) of Plastics ........................................................................ 24
Figure III-B-2 Different types of fluidized beds used in gasification processes. Bubbling fluidized bed (a), circulating fluidized bed (b) and dual fluidized beds (c) ........................................................................ 26
Figure III-C-1 Average timeline to maturity for recycling technologies ........................................................................ 28
Figure III-D-1 General flowsheet for first steps in purifying and recovering polypropylene ......................................................... 33
Figure III-D-2 General flowsheet for final steps in purifying and recovering polypropylene ................................................................. 34
Figure III-D-3 Process flow diagram for production of terephthalic acid ................................................................. 35
Figure III-D-4 Agilyx PS depolymerization process flow diagram ........................................................................ 36
Figure III-D-5 Temperature profiles along process path for PS depolymerization ................................................................. 37
Figure III-D-6 Basic flow diagram of the Fraunhofer IVV CreaSolv process for recovery of polystyrene ................................................................. 38
Figure III-D-7  VolCat reaction scheme ................................................................. 40
Figure III-D-8  Chemical structure of VolCat catalyst, 1,5,7-triazobicyclo [4.4.0] 
dec-5-ene (I) and its analogue (II) ................................................................. 41
Figure III-D-9  Relationship between degradation time of PET and catalyst amount for VolCat process ................................................................. 41
Figure IV-1  Global production, use, and fate of polymer resins, synthetic fibers, and additives (1950 to 2015; in million metric tons) ........................................... 49
Figure IV-A-1  Schematic illustration of PE conversion to aromatics through thermal cracking followed by catalytic aromatization ........................................... 53
Figure IV-A-2  Mechanisms of waste HD-PE plastic using pyrolysis-catalytic cracking over CuCO3 ................................................................. 54
Figure VI-A-3  A) Schematic illustration of hydrogenolysis of PE into high quality liquids (HQLs) catalyzed Pt/SrTiO3. B) Evolution of molecular weight distribution in HQL products from 3 g PE, under 170 psi H2 at 300 ºC. ........................................... 55
Figure IV-A-4  Depolymerization of polyethylene by cross-alkane metathesis between polyethylene and a light alkane (n-hexane) .................................................. 57
Figure IV-A-5  Schematic illustration of oxidative PE conversion to dicarboxylic acids, and subsequent formation of plasticizers ........................................... 57
Figure IV-C-1  Post-functionalization of polyolefins by aliphatic C-H functionalization/ xanthylation ......................................................................................... 60
Figure IV-D-1  Amino-telechelic polyethylene as a reactive compatibilizer for PET/HDPE blends. A) Proposed reaction of ATPE with PET to form a PET-PE multiblock polymer compatibilizer. B) Representative stress-strain curves for PET/HDPE and PET/HDPE/ATPE blends ............... 61
Figure IV-D-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. Rectangular sheets (0.6 cm by 6 cm, 340 mm thick) of PE/iPP were laminated in the melt at 180 ºC, with and without PE/iPP block copolymer layers (100 mm thick), and were pulled apart at 10 mm/min ....................................................................... 63
Figure IV-E-1  Closed-loop recycling of a fiber-reinforced composites: (a) Composite waste containing PDK-6(TREN), carbon nanofibres, TiO2, and various dyes. (b) Complete depolymerization at room temperature in 5.0 M H2SO4 yields a solid mixture of the monomer (TK-6) and pigments/additives. (c) Extraction of monomer into aqueous base at room temperature allows separation from non-soluble components. (d,e) Acidification of the basic extract leads to recovery of the purified monomer ........................................................................ 64
Figure IV-E-2  Degradable PE-mimicking copolymers with biodegradable backbone linkages ......................................................................................... 65
Figure V-A-1 Common phase morphologies of plastic blends (a) Co-continuous phases; (b) Discrete phases; (c) Discrete Phases with compatibilizer at interface. ...... 74
Figure V-B-1 Copolymer Types. improved notched Charpy impact in molded articles is provided below. Similar improvements in dart impact for blown film is also provided in the brochure .................................................. 77
Figure V-B-2 Improvements in strength from Vistamaxx™ compatibilizers .................. 77
Figure V-B-3 Property improvement of PA/PP blends with Eastman G-3003 ............... 81
Figure V-B-4 Notched Izod impact improvement with functionalized PBd in PA11/mLLPDE blends ................................................................. 82
Figure V-B-5 Charpy impact strength improvement with minimum 15-20% PE-g-MAH in LLDPE/PA11 blends ........................................................................ 82
Figure V-B-6 Comparison of Lotader AX8840 vs. Polybond 3029 for compatibilization of HDPE/PLA blends ......................................................... 83
Figure V-B-7 Yield strength of PLA/PP blend with and without PP-g-MAH and DCP ...... 84
Figure V-B-8 Impact of PP-g-MAH addition on PA6/PP blends ..................................... 84
Figure V-B-9 Tensile Strength @ Yield improvement with PPg-MAH compatibilizer in PP-rich PP:rPET blends ......................................................... 85
Figure V-B-10 Elastic modulus increase with vacuum venting during compounding of PP/PET blend with PP-g-MAH compatibilizer .................................. 85
Figure V-B-11 Notched Izod impact improvement with 20% SEBS-g-MAH in 50/50 PP:rPET blend .................................................................................. 86
Figure V-B-12 Influence of the amount of compatibilizer (wt%) on the flexural properties of the studied blends in terms of (a) flexural modulus, E, (b) flexural strength, σFM, and (c) flexural strain and flexural strength, εFM; GE = 70:30 GMA:EHA, EG= 85:15 EHA:GMA, CC= commercial compatibilizer ........................................................................ 87
Figure V-B-13 10% Noted Polymer in PP (Modification includes Peroxide Initiator) ........ 88
Figure V-B-14 Comparison of PE/PP blend phase morphology change using OBC and ImerLink compatibilizer ................................................................. 89
Figure V-B-15 PE/PP blend compatibilized with alternating PE/PP block copolymer has smaller discrete phases and improved tensile strength and elongation .......... 91
Figure V-B-16 FTIR Spectrum Comparison of PP and Photooxodized PP (PPPh) ............. 92
Figure V-B-17 Comparison of SEBS to PP-co-Pr/St copolymer for compatibilizing 80:20 PP: PS blend ............................................................................... 93
Figure V-B-18 Melt index of LDPE/PP blend after repeated heat cycles in extruder ......... 94
Figure VI-A-1 A block diagram of a system for converting mixed polyethylene waste to waxes and grease-based stocks ..................................................... 100
Figure VI-A-2  A process flowchart for a method for breaking down synthetic polymers to synthetic oil and gasoline ................................. 101
Figure VI-A-3  SABIC’s process for converting plastic waste to olefins and aromatics ....... 102
Figure VI-A-4  Anellotech’s Plas-T-Cat process for converting plastic wastes to olefins and BTX ........................................................................... 102
Figure VI-A-5  The general structure of a polymer additive/compatibilizer with tunable polar and non-polar properties. R and R¹ represent alkyl or aryl groups, while X is hydrogen or a C₃ to C₂₀ alkyl substituent .......... 106
Figure VI-A-6  A) Schematic illustration of blending HDPE and MC using a MC-b-HDPE-b-MC ABA triblock copolymer compatibilizer. B) A tensile test of 50:50 HDPE:MC blends made with varying amounts of a MC-b-HDPE-b-MC ABA triblock copolymer compatibilizer . 106
Figure VI-A-7  Schematic illustration of LLDPE crosslinking and cyclization .................. 108
Figure VI-B-1  Mass and energy balance of plastic waste pyrolysis .................................. 109
Figure VI-B-2  Metal alkylidene-catalyzed metathesis degradation of polyisoprene (PIP) or polybutadiene (PBD) in the presence of a bifunctional (biFG) symmetric alkene CTA, affording α,ω-FG telechelic PIP and PBD, respectively .......... 110
Figure VI-B-3  Proposed reaction of ATPE with PET to form a PET-PE multiblock polymer compatibilizer .............................................................................. 112
Figure VII-A-1  Global plastic material production (thermoplastics and polyurethanes)....... 118
Figure VII-A-2  Plastic packaging segments targeted for redesign and innovation in a circular economy) .......................................................................................... 120
Figure VII-A-3  Tomorrow’s polymers resources/waste management hierarchy and smart design .............................................................................................................. 121
Figure VII-A-4  Intune OBCs PP-PE Compatabilization .................................................. 122
Figure VII-A-5  Dow fully recyclable all-PE multilayer pouch solution for food and non-food applications .................................................................................................................. 122
Figure VII-A-6  Diagram of different recycling processes ......................................................... 124
Figure VII-C-1  DEMETO PET depolymerization scheme ................................................... 131
Figure VIII-A-1  Management of plastic waste in Europe in 2016 (EU28 + Norway and Switzerland) ........................................................................................................ 136
Figure VIII-A-2  Recycling rates of common materials in the USA in 2015 .......................... 136
Figure VIII-A-3  Countries with the worst management of plastic waste ............................. 137
Figure VIII-A-4  Main global plastic waste flows before China's ban .................................... 138
Figure VIII-A-5  Impact of volumes due to China and other Asian countries waste import ban ......................................................................................................................... 139
Figure VIII-A-6  Countries with policies to reduce plastic packages and plastic bags .......... 142
Figure IX-1  Global plastic production, use, and fate since 1950 ....................................... 154

TABLES

Table IV-A-1  Ceiling Temperatures† of Various Polyolefins .................................................. 50
Table IV-A-2  Survey of Catalytic Pyrolysis of Polyolefins Reported Since 2017 .............. 52
Table V-B-1  Effect of Block Copolymer Additives on Ionomer/RCP Blends ...................... 79
Table V-B-2  Property Comparison of PP/PE/POE Blends with and without OBC
Compatibilizer and/or Talc .................................................................................................... 79
Table V-B-3  Secant Modulus Increase with Infuse OBC in EPC/PP Blends ...................... 80
Table V-B-4  Results of Bag Drop Test: 9C = PE; 10C = 93:7 PE:COC; 11 = 95:3.5:1.5
PE:COC:HCR; 12 = 90:7:3 PE:COC:HCR (3LPO indicates breakage
upon bag drop) ................................................................................................................. 88
Table V-B-5  Properties of 50:50 PP/PBT Blends ................................................................. 92
Table VII-A-1  Features of Plastic Recycling Process ............................................................ 125
Table VIII-B-1  Progress Reported by Some Top FMGC Companies Endorsing the
Global Commitment ......................................................................................................... 143