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Plastics Recycling and the Circular Economy II: A Perspective on Chemical Recycling Technologies and the Impact on Catalysis

**Multi-Client Study Presentation
“By the Industry, for the Industry”**

October 2022

Plastics Recycling and the Circular Economy II: A Perspective on Chemical Recycling Technologies and the Impact on Catalysis

This TCGR multi-client study was launched in May 2022 and completed in October 2022. The study's scope, and specific contents (as depicted in the ToC on pages 10-16 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. These are leading industrial developers, suppliers, and end-users of plastics recycling technologies.

I. INTRODUCTION

The challenge faced by plastics is not in how they are used, but in the end-of-life management of products made from plastic. In our June 2020 study, *Plastics Recycling and the Circular Economy: Catalytic and Compatibilization Solutions*, TCGR assessed both emerging and commercial technologies for the chemical recycling, upcycling, and compatibilization of plastics waste. While depolymerization technologies for PET and PS are rapidly becoming the norm, the inertness of polyolefins presents challenges in chemical recycling. Choice of recycling technology is not yet well defined, leading to a proliferation of ideas from purification technologies to recover virgin polymers to partial or full depolymerization, often with the aid of catalysts and adsorbents.

Based on feedback from the industry, this new study identifies and assesses new recycling technologies and determines the impact that they will have on the catalyst industry. **It addresses current state-of-art (SoA) in technology and commercial development. The study also provides a techno-economic and life-cycle analyses of the most promising recycling technologies in the late stages of development or early stages of commercialization.** In this study, TCGR has:

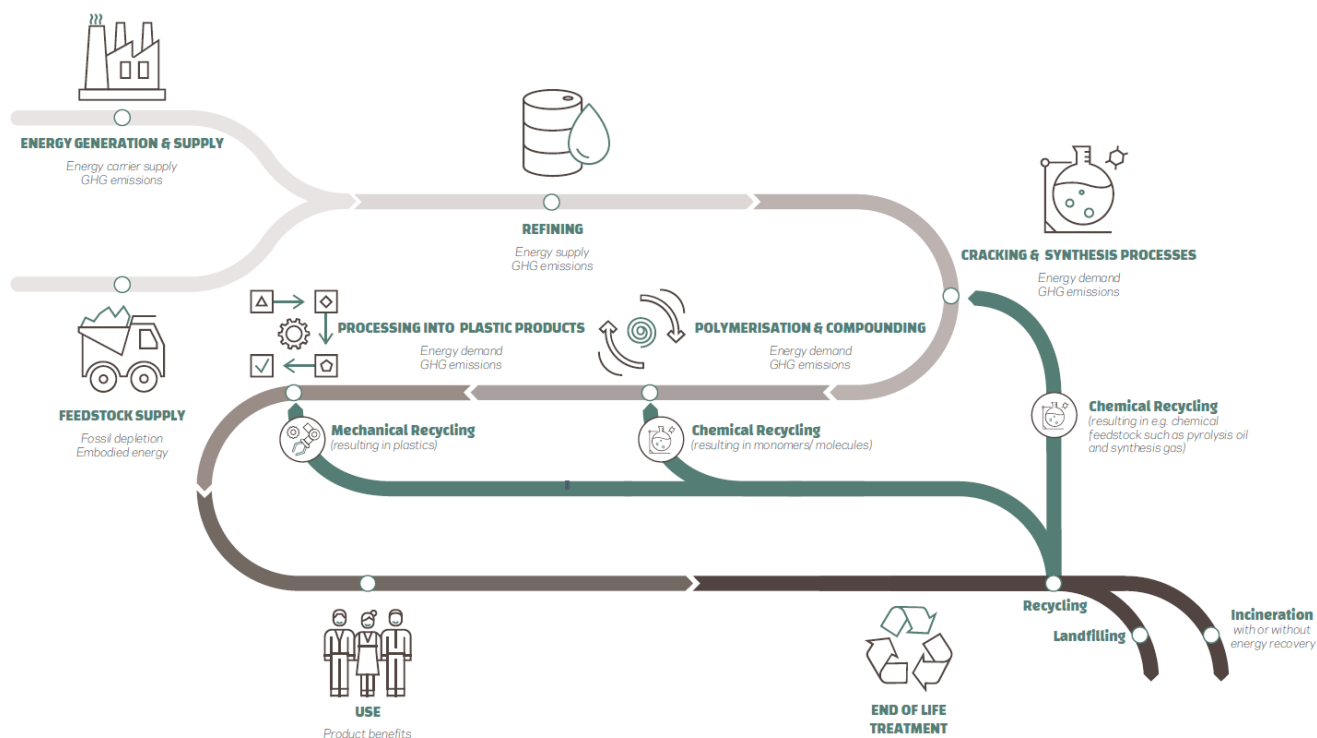
- Defined the current status of leading technologies
- Estimated the required CAPEX and OPEX of those technologies at scale
- Quantified the impact of chemical recycling on the markets for catalysts and adsorbents
- Provided strategic direction for market players in the plastic recycling value chain

It is a "must have," industrially sourced assessment for addressing the current industry needs from olefin and resin producers, process licensors and catalyst and adsorbent suppliers from a practical perspective.

II. BACKGROUND

The need for better solutions for recycling plastics is well known. Recycling plastics has been shown to have a net positive impact on greenhouse gas emissions compared to the production of virgin plastics, and there is growing concern over the leakage of plastic waste into the environment. Furthermore, the absence of practical recycling options leads to an estimated loss of \$80 billion per year of resources when plastic items are disposed. Most recycled plastics are mechanically recycled today, but this solution is limited due to contamination by mixed plastics, limited ability to produce clear or color-matched plastic articles, and loss of mechanical properties due to thermal degradation. Interest in chemical recycling is growing, as introducing recycled plastics earlier into the supply chain, as either monomer or raw material for monomer production eliminates these issues (see Figure 1).

Figure 1 – Value chain of fossil-based plastics



Source: CEFIC 2020

Chemical recycling technologies need to play a key role in the creation of a circular plastics economy. Various technologies have been proposed and are in early stages of commercial development. These technologies will have varying impact on the catalyst industry, from requiring new catalysts, changes to existing catalysts due to differing operating conditions, or reducing the requirements for virgin plastics. This report aids industry participants by identifying promising recycling technologies and quantifying the impact of those on the catalysts and adsorbents required to create a circular plastics economy.

In its 2020 assessment, **Plastics Recycling and the Circular Economy: Catalytic and Compatibilization Solutions**, TCGR highlighted a few emerging technologies for recycling various plastics but focused the report on very early-stage technologies. In this 2022 report, TCGR will focus on technologies for chemical recycling of polyolefins that are closer to commercial stage to examine both their technical and commercial potential. There are several paths being taken towards chemical recycling. The most advanced technology today is based on **gasification** or **pyrolysis** of plastic waste, and there are a number of projects underway, including those sponsored by SABIC, BASF, Clariant and their respective partners. Catalytic based technologies include **catalytic hydrothermal processing** (Figure 2), developed by Licella and licensed to Mura Technology. Mura Technology has announced partnerships with Dow Chemical, Mitsubishi Chemicals, and KBR to commercialize the technology.

Figure 2 – CAT-HTR™ pilot plant for catalytic hydrothermal processing of waste plastic



Source: Licella

CreaSolv® is a registered trademark of CreaCycle GmbH

Another catalytic technology that is under development is **catalytic cracking**, exemplified by the MoReTec process from LyondellBasell. LyondellBasell has opened a pilot plant in Ferrara, Italy (Figure 3) with the goal of building a world-scale commercial plant in 5 years. Not all potential solutions for chemical recycling are catalytic, though. **Solvent-based processes**, such as those proposed by CreaCycle and PureCycle have been scaled to pilot plant with larger-scale (50,000+ mt/yr) facilities planned or already under construction. These processes (see Figure 4) use

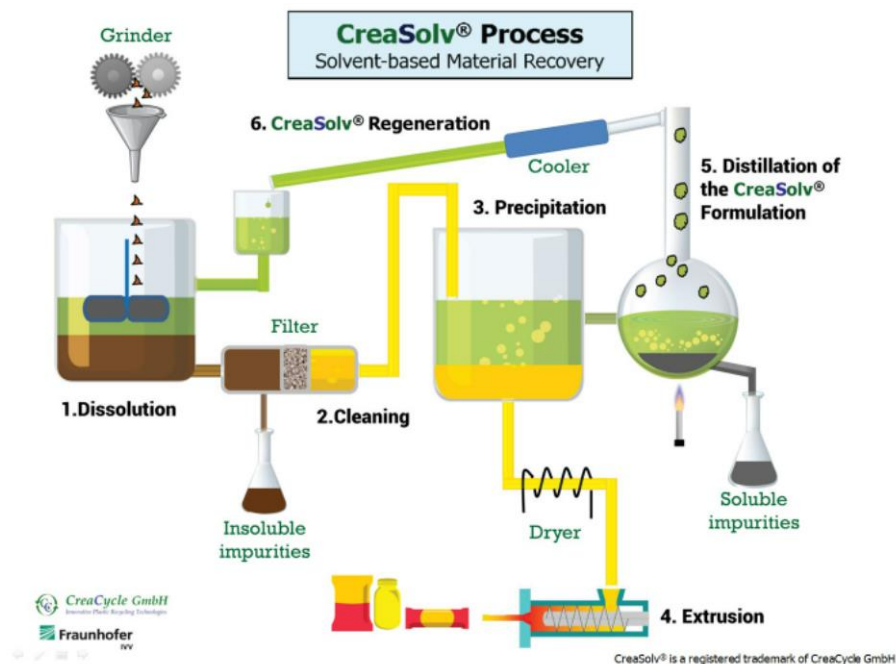
solvents to dissolve polymers so that additives and other contaminants can be removed before precipitating near-virgin polymer.

Figure 3 – MoReTec pilot plant for catalytic cracking of plastics



Source: LyondellBasell

Figure 4 – Schematic of Fraunhofer's CreaSolv process



Source: CreaCycle

While these recent developments are impressive, questions remain as to the effects these processes will have on catalysts and adsorbents used in these processes, how to further process the output from chemical recycling processes in refineries in order to regenerate monomers, and what materials and processes are needed to purify mixed plastics streams for chemical recycling.

To meet the needs of the catalyst industry and those companies willing to enter the plastics recycling value chain, a comprehensive analysis is required to better inform decision makers of the costs, benefits, and trade-offs imposed by various recycling technologies. In this assessment, ***Plastics Recycling and the Circular Economy II: A Perspective on Chemical Recycling Technologies and the Impact on Catalysis***, TCGR analyzes processes for recycling plastics, their environmental impact, and the impact that these processes are having on the market for catalysts and adsorbents. By examining the recycling of plastics from collection to sorting to current chemical recycling technologies, TCGR is able to assess the costs and define the gaps in the current processes. By analyzing the limits of current processes, especially mechanical recycling, TCGR is able to define the potential of chemical recycling for polyolefins and thus the impact of these technologies on catalysts and adsorbents.

By taking an economic view of chemical recycling processes as well as through a life-cycle analysis, the suitability of various approaches towards recycling plastics are gauged for meeting the requirements for a circular plastics economy. TCGR defines the following:

- The current status of each chemical recycling technology
- The potential for scaling these processes to the quantities necessary for market players to meet their commitments on using recycled plastics
- The hurdles for greater adoption of those technologies
- The future prospects of the leading technologies as well as those which are currently emerging
- Impacts of these processes on the catalyst and adsorbents technologies and markets

By doing so, TCGR allows readers to be better informed when making their own choices as to how to participate in a circular plastics economy.

TCGR's independent assessment combined with our "by the industry, for the industry" approach makes this study a needed complement to the readers' own internal evaluations.

III. THE NEED FOR THE STUDY

Due to increasing environmental drivers, the need for such a study has never been timelier. Major plastics producers have voluntarily committed to significant reductions in plastic landfill and the reduction of waste plastics finding their way into our oceans, while extended producer responsibility schemes are gaining traction. New methods of recycling are needed due to tightening emissions and

CO₂ regulations. Furthermore, producers and suppliers of monomers need to be aware of the likely timing and size of the impacts of adoption of chemical recycling on raw or virgin supply.

The benefits of aggregating the multiple technologies into one study creates an opportunity to extract and determine which pathway is the most beneficial given the local circumstances, providing value to chemical (olefins and other monomers) producers and suppliers of polyolefins.

Critical topics this study addresses include:

- State of the Art in polyolefin recycling technology
- Economic analysis of advanced recycling technologies
- Life-Cycle Analyses of advanced recycling technologies
- Needs for catalysts and adsorbents in order to enable chemical recycling
- Critical requirements and remaining hurdles for adoption of chemical recycling

Subscribers will benefit from TCGR's deep industrial knowledge, having been producing techno-economic assessments of polyolefin manufacturing and insights into the polyolefin market for nearly 40 years. This study also complements other recent studies produced by TCGR, demonstrating TCGR's unique capabilities and insight in the polyolefins industry. Recent studies include:

- ***Plastics Recycling and the Circular Economy: Catalytic and Compatibilization Solutions*** (completed in June 2020)
- ***Advances in Catalysis for Plastic Conversion to Hydrocarbons*** (completed in July 2021 for members of TCGR's **Catalytic Advances Program**)
- ***Progress in Technology for Polyolefins Production III*** (completed in December 2020)
- ***Polyolefin (PO) Catalysts and Processes: Competitive Implications of Industry Consolidation*** (completed in July 2018)

As is the case in all TCGR multi-client studies, this is a highly client-centric approach. Charter subscribers were essential in submitting their most pressing questions, thus making this a document that reflects the needs of the industry.

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.
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 - 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 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 II: A Perspective on Chemical Recycling Technologies and the Impact on Catalysis***," was launched in May 2022 and completed in October 2022.

<u>Post-production subscribers</u>	<u>after publication</u>	\$24,000
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Plastics Recycling and the Circular Economy II: A Perspective on Chemical Recycling Technologies and the Impact on Catalysis

Report in PDF format, in addition to subscription price	\$1,000
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Notice to Subscribers of TCGR's 2020 report *Plastics Recycling and the Circular Economy: Catalytic and Compatibilization Solutions*:

*Due to the complementary nature of this study to TCGR's previous report in this area, namely **Plastics Recycling and the Circular Economy: Catalytic and Compatibilization Solutions** completed in June 2020, TCGR is offering a discount of \$1,000 off **Plastics Recycling and the Circular Economy II: A Perspective on Chemical Recycling Technologies and the Impact on Catalysis** to subscribers of that study. Subscribers are requested to contact John Murphy at +1 215.628.4447 or jmurphy@catalystgrp.com if further details are required or to determine if your organization is entitled. When completing the order form, please make sure to indicate your company's subscription to the earlier report.*

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