WHITE PAPER

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# Future of Chemical Recycling in Plastics Domain

FutureBridge

There are different types of plastic recycling, which can be classified into four key types, namely, primary (closed-loop), secondary (mechanical), tertiary (chemical), and quaternary (energy recovery). Mechanical recycling is currently the most commonly used recycling method; however, its drawback is that plastics have to go through a melt-and-remold process, which causes materials to lose important properties, such as strength, flexibility, or clarity. Chemical recycling turns plastic polymers into individual monomers that allow materials to be reused in a variety of ways. In this process, chemical building blocks that make up the recycled plastics are recovered. Some drivers of chemical recycling are more valuable products obtained, the proportion of products (syngas, oil, monomers, oligomers, aromatics, etc.) varied based on operating conditions and catalysts, and colorless plastics obtained from colored plastic wastes that can process mixed plastic waste.

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# Introduction

There are different types of plastic recycling methods *(refer Exhibit 1)*, and at a broad level, they can be classified into four key types:

### 1. Primary (Closed-loop)

- Primary recycling is the most commonly encountered method of plastic recycling, which requires the polymer to be recycled for the same initial use. For example, a recycled bottle is used as material for a new bottle. However, very little post-consumer plastic is recycled in this manner due to purity requirements.

### 2. Secondary (Mechanical)

- Mechanical recycling is also known as downgrading or downcycling. This method uses recycled plastics for the manufacture of products with a lower value use, such as using recycled PET bottles to make carpets.

### 3. Tertiary (Chemical)

- Tertiary recycling process requires the use of a catalyst and is extremely energy-intensive. Temperatures required can be around 300-500 degrees Celsius (572-932 degrees Fahrenheit). If technology were developed to enable chemical recycling of polymers back to the petroleum-derived starting material (known as a monomer), then the isolation and reuse of these starting materials would enable the decoupling of current plastic prices from the current price of crude oil. There are several opportunities in this space to design new catalysts and processes that are less energy-intensive than the current methods.

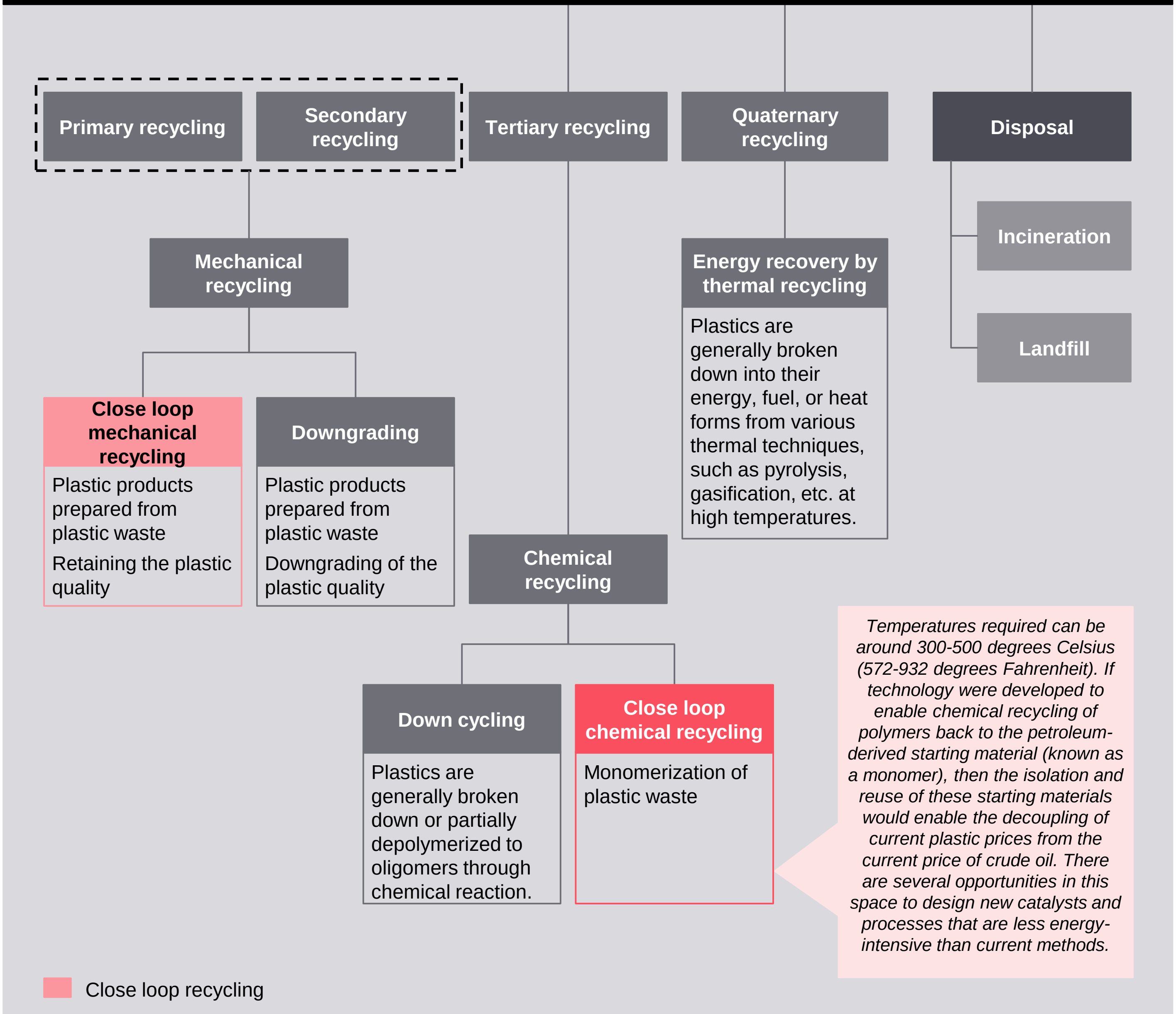
### 4. Quaternary (Energy Recovery)

- Plastic is burned, and energy is recovered in the form of heat; it is possible to obtain approximately 36,000 kJ/kg of energy from incinerating plastic.
- By comparison, recycling plastic saves approximately 60-90,000 kJ/kg of energy. Therefore, incineration as an end-of-life treatment regimen for plastics, ultimately cannot compete with recycling in terms of overall energy savings.

Although mechanical recycling is currently the most commonly used recycling method, its drawback is that plastics have to go through a melt-and-remold process, which causes materials to lose essential properties, such as strength, flexibility, or clarity.

**In theory, if chemical recycling methods were developed that enabled 100% breakdown for plastics to monomer, then plastics could be recycled an infinite number of times.**

**EXHIBIT 1: Plastic Recycling**




Source: IBM and FutureBridge Analysis

Key steps involved in the chemical recycling process include: plastic is chopped up and treated with the combination of water, heat, pressure, and enzymes or catalysts, breaking the resin down into its constituent parts. These chemicals are repolymerized into virgin-quality resins or used as fuel or as raw materials for other products. *(refer Table 1)*

**TABLE 1: Plastic Recycling Routes/Pathways**

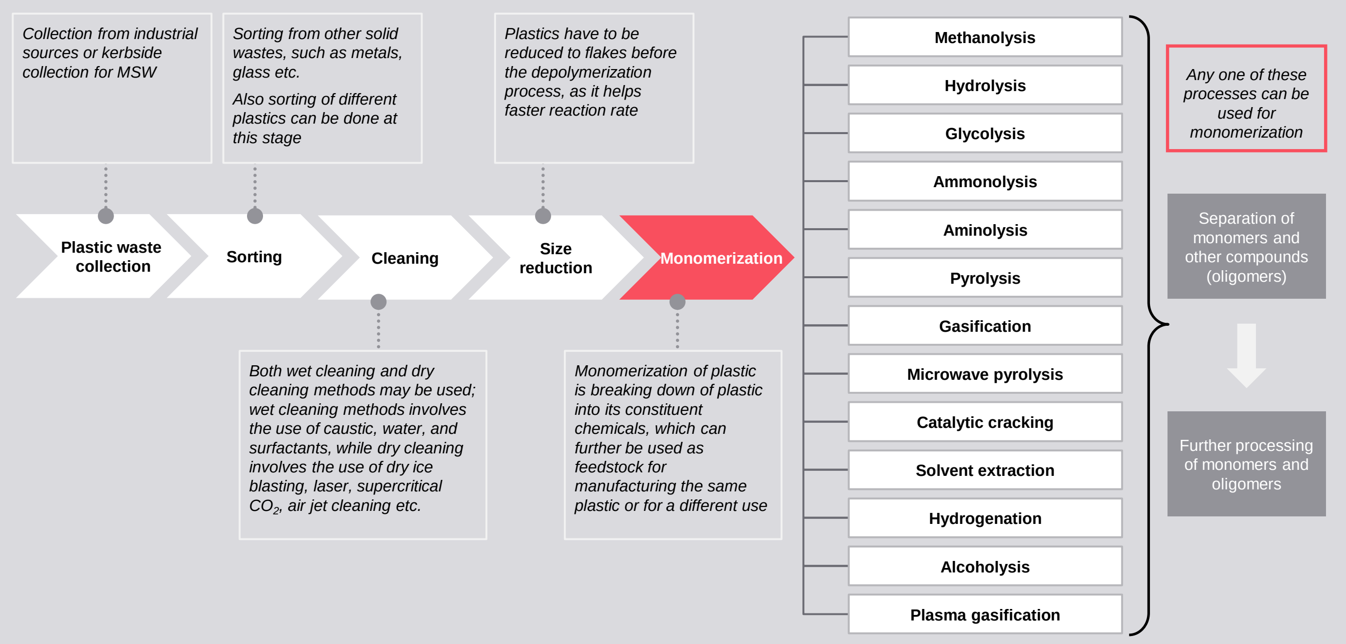
| Recycling Route | Output | Technology Clusters |
|---|---|---|
| **MECHANICAL RECYCLING**<br>*Physical methods are involved that do not change the chemical/molecular structure of the plastics* | Plastic products with equivalent properties<br><br>Plastic products with lower properties | Physical methods<br>▪ Cutting<br>▪ Shredding<br>▪ Washing<br>▪ Pelletizing<br>▪ Extrusion<br>▪ Injection Molding |
| **CHEMICAL RECYCLING**<br>*Breaking down or chemical conversion of polymers to monomers or partial depolymerization to oligomers and a mixture of hydrocarbon compounds* | Monomers, oligomers, other hydrocarbons, waxes, oil, and syngas | ▪ Hydrogenation<br>▪ Glycolysis<br>▪ Gasification<br>▪ Hydrolysis<br>▪ Pyrolysis<br>▪ Methanolysis<br>▪ Depolymerization<br>▪ Thermal cracking<br>▪ Catalytic cracking<br>▪ Aminolysis<br>▪ Ammonolysis<br>**Each unit operation alone can be used to achieve monomerization or breaking down of chains** |
| **THERMAL RECYCLING (INCINERATION)**<br>*Involves direct burning of plastic in the presence of air/oxygen* | Recovery of plastic's energy content | ▪ Incineration/Combustion |

Source: FutureBridge Analysis

# Types of Chemical Recycling Methods

Chemical recycling *(refer Exhibit 2)* turns plastic polymers into individual monomers—allowing materials to be reused in a variety of ways. In this process, chemical building blocks that make up the recycled plastics are recovered. The fundamental building blocks can be repolymerized endlessly, offering them the qualities of brand-new or virgin resin. The transformation can occur through a variety of processes, all of which avoid combustion or burning of plastics.

## EXHIBIT 2: Chemical Recycling




Source: FutureBridge Analysis

### A. Key Features: Methanolysis Process

- End product of the process has a quality similar to the virgin monomer (DMT)
- Easy purification step compared to other solvolysis processes, such as glycolysis and hydrolysis
- Suitable for condensation polymers

### B. Key Features: Hydrolysis Process

- Not widely commercialized or preferred recycling method, as the process is uneconomical due to its pressure and temperature requirement
- Suitable for condensation polymers

### C. Key Features: Glycolysis process

- One of the old solvolysis technologies in the market
- Types of glycolysis: solvent assisted glycolysis, supercritical glycolysis, catalyzed glycolysis, and microwave assisted glycolysis
- Suitable for condensation polymers

### D. Key Features: Ammonolysis and Aminolysis process

- End products are monomers that can be used for virgin polymer production or for other purposes
- Low research intensity around these recycling technologies
- Use of many chemicals and catalysts to obtain end products; high reaction time for these processes
- Suitable for condensation polymers

### E. Key features: Microwave Pyrolysis

- In comparison to conventional pyrolysis, microwave pyrolysis has higher heating rates and more control over the process
- Can process mixed waste stream and require relatively less pre-treatment steps

### F. Key features: Gasification

- The main output of the gasification process is syngas unlike other processes where liquid and solid fractions are in greater proportion
- Gasification technology for processing MPW is relatively recent, and experience in the development of full-scale commercially operating facilities is limited
- Do not require extensive pre-treatment steps

### G. Key features: Catalytic Cracking

- Upgraded technology of pyrolysis in terms of low operating temperature, high-value output, and operating cost
- High research intensity in the catalytic cracking process for plastic recycling

### H. Key features: Solvent Extraction

- Only chemical process where the end product is a polymer
- Solvent extraction is a promising method to separate waste mixed plastics; it is also suitable for homogenous plastic waste streams
- The method is eco-friendly and potentially profitable

### I. Key features: Hydrogenation

- Works at high pressure and requires hydrogen that makes the process economically unfeasible and relatively sophisticated
- Products obtained are highly saturated and valuable

### J. Key features: Plasma Gasification

- Suitable for unsorted waste category
- Solves the problem of toxic compounds in syngas, as the temperature is high enough to decompose them
- Limits the formation of free chlorine from HCl, which is a common problem in other chemical recycling technologies

# Pros and Cons of Chemical Recycling

Although mechanical recycling is currently the most commonly used recycling method, its drawback is that plastics have to go through a melt-and-remold process, which causes materials to lose important properties, such as strength, flexibility, or clarity. In theory, if chemical recycling methods were developed that enabled 100% breakdown for plastics to monomer, then plastics could be recycled an infinite number of times. Several pros and cons of both mechanical and chemical recycling are depicted in *Exhibit 3.*

**EXHIBIT 3: Drivers and Barriers of Mechanical and Chemical Recycling**

| | MECHANICAL RECYCLING | CHEMICAL RECYCLING |
|---|---|---|
| DRIVERS | ▪ Comparatively low investment<br>▪ Recycles almost all types of plastics (homogenous plastic waste)<br>▪ Requires low energy inputs<br>▪ Already proven technology<br>▪ Low negative environmental impact | ▪ More valuable products can be obtained<br>▪ Some chemical recycling methods are truly close loop<br>▪ Proportion of products (syngas, oil, monomers, oligomers, aromatics, etc.) can be varied based on operating conditions and catalysts<br>▪ Colorless plastics can be obtained from colored plastic waste<br>▪ Can process mixed plastic waste |
| BARRIERS | ▪ Degradation of plastics during recycling that reduces the quality<br>▪ Recycled plastic is colored<br>▪ Colored plastic preferably not recycled<br>▪ Required extensive sorting and cleaning | ▪ Comparatively high investment cost and uneconomic without significant subsidies<br>▪ More negative environmental impact as compared to mechanical recycling of plastic waste<br>▪ Energy intensive |

Although valuable output from chemical recycling and its use as a feedstock for the production have driven the attention of industry players in chemical recycling, the present economics are not driving chemical recycling adoption. On the other hand, the same economic factors are driving mechanical recycling of plastic waste.

Source: FutureBridge Analysis

# Recent Activities in the Space of Chemical Recycling

Listed below are recent activities conducted by key players operating in the field of chemical recycling:

## A. SABIC

- SABIC signed a Memorandum of Understanding (MoU) with the UK-based Plastic Energy Ltd., a pioneer in chemical plastics recycling in 2018. The project serves to be a crucial move for SABIC in its commitment towards a circular economy.
- SABIC is the first petrochemical company to start an investment project for the chemical recycling of Mixed Plastic Waste (MPW) and conversion to the original polymer.
- SABIC and Plastic Energy intend to build their first commercial plant (expected to start by 2021) in the Netherlands to refine and upgrade a valuable feedstock known as TACOIL. TACOIL is a patented product of Plastic Energy, which is produced from the recycling of low quality, mixed plastic waste that normally goes for incineration or landfill.

*Source: Process Worldwide (2018) and SABIC (2018)*

## B. LyondellBasell

- LyondellBasell and QCP plant in the Netherlands are developing recycled resins to compete in terms of quality and price with resins obtained from virgin materials via mechanical recycling.
- Food residue, glues, or smattering of the wrong types of plastics may contaminate the resin, making it difficult to reuse. QCP is collaborating with LyondellBasell to provide technical support for the development of recycled resin that can compete with virgin resin in terms of strength and price.
- QCP expects to double its initial capacity of 25 kilotons of resin per year.

*Source: LyondellBasell (2018) and Politico (2018)*

## C. Coca-Cola

- Coca-Cola is extending a loan to Ioniqa Technologies to support the development of technology for PET upcycling, which uses the process of depolymerization to recycle plastics of different colors, qualities, and conditions into purified building blocks. These building blocks are later made into clear, high-quality PET, thereby bringing the vision of a circular economy one step closer to reality. Ioniqa is building its first PET plastic upcycling factory in the Netherlands.

- Additionally, the Coca-Cola system's procurement collaboration has established a framework with Loop Industries, Inc., for authorized bottlers to purchase 100% recycled Loop PET. Coca-Cola European Partners is the first bottler to enter into a multi-year supply agreement with Loop for use in packaging across Western Europe by 2020.

*Source: Coca Cola (2018)*

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**North America**
55 Madison Ave, Suite 400
Morristown, NJ 07960
USA
T: +1 212 835 1590

**Europe**
328-334 Graadt van Roggenweg
4th Floor, Utrecht, 3531 AH
Netherlands
T: +31 30 298 2108

**United Kingdom**
5 Chancery Lane
London EC4A 1BL
United Kingdom
T: +44 207 406 7548

**Asia Pacific**
Millennium Business Park
Sector 3, Building # 4, Mahape
Navi Mumbai 400 710
India
T: +91 22 6772 5700

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