RECYCLING TECHNOLOGIES

for Plastic Packaging

Report For Nestlé

Contents

For feedback, input or news regarding your recycling efforts
get in touch via **support**@ubuntoo.com

ACKNOWLEDGEMENTS

Expert Interviews

For the preparation of this document, the team interviewed several experts in the recycling, sorting, and waste collection arena. These include:

DAVID CORNELL – Former Technical Director of the National Center for Food Safety and Technology
KIM RAGAERT – Professor Circular Plastics, Ghent University
JAIME CAMARA – Founder and CEO of PetStar
MATS LINDER – Circular Economy consultant, formerly with Ellen MacArthur Foundation
NINA GOODRICH – Sustainable Packaging Coalition
MARTIN SCHLUMMER – Fraunhoffer Institute
TAMSIN ETTEFAGH – Mechanical recycling consultant, former VP of Envision Plastics
BRUCE WELT – Professor of Packaging Engineering at the University of Florida

Solution Provider Interviews

NEXUS FUELS – Eric Hartz, Jean Jordan, & Jeffrey Gold
SCARABTECH – Jeffrey Barbee & Simon Davis
POLYTENTIAL – Yuri van Engelshoven
NEXTLOOP & PRISM – Ed Kosior
CADEL DEINKING – Rafael Garcia Vidal
LICELLA CAT-HTR – Steve Rogers
BRIGHTMARK – Kim Holmes
GEO-TECH POLYMERS – Sanjay Dutta
SYNOVA POWER – Van Morris
TOMRA – Carlos Manchado Atienza, Rick Fenton, & Nick Doyle
UBQ MATERIALS – Tato Bigio
SUSTANE TECHNOLOGIES – Peter Vinall
GREENMANTRA TECHNOLOGIES – Christy Sapp
ECO FUEL TECHNOLOGY – Swaminathan Ramesh
ST JOSEPH PLASTICS – Ron Moore & Leighton DeGarmo
P.REACT BY NGR – Patrick Mayrhofer
BANYAN NATION – Mani Vajipey
RENEW ELP – Kim West
TRASHCON – Nivedha

Ubuntoo Core Project Team

The following members of the Ubuntoo team have been involved in the research, collection and compilation of the information used in the creation of this white paper:

VENKATESH KINI
Co-Founder and CEO

ISABELLE VERRON
Research

SANDEEP KULKARNI
Polymer Science

HALEY RANDOLPH
Environmental Sciences

1.0 GLOSSARY

Closed Loop recycling: This refers to a production and consumption cycle where waste material is collected and recycled to provide raw materials for the same packaging format e.g. PET bottle to bottle recycling

Chemical Recycling: A broad term that covers all kinds of recycling technologies that decompose plastic polymers into their component monomers, oligomers, or hydrocarbons, using heat, chemical or biological solvents. It is also sometimes called **Advanced Recycling**, **Enhanced Recycling**, **Conversion** or **Molecular Recycling**

Depolymerization: The process of breaking down plastic polymers into smaller components like oligomers, monomers, or hydrocarbons

EFSA: European Food Safety Authority

Food-Grade: For the purpose of this document, any reference to Food-Grade means recycled material that meets local regulatory standards for use in packaging material that will come into direct contact with dry and wet food items of all kinds.

FDA: US Food & Drug Administration

FMCG: Fast moving consumer goods

Gasification: High temperature conversion of mixed municipal waste into gas without combustion using a controlled amount of oxygen

LCA: Life cycle assessment, a comprehensive environmental assessment methodology

Open-Loop recycling: A system where the recycled material is used as a raw material or input into another manufacturing process, and not back into the same one .g. PP/PE packaging to furniture or PP packaging to car bumpers

Mass Balance: A method of certifying that a certain proportion of recycled material is present in a product or package

Mechanical recycling: Also called Material Recycling or Physical Recycling is a recycling process that does not change the molecular structure of the original plastic polymer

MLP: multilayer plastic packaging

MRF: material recovery facility

NGO: non-governmental organizations like WWF, GreenPeace, etc.

Physical purification: solvent-based extraction, solvent-based purification, dissolution, liquid-liquid extraction, a process that removes impurities from plastic polymers without changing its molecular structure

PE: polyethylene

PET: polyethylene terephthalate

PO: polyolefins, includes PE and PP

PP: polypropylene

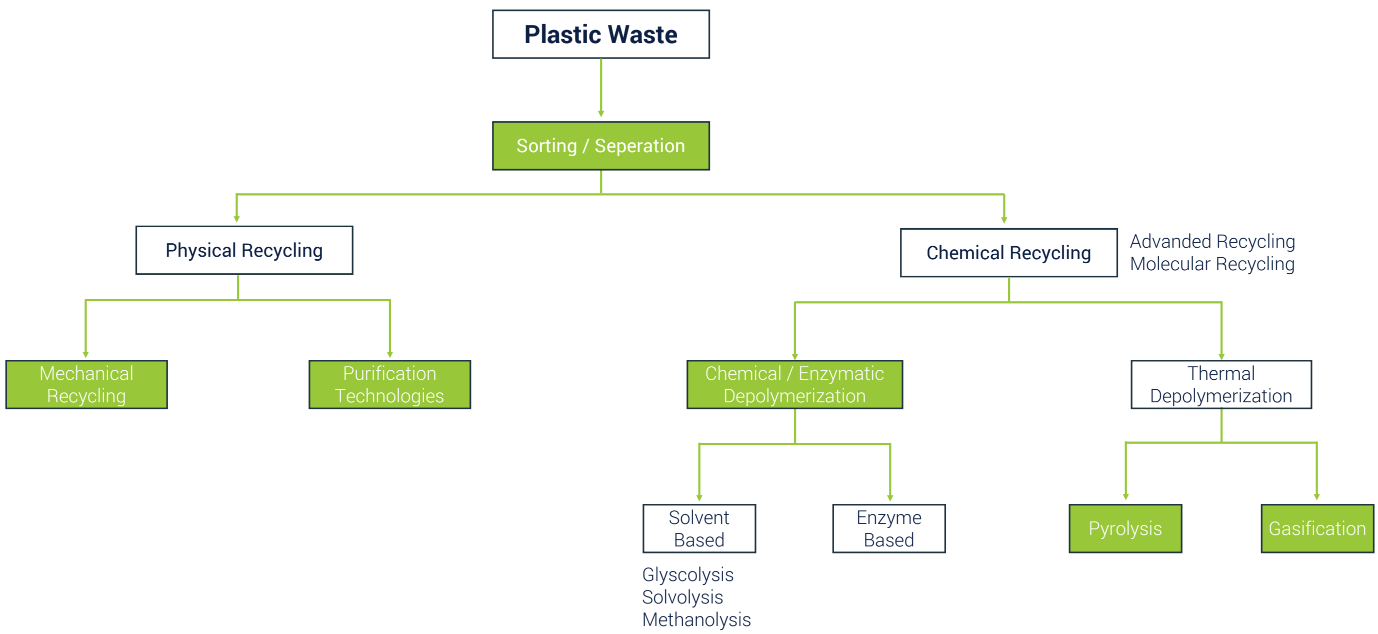
Pyrolysis: depolymerization of plastics using heat in the absence of oxygen, also called thermolysis

TRL: Technology Readiness Level is an industry standard for measuring the stage of development of technologies from concept through lab scale to commercial production. It is typically measured on a scale of 1 to 9

2.0 STRUCTURE OF REPORT

This report has been organized around two intersecting topics – recycling technologies and plastic materials of interest to Nestlé. Recycling technologies have been categorized as

- Sorting / Separation (an enabler for recycling)
- Mechanical Recycling
- Physical Purification
- Chemical / Enzymatic Depolymerization
- Pyrolysis
- Gasification



To identify, categorize, and prioritize different recycling technologies for consideration by Nestlé, we have evaluated them against 4 main types of plastic materials:

- Food-Grade PET
- Packaging-Grade Polyolefins
- Food-Grade Polyolefins
- Multi-Layer Plastics

In this report, each category of recycling technologies, their associated solutions, and their applicability to plastic materials will be explored in further detail.

3.0 SUMMARY OF FINDINGS

- **Demand for recycled plastics, especially food-grade polyolefins will outstrip supply in the short to medium term**, requiring companies to secure supplies through strategic partnerships and long-term procurement contracts or fail to meet public commitments
- Emerging sorting and separation technologies promise to improve volume and quality of feedstock supply for mechanical recycling across all types of plastics, but most are still a few years away from mass commercial scale
- Investments by large players in mechanical recycling and solvent / enzymatic depolymerization technologies are expected to **reduce the supply gap in recycled food-grade PET**
- Supply of recycled packaging grade polyolefins will benefit from improvements in sorting / separation technologies, mechanical recycling, and purification technologies
- Risk of contamination of post-consumer polyolefins makes it challenging to secure large quantities of mechanically recycled food-grade material, **the best recycling option for food-grade polyolefins in the short to medium term is pyrolysis**
- Gasification technologies are predominantly focused on converting mixed municipal waste into fuels or directly into energy, making it less likely to be a large source of recycled plastics

The graphic below provides a visual summary of our key findings.

	Mechanical Recycling	Physical Purification	Depolymerizn /Monomerizn.	Pyrolysis	Gasification
MLP	✗	○	✗	○	○
Food Grade PO	○	○	✗	✓	○
Packaging Grade PO	✓	✗	✗	✗	✗
Food Grade PET	✓	○	✓	✗	✗

✓ **Proven Commercially Viable Solutions Exist**

○ **Solutions in Development Or Technically Feasible**

✗ **Not Recommended or Not Technically Feasible**

4.0 BACKGROUND & OVERVIEW

Thanks to efforts by the Ellen MacArthur Foundation and other prominent NGOs, companies around the world have pledged to fight plastic pollution by making their packaging more recyclable, using more recycled materials, and preventing waste. This has resulted in a wave of innovations in new materials, packaging designs, recycling technologies and recovery systems. These innovations are being funded by industry led consortiums and private equity funds. Examples are the $1.5 billion commitment by the Alliance to End Plastic Waste, $300 million Closed Loop Partners and the $106 million Circulate Capital.

Demand for recycled material has grown exponentially as companies seek to honor their commitments to reduce the use of virgin plastic materials in their packaging. An analysis of sustainability commitments by the Top 200 companies in the world conducted by Ubuntoo indicated that 45 of them had made firm commitments to use 25 – 100% recycled plastic in their packaging by 2025. **This indicates an average of ~5x increase in the demand for recycled plastic vs 2019.**

However, the availability of high-quality recycled plastics for packaging is constrained by lack of collection systems, unfavorable economics, and technology limitations. **The best-case scenarios show that the availability of recycled Food-Grade Polyolefins will be constrained** unless there is a dramatic technological breakthrough, a sustained spike in prices of crude oil, or significant changes in government regulations around the world.

Mechanical recycling, a well-established pillar of the recycling system, has seen advancements in food-grade recycling technologies for PET bottle recycling. This sector has seen significant increases in capacity, including recent major announcements Indorama and CarbonLITE. For Packaging-Grade PO, mechanical recycling technology can be used if combined with high quality sorting and separation.

For the materials that mechanical recycling is unable to process back into virgin quality plastics, which constitute a large portion of plastics in circulation, chemical recycling has emerged as a promising new technology. When executed properly, chemical recycling technologies can accept a wide range of plastic feedstock and recycle it into the building blocks for new, virgin-quality plastics. However, NGOs such as Greenpeace and the Global Alliance for Incinerator Alternatives (GAIA) have published reports that strongly oppose chemical recycling, claiming that the technologies are the plastic industry's latest attempt at misleading the public. The NGOs claim that these are not truly circular solutions for plastics and that many technologies have failed to live up to their promise.

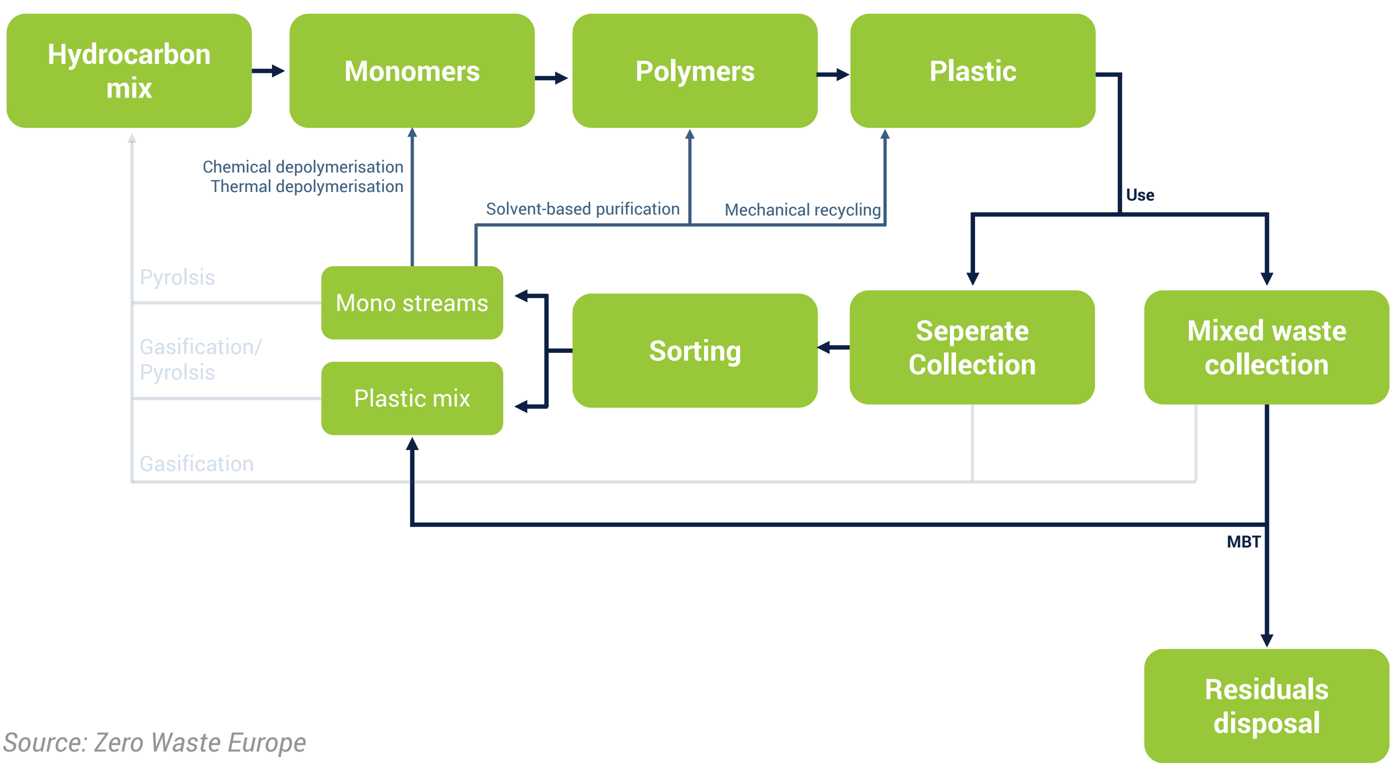
"We have a 3-legged recycling stool consisting of collection, process, and market. Without government mandates that create a market, I'm not sure that industry will be able to afford the cost."

- David Cornell, Technical Director of the Association of Plastic Recyclers

"When we think of the circular economy, we're thinking too narrowly. We have no price supports, there's no competition for the (recycled) material. If you need a biscuit package to be returned into a biscuit package, you're limiting competition"

- Nina Goodrich, Executive Director of the Sustainable Packaging Coalition

Mass-balance certifications provide third-party validation of recycled content claims used on packaging. These standards will likely play an important role in the expansion of the chemical recycling industry, and address some of the concerns raised by the NGOs.



Source: Zero Waste Europe

5.0 SORTING & SEPARATION

Sorting and separation hold the key to unlocking the potential of mechanical and chemical recycling as high-quality sorted feedstock is required for many recycling technologies. A variety of automated sorting technologies exist and have een implemented in varying degrees at MRFs. One of the challenges with the automated sorting technologies available in the market is their relatively high capital cost and large-scale requirements. This makes their use restricted mainly to developed markets and highly populated areas with large concentrations of waste.

Many startups are developing AI and robotic solutions to augment the more traditional optical, laser and infrared technologies. While these technologies are very efficient at separating different types of plastics at high speeds and with high levels of accuracy, they do not currently have the capability to distinguish between food-grade and non-food-grade PO feedstock in the incoming waste stream. Another approach to sorting and separation is to digitally tag packages so that automated sorters can more easily separate packages based on their precise characteristics.

There are very few emerging market solutions that can separate plastic waste at smaller scales with lower capital costs. One example is TrashBot, a solution from India that claims to separate mixed municipal waste into dry and organic waste with a 99% accuracy rate at small scales.

5.1 Sorting & Separation - Food Grade PET

Due to high demand and its high value, PET has been targeted for sorting from the recycling waste stream. Automated sorting machines can target and separate PET from mixed waste streams with a very high degree of accuracy. In emerging markets, ragpickers scour through mixed municipal waste and litter to pick up PET, amongst other valuable waste streams.

However, one of the challenges remains the contamination of waste PET feedstock by labels, especially shrink sleeves that are predominantly made from PVC. Innovations such as Design2Recycle are trying to improve the quality of recycled PET by creating magnetizable inks for labels, enabling easier separation from bottles at MRFs. According to the solution provider, their technology significantly improves the quality of the resultant recycled PET. They have successfully conducted trials with a beverage company in USA.

5.2 Sorting & Separation - Packaging Grade PO

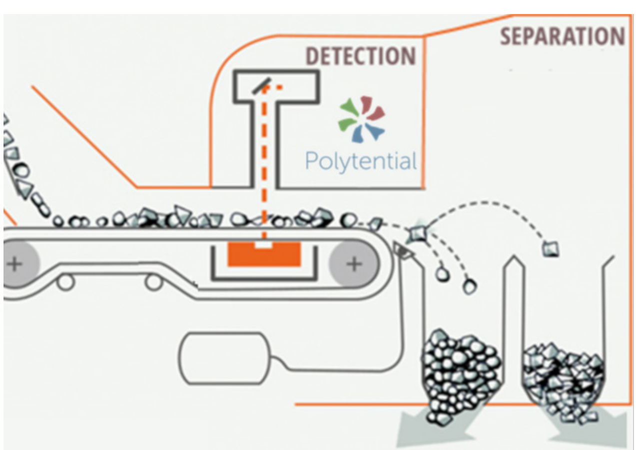
A variety of separation technologies exist for packaging grade PO. The limitation of sorting and separation technologies is its ability to distinguish food grade from non-food grade applications. Traditional optical sorting technologies by TOMRA can separate PO materials with a claimed accuracy of 95%. New technologies are emerging that attempt to reduce the cost and increase the accuracy of sorting. Examples are BOSS, Waste Robotics, AMP Robotics, and Umincorp. As these technologies get adopted by MRFs, the rate of recovery of packaging grade PO will improve significantly.

5.3 Sorting & Separation - Food Grade PO

In order to produce recycled food-grade PO through mechanical recycling, the feedstock must include only waste plastic that was originally certified food-grade. Sorting technologies that can identify whether an incoming package was originally food-grade are not fully commercialized at this time, but efforts such as Project HolyGrail and PRISM are working to change this.

HolyGrail is promoting the implementation of chemical tracers and digital watermarks that can help sorting machines distinguish between types of plastics and their original use, producing high-quality sorted feedstock for recycling facilities. PRISM utilizes fluorescent markers printed on packaging sleeves and labels that will help sorters distinguish between food-grade and non-food grade packaging. Both these technologies will require industry wide collaborations and upgrades to the sorting capabilities at MRFs.

Polytential has developed an inline detection module (IDM) that can be implemented in any sensor sorter for plastic flakes. The IDM combines NIR sensors with proprietary AI algorithms and can detect the polymer grade, original packaging application, and melt-flow index of the plastic. This technology could be implemented as a part of existing sorting infrastructure. Polytential is collaborating with undisclosed CPGs to deploy their product.



Despite these advances, post-consumer waste Food-Grade PO feedstock remains a challenging problem, especially when it is mixed with non-food grade contaminants. The molecular structure of PO makes it highly susceptible to absorbing potentially harmful substances, which cannot be removed through simple sorting and separation technologies.

5.4 Sorting & Separation - MLP

The biggest strength of MLP is its light weight relative to its ability to protect its contents, thanks to its multi-material composition. However, this very strength makes it a very low value item to collect and recycle. For MLP to be successfully recycled back into packaging, each different polymer layer needs to be separated back into its component material. So, collection and sorting is not good enough to achieve circularity. Saperatec claims to be able to separate composite layers, releasing individual materials and creating more recyclable material from the MLP packaging. However, the economics of material recovery will be a bigger constraint to MLP recycling than sorting and separation.

5.5 Summary of Findings – Sorting & Separation

<table>
<tr><td>Multi-layer Laminates</td><td>Potential solution</td><td></td><td></td><td></td><td>Potential solution</td><td></td><td></td><td></td></tr>
<tr><td>Food Grade PO</td><td></td><td colspan="2" rowspan="3">Improves separation at package level with high level of accuracy. Requires industrywide collaboration and upgrades to recycling infrastructure.</td><td></td><td></td><td></td><td></td><td rowspan="3">Well established technologies for sorting and seperation to create quality feedstock for Mechanical recycling</td></tr>
<tr><td>Packaging Grade PO</td><td></td><td colspan="4" rowspan="2">Potentially improves separation of plastic at lower cost and higher accuracy than current systems.</td></tr>
<tr><td>Food Grade PET</td><td>Proven for PET shrink wrap</td></tr>
<tr><td></td><td>Design 2 Recycle (TRL 8)</td><td>Holy Grail (TRL 4 / 5)</td><td>Prism (TRL 4 / 5)</td><td>UminCorp (TRL 8 / 9)</td><td>Saperatec (TRL 4 / 5)</td><td>Polytential (TRL 4 / 5)</td><td>TrashCon (TRL 9)</td><td>TOMRA / Starlinger TRL 9</td></tr>
</table>

← Domain of brand owners → ← Domain of recyclers →

Proven commercially viable solution

Solution in Development or potentially applicable

6.0 MECHANICAL RECYCLING

Mechanical recycling has represented the predominant form of recycling technology for the last 50 years. It is a mature and well-established process. Mechanical, or physical, recycling relies on sorted and cleaned sources of plastic and involves re-melting plastics into granulates. The process requires single monomer streams, hence the reliance on proper sorting and separation. In the process of recycling, the chemical structure of the polymer is not changed, but the heating causes polymers to degrade with each cycle. As a result, plastics cannot be mechanically recycled more than 7 – 9 times.

From an LCA viewpoint, mechanical recycling is a relatively low-energy, low-carbon footprint process for producing recycled content. Due to its lower environmental impact, mechanical recycling is prioritized above chemical recycling in the hierarchy of waste management.

6.1 Mechanical Recycling - Food Grade PET

PET is a polycondensation polymer that can be both mechanically and chemically recycled. Among the mature mechanical recycling solutions evaluated by Ubuntoo, the main differences are where and how the solid stating takes place and if it is done to a flake or a pellet. Bottle-to-bottle solutions exist for the mechanical recycling of food grade PET and are market-ready. One challenge of food grade PET recycling is that feedstock is usually limited to bottles with some countries preferring materials collected from deposit schemes.

Polymetrix, DEJA by Indorama, and Verdeco Recycling are just a few examples of companies who have technologies to produce rPET of food grade quality. Many more regional players exist around the world, and indications are that this space is consolidating in the hands of large global players. Viscotec's DeCon device contaminates PET bottle flakes, produces EFSA and FDA compliant rPET, and has been installed in recycling facilities around the world. Another technology is P:React by NGR, that uses liquid state polycondensation in a vacuum to decontaminate PET.

According to the experts interviewed by Ubuntoo, with the right collection systems in place, mechanical recycling technology can meet the demand for recycled Food-Grade PET in the short to medium term. The challenge in many countries is ensuring that post-consumer PET waste is recovered through a systematic recycling program. However, two big challenges remain for the long-term availability of Food-Grade recycled PET.

The first is the demand from the clothing, apparel, and carpet industry for recycled polyester yarn that uses recycled PET bottles as feedstock. Since food grade quality is not a consideration, the capital cost of a recycled polyester plant is low. Also, in countries like China and India, government regulations prevent the conversion of post-consumer PET bottles back into recycled food-grade PET. As a result, over 90% of recovered waste PET bottles in these countries are converted into yarn. The second challenge is the degradation in color and strength with repeated cycles. Recyclers will need to add virgin PET resin to maintain quality beyond a point, reducing the circularity potential of the material.

6.2 Mechanical Recycling - Packaging Grade PO

PP and PE are addition polymers that are harder to recycle mechanically due to their long chains, over 30,000 units long. Additives are added to improve the performance of recycled PO, but degradation occurs with every heat history. Mechanical recycling of PO into packaging grade is less established and currently most recycled PO is used to produce durable goods. However, there are recycling technologies on the market for packaging grade PO, and even with current sorting and purification technologies, mechanically recycled packaging grade PO is achievable.

Banyan Nation in India has set up a unit for recycled packaging grade PO that is used by Unilever for their personal products. They claim to have a proprietary process for cleaning and deinking the waste PO, and a robust source control through waste pickers to obtain only high-quality post-consumer PO. Envision Plastic's OceanBound Plastics also involves collection of plastics by waste pickers and consequent conversion into recycled plastic resin.

Quality Circular Polymers produces recycled PP and HDPE from post-consumer waste. TOMRA has a demonstration unit in Germany where they have proven the ability to produce high quality recycled packaging grade PO using a combination of the best sorting, separation, and cleaning technologies in the market.

6.3 Mechanical Recycling - Food Grade PO

Polyolefins absorb contaminants with relative ease. Even if input materials were sorted to include only food-grade packaging, as is required in some countries, thorough cleaning and removal of contaminants would be required to achieve a suitable end product. Interviews with experts reinforced this idea as they were not hopeful about the possibility of mechanically recycled food grade PO gaining EFSA approval in the EU. The US FDA has issued a few "no-objection" certificates for food-grade PO, but they lack the scale to supply the demand in the market.

Envision Plastics and St. Joseph Plastics are two recycling companies that show promise in the United States. Envision uses a cleaning process involving heat and air to ensure that post-consumer HDPE is processed into a fragrance-free, food-grade recycled material. St. Joseph Plastics is pursuing post-consumer FDA certification and anticipates approval as their recycled material used in the products of CPG companies has met the standards.

Source: St. Joseph Plastics

6.4 Mechanical Recycling - MLP

At this time, processes to mechanically recycle MLPs back into packaging are not available due to the complexity of handling multiple types of plastic within one piece of packaging. The only solutions currently available are "open-loop" compression technologies that convert mixed plastic waste into low value, end of life plastic items like roads, plastic timber, boards, and other items. These solutions are not specific to MLP but most can accept between 20 – 50% MLP in their feedstock.

One promising solution is "Wow Boards" from India. This is a technology that can convert clean 100% MLP waste into plastic boards that replace plywood or fibre boards for use in construction, carpentry, and furniture.

6.5 Summary of findings – Mechanical Recycling

Multi-layer Laminates	✖			✖	✖	✖	✖	✖
Food Grade PO	✖				✖	✖	Obtaining FDA No-Objection Letter	FDA No-Objection Letter for HDPE
Packaging Grade PO	✖			HDPE&PP Emerging market solution	HDPE Emerging market solution	HDPE & LDPE	HDPE, LDPE, PP, PE	
Food Grade PET	This is a small sample of many recycled PET players around the world			✖	✖	✖	✖	✖
	Polymetrix (TRL 9)	**DEJA (TRL 9)**	**Verdeco (TRL 9)**	**Banyan Nation (TRL 9)**	**Ocean Bond Plastics (TRL 9)**	**Quality Circular Polymers (TRL 9)**	**St. Joseph Plastics (TRL 9)**	**EcoPrime (TRL 9)**

7.0 PHYSICAL PURIFICATION

Physical purification, or solvent-based purification, is a physical reaction in which the state of the polymer changes from solid to liquid, then back to solid again, while the chemical composition of the polymer remains unchanged. The polymer is dissolved, cleaned, and precipitated. Next, the polymer is separated from impurities, dried, and extruded to granulates.

Solvent-based purification is technically a form of mechanical recycling, but due to the different nature of the recycling process, it has been categorized separately. Unlike traditional mechanical recycling, physical purification is better equipped to handle impurities and can theoretically handle multi-material plastics.

7.1 Physical Purification - Food Grade PET

Through selective collection and sorting, food grade PET has been achieved without the need for physical purification processes. Food grade PET can be achieved through cleaning processes that already occur as part of the mechanical recycling process.

7.2 Physical Purification - Packaging Grade PO

APK's Newcycling process uses a solvent-based recycling technology to produce recycled LDPE, HDPE, and PP from mixed plastic waste and multi-layer packaging. Their recycled material does not appear to be food grade, rather is appropriate for non-food flexible packaging, technical injection molding for technical application, labels/stickers, films, and laminates. Their technology appears to be derived from Creasolv, a process patented by Fraunhoffer Institute.

7.3 Physical Purification – Food-Grade PO

Given the ease of contamination of PO, and the limitations of mechanical recycling, many purification technologies are attempting to overcome this challenge to produce Food-Grade PO.

Cadel Deinking is in the process of obtaining food grade certification. Their technology removes printed inks from plastics to create a higher-value product with improved mechanical properties and can accommodate surface printed PP, PET, LDPE, and HDPE. Technically, this is not a recycling technology, but more of a cleaning process that feeds mechanical recycling.

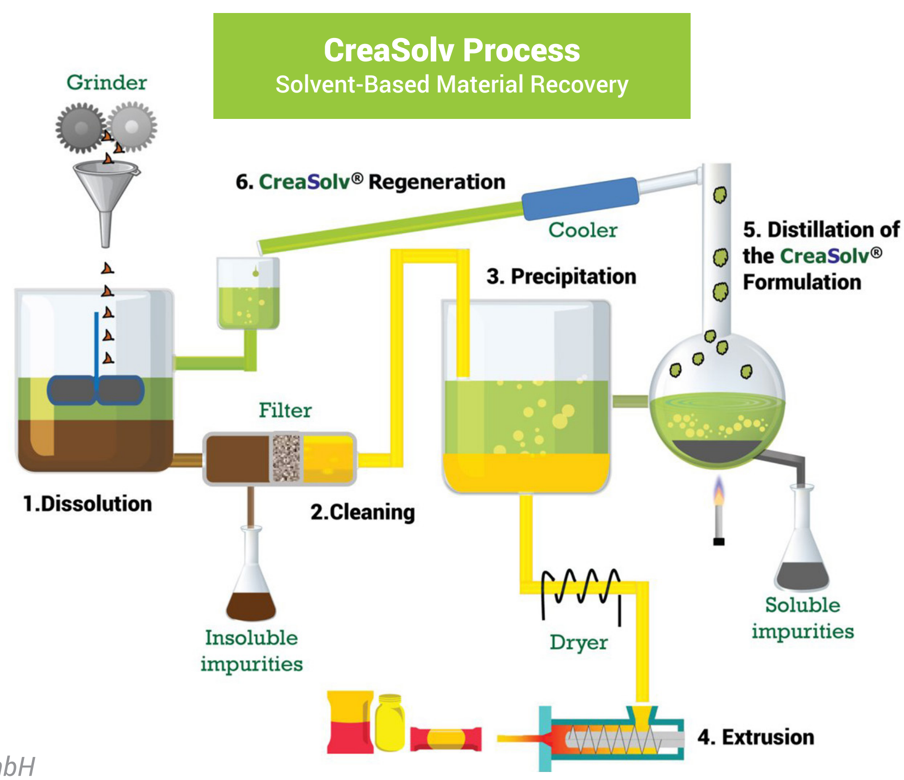
PureCycle Technologies has developed a recycling process that removes colors, odors, and other contaminants from polypropylene feedstock and can produce food grade resins.

The technology was originally developed by P&G and has now been licensed to PureCycle for commercialization. Nestlé has an established relationship with PureCycle. Their pilot plant in the USA claims to have completed the first successful test run converting waste carpet material into virgin grade PP. They plan to create a 100,000 ton per annum PP recycling unit in Ohio, USA, and are currently seeking FDA approval for Food-Grade PP certification.

Nextek has developed a process for recycling PP wastes into food grade packaging. Decontamination consists of a high-level melt phase in an extruder and a heated, high vacuum degassing reactor, resulting in decontaminated, deodorized rPP that can be blended with virgin PP in combinations up to 50%. Nestlé is already engaged in discussions with Nextek.

7.4 Physical Purification – MLP

The CreaSolv Process can process MLPs to create packaging grade PO. Working with Unilever, they installed a 700 ton/annum pilot plant in Indonesia in 2018. The results have been mixed. Ubuntoo has interviewed NGOs in Indonesia that supplied waste MLP to the unit, who claim that the demand has dried up. Additionally, there has been no announcement of expansion of this technology by Unilever, and their last update in 2019 claimed success for the technology, but nothing new has been announced in 2020. Ubuntoo has a view that the technology may have been proven, but the economics remains a challenge, and it requires consistent feedstock supply. Mainly, the ability to economically collect, separate, and feed MLP to this process is the limiting constraint.



Source: CreaCycle GmbH

7.5 Summary of Findings – Physical Purification

	PureCycle (TRL 8)	Creasoly (TRL 6 / 7)	NexTek (TRL 4 / 5)	APK (TRL 4 / 5)
MLP	✖	Indonesia trial appears to have stopped	✖	✖
Food Grade PO	Most promising technology so far for PP	✖	Has potential to be a game changer for PP	✖
Packaging Grade PO	✖	✖	✖	Possible solution for PP and HDPE
Food Grade PET	✖	✖	✖	✖

8.0 SOLVENT / ENZYMATIC DEPOLYMERIZATION

Depolymerization is a chemical recycling process in which polymers are broken down into monomers through the use of alcohols, alkalis, acids, and/or amines to reverse the condensation reaction required to produce such polymers. Hydrolysis and glycolysis are depolymerization reactions that use water and glycol, respectively, as the base solution of the reaction, assisted by the addition of catalysts. A high-quality sorted feedstock is required for depolymerization because secondary reactions with foreign polycondensates can form during the reversal of the condensation reaction, affecting the purity of the monomers being produced.

Depolymerization has many technologies that are in the development stage. The hindrances to growth include the cost of acquiring and sorting feedstock and finding a partner or investor who can provide the capital needed to bring the technology to scale.

"The chemical recycling debate is politicized and emotional; despite demand there is yet to be proof that it will work economically."

- Mats Linder, Circularity Consultant

"Chemical recycling produces a higher quality product, but without policy there won't be enough supply. They currently rely of post-industrial supply."

- Tamsin Ettefagh, former VP of Envision Plastics

8.1 Depolymerization - Food Grade PET

As more PET is mechanically recycled, it will become necessary to complement mechanical recycling with chemical recycling. As PET degrades with each successive round of mechanical recycling, chemical recycling can be used to recycle PET into its precursor monomers. Also, a lot of PET recovered from litter, landfills, rivers, and oceans is too degraded or contaminated to be used as feedstock for mechanical recycling. Ubuntoo is of the opinion that chemical and enzymatic depolymerization technologies, when scaled up, can make PET a near circular polymer, making recycled material available at prices comparable to virgin materials.

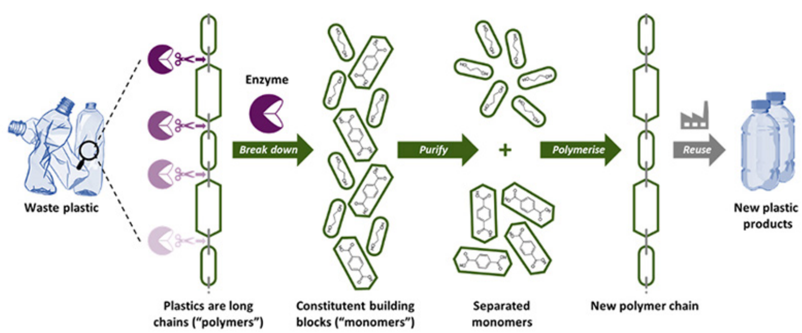
Loop Industries technology can recycle polyester fibers and PET bottles of all colors into food grade packaging without the use of heat or pressure during the depolymerization reaction. Loop has announced multiple collaboration and supply agreements, including with Pepsico, Coca-Cola, Indorama, Suez, etc. However, a recent article by Hindenburg research has accused Loop of falsifying data and lacking a viable technology.

Similarly, ChemPET is a depolymerization technology capable of recycling multi-layer films, rigid containers, black PET, nonwoven fabric waste, and polycotton blends. ChemPET has partnered with Indorama, Plastipak, and Ikea. Two expert reviews pointed out that Plastipak's involvement with ChemPET is reflective of Plastipak's trust that the ChemPET process can consistently provide high quality recycled raw materials.

IBM's VolCat process can accept dirty waste including polyester carpets, clothes, and low-grade mixed post-consumer resin of PET. The VolCat process does not require washing and runs its depolymerization reaction at low temperatures with the assistance of catalysts.

Utilizing microwave technology, the Gr3n Recycling Project claims to depolymerize PET and olyester textile into a food grade recycled product while maintaining favorable economics. H&M, Adidas, Nestlé, and Unilever are among the global companies who have partnered with Gr3n.

Carbios's Biorecycling technology uses enzymatic bioprocesses to depolymerize plastic and textile polymers into monomers. Carbios has partnered with L'Oreal, Pepsico, and Nestlé Waters. Similarly, PETase uses enzymes to achieve its PET recycling, although this technology does not appear to recycle textile waste. Both of these technologies need to prove their commercial viability but show promise.



Source: University of Portsmouth Centre for Enzyme Innovation

While mechanical recycling for food grade PET is well established, Loop Industries, Gr3n Recycling Project, and Biorecycling all offer the ability to upcycle polyester fibers into food grade PET, unlocking an entirely new source of feedstock for PET recycling.

Ioniqa removes the colorant from PET feedstock and produces food grade rPET using its proprietary Smart Material catalyst. Ioniqa has partnered with Coca-Cola and Unilever to implement this technology and was well reviewed by one of our experts.

8.2 Depolymerization - Packaging Grade PO

BioCellection has completed proofs of concept using films, rigid plastics, and foam plastics, but is most developed for treating plastic films, mainly LDPE and HDPE, at a TRL of level 6. Experts expressed concern about the limited feedstock capabilities, reliance on sorting and purification, and believed that as pyrolysis develops, BioCellection's process will not be economically competitive.

8.3 Depolymerization - Food Grade PO

According to our experts, depolymerization is not well suited for recycling polyolefins due to the strong chemical bonds that cannot be easily cleaved with the assistance of catalysts as in the case of PET. As the structure of PO has no attachment points or polar regions for chemical reactions to occur, PO must be broken down through the use of heat. While there has been some research into catalytic depolymerization of polyolefins, its performance compared to pyrolysis is unclear and the research is in early stages.

8.4 Depolymerization - MLP

Due to the chemical structure of polyolefins and the added complexity of multiple layers and potentially multiple types of plastics, MLPs have not performed well with depolymerization technologies.

8.5 Summary of Findings - Depolymerization

<table>
<tr><td>MLP</td><td>✖</td><td colspan="8" rowspan="3">✖</td></tr>
<tr><td>Food Grade PO</td><td rowspan="3">Early stage project, poorly reviewed by Experts</td></tr>
<tr><td>Packaging Grade PO</td></tr>
<tr><td>Food Grade PET</td><td colspan="2">Commercial production has begun, scale up plans in place, industry alliances formed</td><td colspan="5">Promising technologies</td></tr>
<tr><td></td><td>Biocellection (TRL 2/3)</td><td>Ioniqa (TRL 9)</td><td>Loop (TRL 9)</td><td>Gr3n (TRL 6/7)</td><td>Carbios (TRL 6/7)</td><td>VolCat (TRL 4/5)</td><td>PETase (TRL 4/5)</td><td>ChemPET (TRL 6/7)</td></tr>
</table>

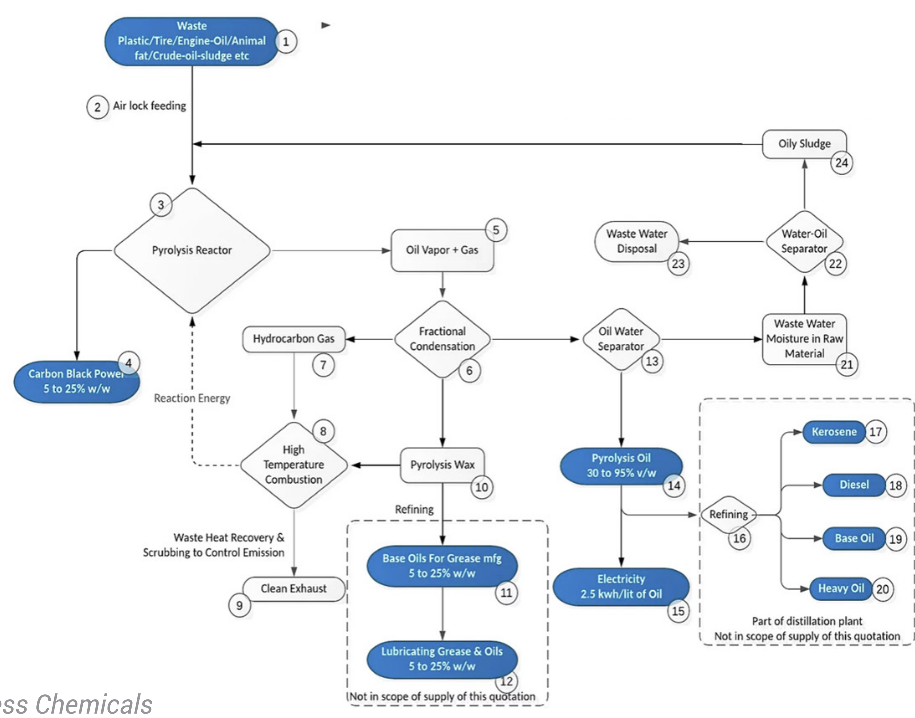
**Note: Loop Industries has just been accused of misstating its technical capabilities, and was not well reviewed by one of our experts*

9.0 PYROLYSIS

Pyrolysis is a chemical recycling technique that uses high temperatures in the absence of oxygen to convert polyolefin waste products into hydrocarbon liquids, syngas, wax residues, carbon char residual, and ash byproduct. Pyrolysis oils can be used as chemical feedstocks for the petrochemical industry for energy supply or for the manufacture of polymers. Syngas and naphtha outputs are desired as precursors for producing plastics. As many pyrolysis technologies develop, those who are best suited at producing plastic-to-plastic outputs will likely emerge as winners as they are an important contributor to truly circular systems.

According to the EU Waste Directive, when pyrolysis outputs are used as feedstock for new polymers, this is considered recycling. Any output material used for energy recovery is not considered recycling and is classified as recovery. When pyrolysis oil is converted back into virgin grade polymers by petrochemical companies, using a mass balance approach, their customers can claim an equivalent volume of recycled content in their packaging.

Pyrolysis is dependent on reliable sorting and different processes can handle varying degrees of contamination. An advantage of pyrolysis is its ability to process mixed polyolefin plastic waste, particularly films, which has historically been difficult for mechanical recycling to accommodate. This is a major advantage as larger volumes of film are currently landfilled than rigid PP and PE containers in certain markets. Compared to mechanical recycling, pyrolysis is more GHG and energy intensive with potentially less favorable economics.



Source: Agile Process Chemicals

Economics of Pyrolysis

Since most pyrolysis units are either privately held startups or divisions of large companies, there is very little publicly available information about the economics of the business. However, based on interviews with industry experts and an analysis of announcements by companies, Ubuntoo has gathered some insights into the drivers of cost and success.

Pyrolysis is a capital-intensive industry, requiring $1,000 - $2,000 per ton of installed capacity. The output has to compete with crude oil prices, while the feedstock needs to be sorted, cleaned and dried before use. According to estimates by McKinsey & Co, technologies like pyrolysis are unlikely to be profitable at crude oil prices below $50 per barrel. This makes any investment into pyrolysis units an inherently risky proposition, given that projections for long term crude prices are below $50 for the foreseeable future.

Pyrolysis Capacity Projections

The total capacity of all commercially operated pyrolysis units that can supply feedstock for recycled plastics mapped by Ubuntoo amounted to less than 300,000 tons per annum in 2020. Based on available news reports and Ubuntoo's own analysis, the total recycled virgin grade PO plastic from pyrolysis in 2025 is expected to be less than 1 million tons.

CAPACITY PROJECTIONS FOR CIRCULAR PLASTIC PYROLYSIS PLAYERS (TONS / ANNUM)			
Company	**2020-2021**	**2025**	**Basis**
Plastic Energy	20,000	300,000	News reports
Brightmark Energy	100,000	300,000	
Nexus Fuels	18,000	100,000	Optimistic projections assuming they are all funded and scale up succesfully
Cat-HTR	20,000	20,000	
Renew ELP	80,000	200,000	
Resynergi	1,800	100,000	
Fuenix Ecogy	20,000	100,000	
Alterra Energy	20,000	100,000	
Quantafuel	20,00	100,000	
Others	20,000	200,000	
Total Capacity	**319,800**	**1,120,000**	
Average Yield	75%	75%	
Pyrolysis Oil	239,850	840,000	

Note: The above chart is an initial estimate. Ubuntoo will continue to refine these numbers as more data is uncovered.

9.1 Pyrolysis - Food Grade PET

PET is not the preferred feedstock for pyrolysis systems as it can be successfully recycled via mechanical and/or depolymerization techniques that require less energy and have more favorable carbon footprints. Also, PET generates a large amount of char while reducing the efficiency of a pyrolysis process, so it is considered a contaminant.

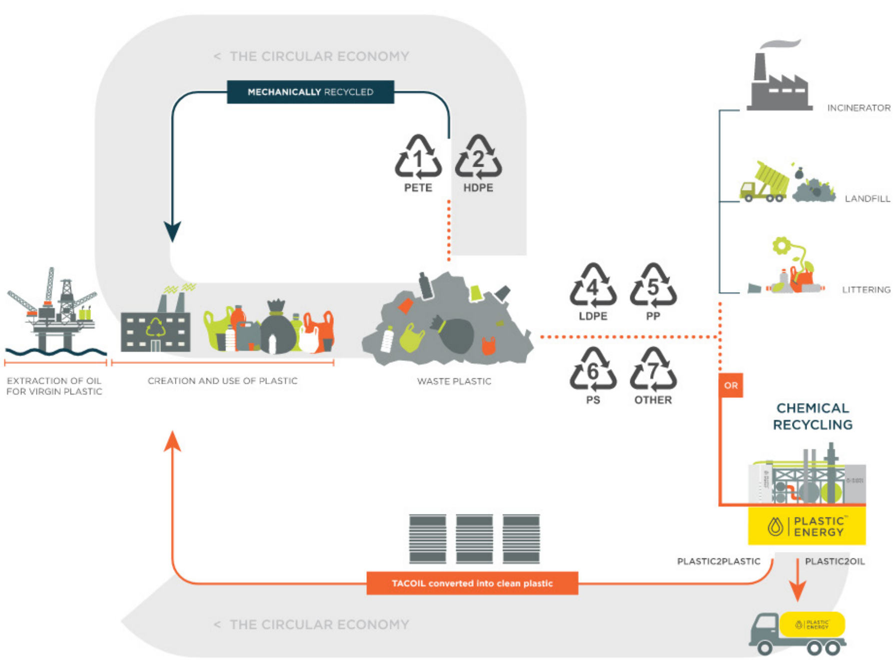
9.2 Pyrolysis - Packaging Grade PO

The naphtha generated via pyrolysis can be used to create plastic products of food-grade and packaging grade quality. However, the first preference for obtaining packaging grade PO remains mechanical recycling, given its lower energy footprint and higher recovery rates.

9.3 Pyrolysis - Food Grade PO

Research and corroboration from experts have shown that pyrolysis is the most developed, market-ready technology to produce recycled food grade PO.

Plastic Energy is a pyrolysis company based in London that has a commercial scale plant at a capacity of 18,144 tonnes/annum in Spain. They obtained the ISCC Plus mass balance certification and have partnered with Unilever's Magnum Ice Cream brand. They appear to have gained a lot of traction and partnered with Sabic among others.



Source: Plastic Energy

Brightmark Energy currently has one plant that will be operational at the end of 2020 and plans on expanding to three other plants on the east coast of the United States by 2021. Their Indiana plant has a capacity of 90,718 tonnes/annum and the company has an offtake agreement with BP. Brightmark has recently announced what it calls the largest-ever solicitation of plastic waste which they will process in their new facilities..

Nexus Fuels is an operational 16,556 tonnes/annum pyrolysis facility in Atlanta, Georgia. They accept post-industrial PO and PS waste and have an offtake agreement with Shell. Nexus is discussing a pilot project with TOMRA to test their ability to expand to well-sorted post-consumer waste. Nexus's business model has proven that pyrolysis can succeed commercially at scale, an important differentiator as many pyrolysis plants fail to produce favorable economics.

Cat-HTR is the hydrothermal liquefaction technology behind Renew ELP's recycling plant in the UK. This technology can take a mixed plastic waste feedstock and will process 80,000 tonnes/annum. The Cat-HTR process is differentiated by its ability to accept post-consumer mixed plastics and operate at lower temperatures that don't generate toxic gases.

Synova is not traditional pyrolysis and it falls somewhere between pyrolysis and gasification in terms of the temperatures used during their process. Their feedstock consists of MSW, wood and agricultural waste, and industrial waste. Their fully commercialized plant in Thailand has partnered with SCG to offtake their pyrolysis oil. Synova's market advantage is that their hybrid pyrolysis-gasification process doesn't crack tars, rather they remove them which produces a higher quality, higher value product with a lower carbon dioxide footprint.

Fuenix Ecogy did not respond to our request for information, but from public information, they have partnered with Dow Chemicals to offtake their pyrolysis oil and have achieved process yields of 70%.

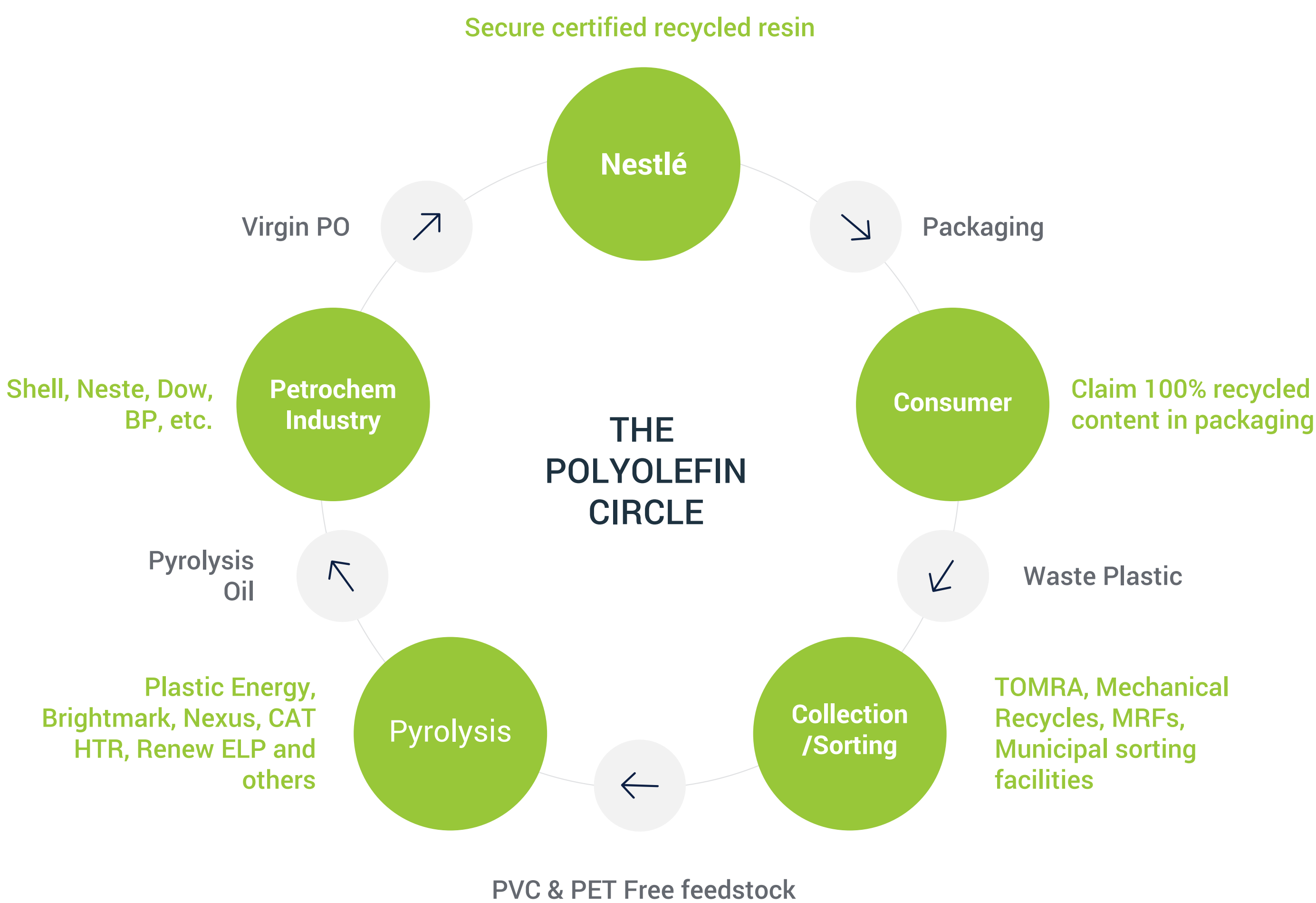
9.4 Pyrolysis - MLP

Enval specializes in recycling plastic aluminum laminates through pyrolysis. The process can separate aluminum from plastic, producing both recycled aluminum and pyrolysis oil output. As with other pyrolysis technologies, the naphtha resulting from the reaction can be used to create food-grade plastics. While Enval specializes in MLP recycling, Plastic Energy, Brightmark Energy, Cat-HTR, Renew ELP, and Synova recycle MLPs via pyrolysis while concurrently processing other PO feedstock.

9.5 Summary of Findings - Pyrolysis

There are many players in the pyrolysis value chain that contribute to the circularity of polyolefins. Specifically, as can be seen from the graphic below, post-consumer or post-industrial polyolefins are first separated at Material Recovery Facilities or are generated as a byproduct from conventional mechanical recycling facilities, then fed to pyrolysis units, who supply their oil fraction to petrochemical industry partners, who then convert it back into virgin quality polyolefins.

This "Polyolefin Circle" will require committed long-term demand by brand owners like Nestlé to drive investments and partnerships through the value chain. Otherwise pyrolysis oil will end up as transportation fuel or directly get converted into energy.



10.0 GASIFICATION

Chemical recycling via gasification uses temperatures higher than pyrolysis and requires some oxygen to function. Gasification produces outputs similar to pyrolysis; however, it does not produce char as the process converts waste materials to additional syngas. Compared to pyrolysis, gasification accepts a wider range of inputs; however, the technology appears to be less suited at producing products that can be used to create new plastics than it is for plastic-to-fuel or plastic-to-energy applications.

Because gasification is best suited for unsorted mixed municipal waste, the proportion of plastic waste in feedstock for most gasification units tends to be low, in some cases less than 30%. Additionally, the net yield after accounting for the energy required to run the process is significantly lower than that for pyrolysis units. As a result, there are few gasification projects focused exclusively on plastic waste.

10.1 Gasification - Food Grade PET

PET is not the preferred feedstock for gasification systems as it can be successfully recycled via mechanical and/or depolymerization techniques that require less energy and have more favorable carbon footprints.

10.2 Gasification - Packaging Grade PO

As with pyrolysis, the naphtha generated via gasification can be used to create plastic products of food-grade and packaging grade quality.

10.3 Gasification - Food Grade PO

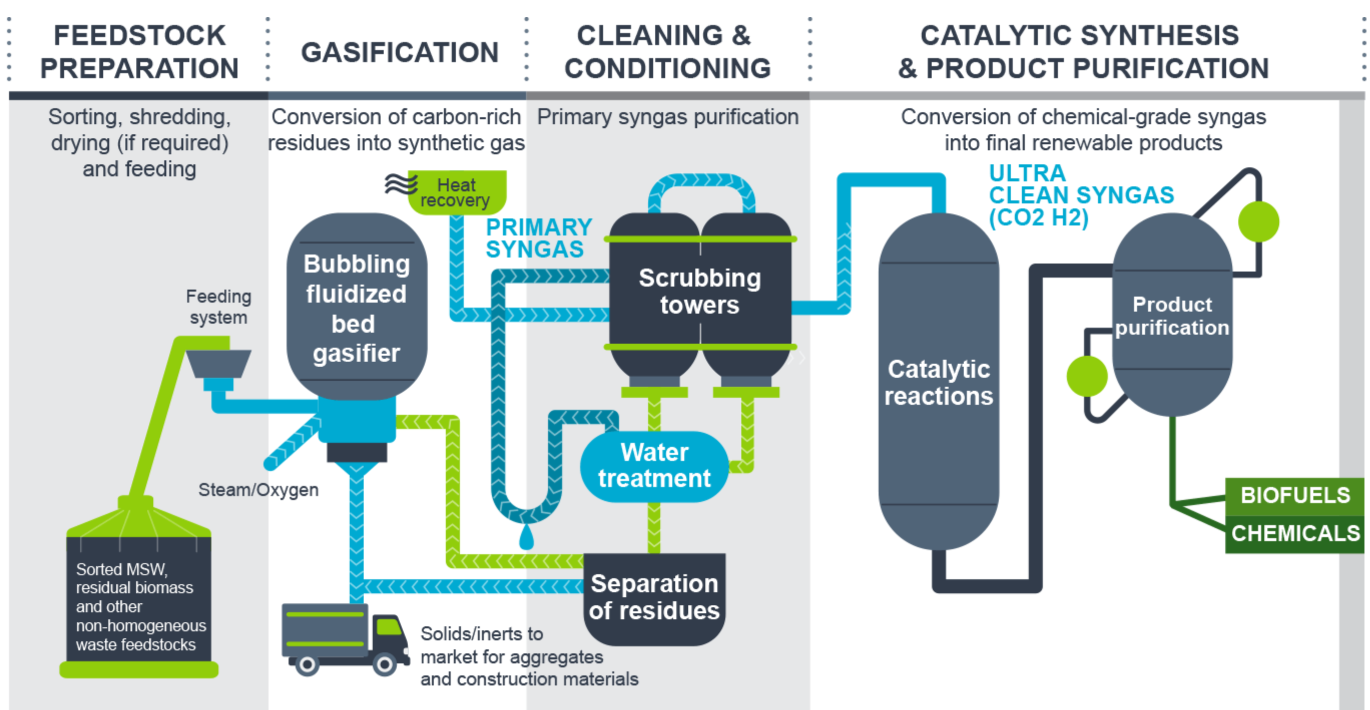
Enerkem has developed a process that takes a wide range of feedstock intended for landfill, including textiles and non-recyclable plastics, and converts them into biofuels and renewable chemicals. While the technology helps decrease landfilling and improves waste diversion, it is unclear what proportion of their final product can be used to create plastics.

Eastman Chemical Company's Carbon Renewal Technology can recycle mixed plastics, non-polyester plastics, flexible packaging, and plastics films into the molecular building blocks that are used to generate new, virgin-quality plastics products. The Carbon Renewal Technology can accept all plastic types except PVC, which is anticipated to be an acceptable feedstock in the second generation of the technology. Eastman has partnered with Circular Polymers and Carpet America Recovery Effort to give carpets an infinite life.

Plastic-to-energy gasification systems are not generally of relevance to this project because they focus on creating fuels instead of the building blocks for plastics. While gasification can produce the necessary output to create plastics, these companies appear to have focused on the plastics-to-energy output: Boson Energy, FastOx technology, and DMG Technology.

10.4 Gasification - MLP

The same technologies that process plastic waste into food grade material are capable of accepting MLP feedstocks. The high temperatures employed by gasification technologies are capable of breaking apart the multiple layers, aiding in conversion to syngas.



Source: Enerkem

10.5 Summary of Findings - Gasification

	FastOx (TRL 8)	DMG Technology (TRL 8)	Enerkem (TRL 9)	Cogent (TRL 8)	Carbon Renewal Technology (TRL 9)
Multi-layer Laminates		○		○	While Eastman's technology uses waste polyolefins and MLP as feedstock, their output does not include polyolefins. They seem to focus more on producing cellulosic polymers.
Food Grade PO		Potential for plastic-to-plastic solution, but current focus appears to be plastic-to-energy		Current focus on plastic-to-energy, emerging market solution	
Packaging Grade PO		○		✖	
Food Grade PET		✖		✖	✖

11.0 SMALL SCALE TECHNOLOGIES

Recycling technologies require large scales to be cost efficient, so they work best in areas where waste plastics can be collected back in large quantities. The challenge for remote areas and emerging markets is that plastic waste quantities are too small and distance to recycling centers makes reverse logistics unviable. Many solutions have emerged to address this challenge, though none have achieved scale yet, due to technological drawbacks or lack of an economically viable business model. Ubuntoo has identified a few promising candidates that have potential.

ScarabTech designed a pyrolysis plastic-to-energy machine with the aim of replacing diesel generators in remote areas and on islands while reducing plastic pollution. Their machines convert plastics into fuels that can be fed into a generator to create electricity or can be used for other applications. Up to 600kg of plastic can be processed per day by their compact machines at a cost of $0.08/kW compared to the $0.34/kW cost of electricity generation with diesel. Additionally, their machines have a carbon capture feature, making these plastic-derived fuels a lower carbon alternative to virgin diesel used in generators.

Cogent Energy Systems developed a gasification technology for small-scale waste producers and remote communities to convert waste into clean energy on-site. The energy produced from processing MSW, plastics, biomass, and hazardous waste can be utilized to generate electricity, create liquid fuels, hydrogen, and valuable chemicals. Each day, the process is capable of converting 4 tons of waste into approximately 3MWh of available surplus energy.

TrashBot has built a technology that takes unsorted trash and segregates it into bio-waste and non-bio waste with an efficiency of 99.6%. The bio-waste is composted to produce manure and to produce bio-gas, while the non-bio waste is used to make oil, plastic roads, and furniture boards. Waste can be processed at 2-25 tons of material a week. TrashBot is supported by Unilever and Shell, among others, and is based in India.

12.0 CONCLUSIONS AND RECOMMENDATIONS

12.1 Summary

- The field of plastic recycling is rapidly evolving, with many promising technologies on the horizon that need to be tracked, continuously evaluated, and where relevant, engaged by Nestlé
- Mechanical recycling will always be the mainstay of this industry because of its cost and environmental benefits, while chemical recycling will emerge as a strong complementary technology, especially for food-grade polyolefins
- However, we advise caution when navigating this space, because chemical recycling has been the subject of criticism from environmentalists, lack of standardization, regulatory uncertainty, and a history of failed or overhyped promises
- In the short to medium term (< 3 years)
    - Mechanical recycling will continue to be the biggest source of recycled food-grade PET and, with investments in the right sorting technologies, supply of recycled packaging-grade polyolefins can also be increased
    - Pyrolysis is emerging as the chemical recycling technology with the highest potential to provide Nestlé with virgin quality food-grade polyolefins from recycled plastic at large scales
- In the longer term (> 3 years)
    - Purification technologies have the potential to unlock enhanced supplies of recycled food-grade polyolefins
    - Chemical depolymerization technologies have the potential to expand the availability of recycled PET by recycling polyester

In the following sections, we recommend "Engaging" with selected solution providers to explore opportunities to collaborate, strike long term procurement agreements, or direct investments towards them to accelerate their growth.

12.2 Sorting / Separation Technologies

This space features a lot of innovations that can unlock the availability of high quality and quantity feedstock for mechanical recycling.

- Packaging solutions
  - Nestlé is already engaged with the HolyGrail & PRISM projects, both of which have the potential to help MRFs separate waste packaging into mono-material streams by reading digitally tagged packaging
  - Design2Recycle by Magnomer is a solution that can be implemented with current technology and a minimal upcharge to improve separation of labels, films, and MLP at MRFs. Recommendation: **ENGAGE**
- Polytential has technology that claims to be able to identify whether waste plastic was originally used for food grade applications, among other things. If proven, this is a breakthrough in the sorting industry. Recommendation: **ENGAGE**
- Saperatec is the most promising solution for separating multi-layer plastic waste into its aluminum, PE and PET components. Recommendation: **ENGAGE**
- Umincorp is a unique separation solution that is worth exploring. Ubuntoo has not been able to establish contact yet and will gather more information about them to provide a more definitive recommendation shortly.
- Cadel Deinking is a cleaning technology that does not appear to be of high direct relevance to Nestlé. Recommendation: **MONITOR**

12.3 Mechanically Recycled Food-Grade PET

Our research did not uncover any new technology that is likely to disrupt established methods of producing recycled PET. As a result, this is turning into a mature industry, dominated by large players with large plants. We see this as the domain of the procurement department at Nestlé, who are best suited to enter into long term contracts with established recycled resin producers based on the most favorable commercial terms.

- DEJA by Indorama Ventures Limited is the most aggressive and fastest growing player in this space with a planned recycling capacity of 750,000 tons by 2025, and recent acquisitions of rPET players like Green Fibres.
- Other global and regional players include Verdeco (USA), CarbonLITE (USA), ALPLA (Europe / Global), Plastipak (UK / Global), PetStar (Mexico – Coke owned

12.4 Chemically Recycled Food-Grade PET

There are multiple startups and even a few established players operating in this space. None have achieved commercial success yet, and recent news reports about the potential fraud at Loop Industries will cause some investor hesitation in funding this kind of technology. This technology space requires collaboration with Packaging R&D.

- Ioniqa (rated 4 stars) appears to be furthest along the TRL scale with a 10,000 ton plant in operation and partnerships with Unilever, Coca-Cola and Indorama.
  Recommendation: **ENGAGE**
- Loop Industries (rated 3.5 stars) is currently under a cloud. Our expert has provided this explanation: *"The Loop technology is real, though not 'room temperature' or '100% yield' as has been said. The Loop methoxide chemistry (the reason for the low temperature operation) has been done by others (expired patent), which leads to weak patent protection if someone else wanted to practice the chemistry. The methoxide chemistry creates almost as many issues as it solves. DMT, which can be produced at high purity, as a product is not favored for PET making – the polymer is uneconomical vs. current PTA-based polymer. That Indorama Ventures Limited is still in discussions says to me the business arrangement is the problem, not the chemistry."* We have moved this solution to "Parked" status as a matter of abundant caution until further clarity emerges. Recommendation: **MONITOR**
- Nestlé already collaborates with Gr3n, Carbios, and Origin Materials, all of which show promise, but are a few years away from commercialization at scale, if at all.
- ChemPET by Garbo (rated 3.75 stars) shows promise, though more needs to be learnt about their patent and economics. Recommendation: **ENGAGE**
- VolCat by IBM has been written about a lot by the media but is barely mentioned in the IBM website other than in a press release. Recommendation: **MONITOR**

12.5 Mechanically Recycled Polyolefins

Some of our experts were skeptical about the potential for mechanical recycling to be a **long-term source of high-quality recycled food-grade polyolefins at scale.** One expert says *"I believe that mechanical recycling is very limited for polyolefins. As an addition polymer the molecule is very long and is the best it can be the day it is made. It can only get worse with each heat history. Most processes require additive packages to effectively glue it back together. If we get good at collecting the quality will drop as materials make more than one trip. Food-grade requires sortation to insure it is made from materials that had food in them. Most mechanically recycled PP and PE end up in durables."*

- **Packaging Grade Polyolefins:** given the wide range of specifications and quality parameters, it is hard to pinpoint any one solution provider for this category. There are over 1,000 recyclers around the world that claim to recycle PP, LDPE and / or HDPE into various grades, though most of the output is used for durables, especially PP. A good partner to engage with here is TOMRA, who are a sorting / separation technology provider, but have set up a demonstration unit in Europe for high quality packaging grade polyolefins.
- **Food-Grade Polyolefins:** Experts did not believe that EFSA would ever approve food-grade recycled polyolefins using current mechanical recycling technology. According to them, the molecular structure of polyolefins makes them highly susceptible to absorbing contaminants from the environment. The US FDA has issued no-objection certificates to the following recyclers for food grade polyolefins for certain applications, provided the post-consumer recycled material was originally used for food contact. The exact grades and applications will need to be discussed further between Nestlé and the solution providers.
  - Ecoprime by Envision Plastics has patented technology and years of experience in this space. Recommendation: **ENGAGE**
  - KW Plastics claims to be the world's largest supplier of HDPE and PP resin. Recommendation: **ENGAGE**
  - Others include Nuvida, Aaron and Total (only authorized for 60% rHDPE) – listings will be active on the Nestlé GreenHouse by end-October 2020
- Banyan Nation produces high quality recycled HDPE grade that is approved for sensitive personal care products by Unilever India and are confident of being able to achieve food-grade standards. Recommendation: **ENGAGE**

12.6 Purification Technologies - Polyolefins

Nestlé already collaborates with the two highest potential technologies in this space – Nextek and PureCycle Technologies. All other technologies evaluated by Ubuntoo only had capability to recycle packaging-grade polyolefins, which can be better served by mechanical recycling combined with superior sorting technology.

12.7 Pyrolysis – Polyolefins

Pyrolysis is not a silver bullet, but amongst the options available to Nestlé, it is the only one that has the potential to provide recycled food-grade polyolefins in volumes exceeding 100,000 tons per annum in a 1 to 3 year timeframe.

We strongly recommend that Nestlé engage in immediate discussions with pyrolysis companies and their petroch emical partners to secure future supplies of virgin polyolefins using the mass balance approach to qualify as recycled plastics. We see announcements about new capacities and brand partnerships in this space almost every month, and our assessment is that supplies will be limited to the early movers amongst brand owners.

Since this industry is at a nascent stage, long term commercial success of specific partners is yet to be validated. The best approach will be to spread your supply risks across multiple partnerships.

Our Recommendation – Engage immediately with these four companies

SOLUTION NAME	PETROCHEMICAL ARTNER	LOCATION	ASSESSMENT
Plastic Energy	SABIC	UK / Europe /ASEAN	**Pros:** High traction, broad partnerships, rapidly scaling up, well-funded, recycled products in market, accepts post-consumer polyolefins including MLP, proven technology **Cons:** Already engaged with food brands
Brightmark Energy	BP	USA	**Pros:** Large scale, well-funded, accepts post-consumer polyolefins including MLP, big scale up plans **Cons:** BP has not announced conversion of their output into plastics yet
ReNew ELP / Cat-HTR	Neste	UK / Australia	**Pros:** Large scale, accepts post-consumer polyolefins including MLP **Cons:** Some questions about the robustness of technology by experts
Nexus Fuels	Shell	USA	**Pros:** Efficient with capital and energy, proven commercial viability, open to brand partnerships **Cons:** Only accepts post-industrial plastic waste, does not accept MLP

+ Synova appears to be more of a low temperature gasification technology for mixed municipal waste than a true pyrolysis solution that is fit for mixed plastic waste. Recommendation: **MONITOR**
+ Enval technology is specially designed to separate the layers in MLP, but it may be rendered obsolete if other pyrolysis companies are able to prove they can process MLP waste. Recommendation: **MONITOR**
+ Technologies that are small scale and focus on modular systems for distributed processing of waste do not have a clear applicability to providing Nestlé with recycled polyolefins at scale
  - Resynergi, Braven Environmental, Recycling Technologies
+ Technologies at an early or pilot stage that should be monitored for progress and engaged with when they achieve critical milestones
  - ChemCycle, Plas-TCat, Quantafuel, MoReTec, Clariter
+ Many other pyrolysis solutions were kept out of the scope of this project because their outputs were used for transportation fuel or directly burnt for energy

12.8 Gasification Technologies

Experts do not recommend gasification as a preferred route to convert waste plastics back into virgin polymers. Disadvantages are high energy consumption, use of mixed municipal waste as feedstock that contains low percentage of mixed plastic waste, and the **challenges of obtaining mass balance certification**. Most gasification projects reviewed by Ubuntoo focus on direct conversion of waste to energy. Carbon Renewal Technology by Eastman is an exception, but they do not produce polyolefins.