WHITE PAPER

CIRCULAR POLYOLEFIN CAPACITY SET TO REACH 1 MILLION TONNES GLOBALLY IN 2025

Dr. Jeroen Wassenaar
Circular & Renewable Plastics Manager
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Qenos

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Discover how circular PE and PP are moving from an academic curiosity to an industrial scale recycling solution.
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Production of circular polyethylene and polypropylene through advanced recycling is expected to increase significantly between 2023 and 2026. While global capacity is estimated at just over 100,000 tonnes per annum today, announcements from technology providers and petrochemical manufacturers suggest that capacity is expected to ramp up to 1.4 million tonnes in 2026. Growth will occur in regions that have a well-developed policy supporting the circular economy, a well-regulated waste management sector and existing virgin polyolefin manufacturing infrastructure. Despite the strong growth, it is expected to take more than a decade before the supply of circular polyolefins will begin to approach latent demand.

TARGETS FOR RECYCLED CONTENT IN PLASTIC PRODUCTS AND PACKAGING, DRIVEN BY CONSUMER DEMAND AND SET BY GOVERNMENTS AND BRAND OWNERS, HAVE STIMULATED DEMAND FOR FOOD GRADE RECYCLED PLASTICS THAT CANNOT BE MET BY MECHANICAL RECYCLING ALONE. CIRCULAR POLYOLEFINS PRODUCED THROUGH PROCESSES SUCH AS ADVANCED RECYCLING ARE CRITICAL IN MEETING THIS DEMAND, COMPLEMENT MECHANICAL RECYCLING AND BRING THE ADDED BENEFIT OF PERFORMANCE THAT IS IDENTICAL TO VIRGIN RESIN. THIS WHITE PAPER SUMMARISES THE PRODUCTION CAPACITY THAT HAS BEEN ANNOUNCED TO DATE, DESCRIBES THE CONDITIONS THAT SUPPORT THIS NEW CAPACITY, AND EXPLORES HOW THE SUPPLY AND DEMAND BALANCE FOR CIRCULAR POLYOLEFINS MAY EVOLVE IN THE FUTURE.

WHAT ARE CIRCULAR POLYOLEFINS AND HOW ARE THEY PRODUCED?

Polyolefins are the most used plastics in the world with current demand estimated at more than 200 million tonnes globally, representing two thirds of all plastics consumption [CMA 2022]. The polyolefins category includes the three forms of polyethylene (HDPE, LLDPE & LDPE) and polypropylene (PP). Whilst technically recyclable through conventional mechanical processes, recycling rates have remained below 10% globally for a range of well documented reasons [Mann 2022]. Technology advances in collection, sorting, design for recycling, and processing are bound to increase mechanical recycling rates. However, alternative and complementary methods are required to increase overall plastics circularity to a sustainable level within planetary boundaries [Bachmann 2023].

In the context of this paper, circular polyolefins are defined as polyolefins that exhibit identical properties to virgin material and are derived from waste plastics. Some mechanically recycled polyolefins or materials obtained through a dissolution processes – also referred to as physical recycling – come close to matching the properties of virgin material and may in some cases be used in food contact applications. However, such materials will always be distinguishable from virgin polyolefins by exhibiting thermal degradation, oxidative degradation, or the presence of contaminants. With circular polyolefins, the end-of-life material is completely chemically deconstructed to its hydrocarbon building blocks and subsequently recreated using the same process used to manufacture virgin polyolefins. Circular polyolefins have been used in a great variety of food packaging applications, including dairy, frozen foods, confectionery, and dry foods. They have also been used in demanding non-food applications such as cosmetics, automotive and building & construction.

Circular polyolefins not only deliver recycled content in a high-performance material but have also been shown to reduce greenhouse gas emissions in comparison to virgin plastics that are incinerated in waste to energy plants after use [JRC 2023]. Depending on the electricity mix and exact technology applied, circular polyolefins provide a 40-60% reduction in greenhouse gas emissions [Sphera 2022]. Other environmental benefits include a 75-90% reduction in fossil resource use. Importantly, with electricity grids continuing to decarbonise, the benefits of circular polyolefins over fossil-based materials and waste to energy schemes will only increase.

The advanced recycling methods to create circular polyolefins are based on thermochemical conversion processes such as pyrolysis and gasification of waste plastics. Pyrolysis is a process in which waste plastics are heated to temperatures of about 400°C in the absence of any oxygen. Under these conditions the bonds in the plastics' polymer chains will break, creating a range of smaller hydrocarbon molecules that remain gaseous, condense into oil, or solidify upon cooling to ambient temperature. Over twenty different processes employing this basic principle have been commercialised to date, using a diverse range of reactor designs, catalysts (in some cases) and reaction media such as supercritical water or other diluents to achieve optimal efficiency. Pyrolysis oil is the desired liquid fraction which is further converted into a naphtha-like feedstock typically through hydrotreatment or with optional hydrocracking. This circular naphtha is then compatible with existing polyolefin production processes and can be used as feedstock in a steam cracker to produce ethylene and propylene as well as other building blocks for the chemical industry such as butadiene and BTX (Benzene, Toluene, Xylene). Typically, circular naphtha is co-processed with conventional feedstock and the recycled content is attributed to products using a mass-balance approach. The circular ethylene or propylene is then polymerised into circular polyethylene or polypropylene in the same reactors as conventional polyolefins, ensuring that final properties and batch consistency are identical to those of virgin material. A more detailed discussion of the production process as depicted in Figure 1, including mass-balance attribution, has been published in a previous white paper [Wassenaar 2022].

> **WITH OVER TWENTY DIFFERENT ADVANCED RECYCLING TECHNOLOGIES AND THE ACTIVE INVOLVEMENT OF MOST OF THE MAJOR INTERNATIONAL PETROCHEMICAL MANUFACTURERS, WE EXPECT THE INDUSTRY TO CONTINUE TO DEVELOP AND PROVIDE A REAL CIRCULAR SOLUTION FOR FOOD GRADE PLASTICS TO COMPLEMENT MECHANICAL RECYCLING.**

Gasification is another form of thermochemical conversion that takes place at temperatures above 900°C in the presence of controlled amounts of oxygen, resulting in the formation of syngas (mixture of hydrogen and carbon monoxide) as the primary product. Syngas may be converted into naphtha or methanol and subsequently converted into polyolefins. Most waste plastic processed by gasification ends up as syngas that is burned for electricity generation as further conversion into polyolefins is cost prohibitive. There are exceptions to this including some pilot installations and in regions that have a well-developed methanol-to-olefins (MTO) industry.

Depolymerisation is an advanced recycling process that converts polymers into monomers and is being applied at commercial scale in the production of polyesters and polystyrene. The strong carbon-carbon bonds in polyolefins do not allow for a selective depolymerisation to ethylene and propylene at commercial scale even though some strategies are being explored at lab-scale [Wang 2022, Conk 2022].

METHODOLOGY AND ASSUMPTIONS

The supply capacity of circular polyolefins presented in this paper has been compiled from press releases and announcements from recycling technology providers and petrochemical manufacturers as well as open-access literature and press. The data is current as of February 2023, which is important to note given the rapid development of this industry. Inclusion has been limited to projects that have a defined start-up date, capacity, and location. Advanced recycling plants treating tyres have been excluded as they will typically not yield a suitable oil for processing into circular polyolefins. Also, plants that only target fuels as a product have been excluded. The 2025 and 2030 recycling ambitions and targets issued by industry participants have not been considered.

Figure 1. **Typical process flow to produce circular polyolefins from mixed plastic waste**

A 60% conversion efficiency of waste plastic feedstock into circular polyolefins for pyrolysis-type processes has been assumed. This yield is based on the profile of by-products such as fuel gas and char and accounts for any losses during purification. The yield calculation relies on the mass balance approach described by ISCC Plus where all recycled content is allocated to ethylene or propylene in the steam cracking step [ISCC 2021]. Where publicly available, more detailed data was used. For the purposes of this paper, capacities for polyolefins are grouped together rather than attempting to split them into polyethylene and polypropylene. The reason for this is that using the mass-balance approach the producer may allocate recycled content to the monomer of choice and most petro-chemical manufacturers with steam crackers are integrated with both polyethylene and polypropylene downstream production assets. Whilst care has been taken to incorporate all capacity announcements made to date to the best of our knowledge, this paper does not claim to be exhaustive and makes no representations about whether incorporated projects will go ahead.

The demand for circular polyolefins is estimated based on recycled content targets announced globally for packaging by brand owners, governments, and NGOs. They broadly converge on a 30% recycled content target for plastics in packaging by 2030 [EC 2022, DCCEEW 2022, EMF 2022, HMRC 2021, Calrecycle 2020, Singh 2023]. Packaging globally represents about 40% of all polyolefin demand of which 25% is assumed to require approval for food contact that is unable to be met by mechanical recycling. The resulting demand for circular polyolefins is thus estimated at 30% x 40% x 25% = 3% of global PE & PP demand, corresponding to 6 million tonnes in 2022 as reported by CMA and Wood Mackenzie, respectively [CMA 2022, McDermott 2022]. This approach may overestimate the demand as certain regions will be lagging in implementing recycled content targets and regulations whilst at the same time it may underestimate demand as some end users have higher targets and circular polyolefins will also find application in non-food packaging and non-packaging applications such as automotive. The demand for circular polyolefins is also dependent on their price differential to virgin polyolefins.

As capacity and experience to produce circular polyolefins increases and R&D in this area continues, the price is expected to decline thus further stimulating demand. It is therefore believed that this approach is a reasonable indicator for the latent demand for circular polyolefins at the present time and in sophisticated markets.

CURRENT CAPACITY

Table 1 lists the advanced recycling plants currently deemed operational that produce pyrolysis oil as feedstock for circular polyolefins. The current total circular polyolefins production capacity is estimated at 104 kilotonnes per annum (kta), representing 0.05% of global polyolefin demand. Table 1 lists capacities as communicated publicly. The actual operating rate and production volumes are not publicly available.

According to this data, Plastic Energy's two facilities in Spain were the first plants to produce pyrolysis oil suitable as feedstock for circular polyolefin production. This oil has been used by various European polyolefin manufacturers to produce circular polyolefins as documented in several case studies and press releases.

In the US, Alterra Energy, Nexus, and New Hope have pioneered the first commercial advanced recycling plants since 2020, supplying feedstock to several of the major polyolefin producers in North America. In early 2023, ExxonMobil commissioned one of the largest plants thus far, integrated at their Baytown complex in Texas. It is based on proprietary technology developed in-house.

Whilst Asia is arguably lagging in terms of political commitments to plastics circularity, two plants are operational in Thailand and Singapore.

Of further note is the plant operated by Renasci in Belgium. Whilst most plants operational to date use a pre-sorted polyolefin-rich feedstock in many cases from post-industrial sources, this plant takes in a wide range of plastics, metals, organics, and paper that are subsequently composted or recycled mechanically where possible. Only the remaining plastic fraction is converted into feedstock for circular polyolefins, explaining the lower yield.

TABLE 1. LIST OF CURRENTLY OPERATIONAL ADVANCED RECYCLING PLANTS, PROVIDING FEEDSTOCK FOR CIRCULAR POLYOLEFINS

Operator	Country	Publicly known offtaker(s)	Input volume (kta)	Assumed yield of circular PE/PP	Circular PE/PP (kta)	Year online
Plastic Energy	ES	TotalEnergies, Ineos, Sabic, LyondellBasell	10	60%	6	2015/2017
Alterra Energy	US	Neste	18	60%	11	2020
Nexus Circular	US	Shell, Dow, Braskem, Chevron Phillips, LyondellBasell	3.6	60%	2	2020
Quantafuel	DK	BASF	20	60%	12	2020
Circular Plas	TH	SCG	4	60%	2	2021
New Hope	US	Dow, TotalEnergies, Chevron Phillips	16	60%	10	2021
Renasci	BE	Borealis	120	20%	24	2021
ESA	SG	Shell	20	60%	12	2021
Arcus	DE	BASF	4	60%	2	2022
ExxonMobil	US	ExxonMobil	36	60%	22	2023

CRITICAL ENABLERS

Four critical enablers have been identified that need to be in place to drive the required increase in advanced circular recycling to make plastics more sustainable. These are access to waste plastics feedstock, supportive policy and regulatory framework, access to capital, and an existing virgin plastic manufacturing industry.

Access to waste plastic feedstock is critical for all advanced recycling plants. Whilst it may seem that waste plastics are all around us, collecting the right material can be challenging as waste polyolefins – especially in flexible packaging – have not typically been collected separately and new collection and logistics strategies need to be devised. Underpinning this is a well-regulated waste management industry that ensures that waste plastics do not leak into the environment.

As advanced plastics sorting infrastructure is typically not in place, extended producer responsibility (EPR) and other policy instruments may be needed to incentivise investment in such critical infrastructure. Policy settings could include specific and ideally enforceable recycled content targets, environmental legislation that recognises conversion of waste plastics into circular polyolefins as a manufacturing process, elevated levies for landfill, design for recycling obligations, chain of custody protocols that recognise the mass-balance approach, and inclusive kerbside collection standards.

Changing from a linear to a circular business model requires reinventing established business practices that demand investments which typically will not yield a return in the short term. Both private and public capital with a long investment horizon will be important in facilitating this transition.

Circular polyolefins need to integrate into an existing virgin polyolefin manufacturing industry. This industry has invested heavily in capital infrastructure over many decades. Taking advantage of this infrastructure through the mass-balance approach significantly reduces the capital requirement to produce circular polyolefins. Importantly though, this means that circular polyolefin production can only take place where the conditions exist for the virgin polyolefin industry to remain viable into the future.

CAPACITY ANNOUNCEMENTS

Within the last three years, we have seen a flurry of announcements by advanced recycling technology licensors and petrochemical manufacturers about new plants and offtake agreements to produce circular polyolefins. Assuming all these projects go ahead as planned, this would result in a global capacity of more than 1 million tonnes in 2025 (Figure 2). The data in the figure is based on 49 individual plants with an average capacity of 30 kta and median capacity of 18 kta of circular polyolefins. Three projects of more than 100 kta capacity are expected to start up in 2025 and 2026. More than 2.8 million tonnes of waste plastic feedstock would be treated by these facilities with varying yields depending on technology and marketing strategy to direct product to the production of circular polyolefins or alternatively to fuels and energy.

Consistent with the current capacity, these new projects will be located predominantly in Western Europe and North America. In these regions, the policy, regulation, and extended producer responsibility (EPR) environment places a higher value on recycled plastics than virgin plastics and also recognises advanced recycling and the mass-balance in legislation, differentiating it from waste treatment. Mature economies in Asia Pacific that are developing their circular economy policy and have petrochemical industries such as South Korea, Singapore, Malaysia, Japan, and Australia, will also see significant capacities added. A few projects are considered for the Middle East and North Africa but details on capacity and start-up dates have been insufficient to incorporate them in this analysis.

This analysis has only considered projects that expect to come on-line by 2026. Insufficient data is available about discrete projects in later years at this stage. A combined target to produce more than 14 million tonnes of sustainable plastics by 2030 has been announced by the world's largest international petrochemical manufacturers (Figure 3). It should be noted that this also includes plastics produced by mechanical recycling and bio-based plastics, making it impossible to isolate a specific target for circular polyolefins. Despite that, we can anticipate that by 2030 the global capacity for circular polyolefins will have increased significantly from the projection for 2026.

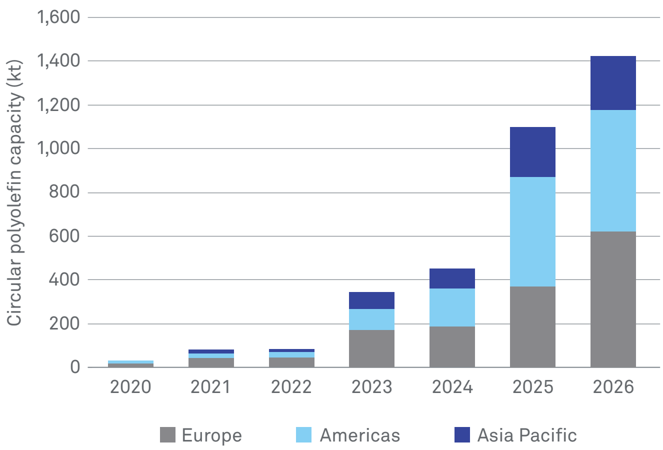

Figure 2. Cumulative circular polyolefin production capacity in operation and announced from 2020 until 2026

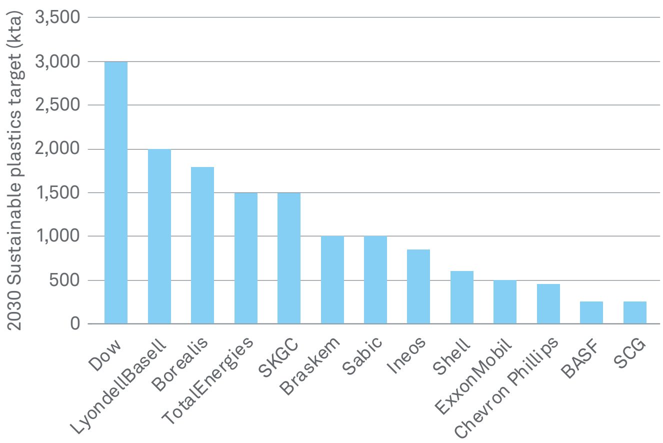

Figure 3. 2030 Sustainable plastics production targets by major international petrochemical manufacturers as stated in press releases and on corporate websites. Numbers include plastics produced by chemical and mechanical recycling as well as bio-based plastics.

KEY TECHNOLOGY PROVIDERS AND MANUFACTURERS

Over twenty different technologies have been or are being commercialised to produce circular polyolefins. The top 5 technology licensors in terms of announced pyrolysis oil (PyOil) capacity together with the largest offtakers are listed in Figure 4. Whilst most of the technology licensors have built a first commercial plant, further expansion is often done by licensing the technology to investors and project developers. These are typically petrochemical manufacturers but can also be waste management firms that can source the waste plastic feedstock requirements. Most projects are supported by long-term offtake agreements with petrochemical manufacturers able to transform PyOil into circular polyolefins or precursors. Many of the petrochemical manufacturers that have signed offtake agreements invest in purification plants that are co-located with their steam crackers to upgrade the PyOil into circular naphtha. Others may use third party refiners to upgrade the PyOil.

The multitude of off-take agreements that have been announced in the past couple of years, suggests that PyOil will eventually become a globally traded commodity with an associated price marker. For the moment, however, PyOil from waste plastics is scarce and production volumes have already been committed. It is conceivable that it may not be until the beginning of the next decade that this commoditisation of PyOil will occur.

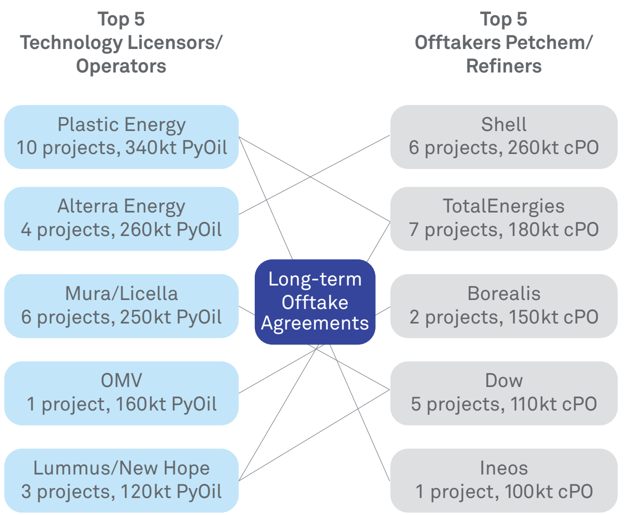

Figure 4. **Top 5 technology licensors and offtakers of pyrolysis oil (PyOil). PyOil capacities are estimated based on waste feedstock capacities announced and stated or estimated PyOil yields. PyOil and circular polyolefin (cPO) capacity numbers refer to total capacity, not only the connections/agreements displayed here.**

SUPPLY & DEMAND BALANCE

Demand for circular polyolefins is fuelled by government policy targets, incentives, and taxes as well as brand owner commitments to incorporate recycled content in plastic products and packaging. In polyolefin applications that do not require food contact or need elevated aesthetic or mechanical properties, mechanically recycled solutions are the most economic and sustainable option. However, there is a significant demand for high performance recycled plastics that can only be met by circular polyolefins. Our assumption of the latent demand for these materials is based on a 30% recycled content target in global food contact packaging, equating to 3% of all polyolefin demand (see section Methodology and Assumptions for more detail, page 3).

The supply & demand balance for circular polyolefins depicted in Figure 5 suggests that the gap between the two will diminish over time but is not expected to close until after 2035. Capacity beyond 2026 is estimated based on an anticipated year-over-year growth rate of 20% as forecast by McKinsey & Company [Peng 2022]. This analysis further highlights that despite circular polyolefins reaching industrial maturity in the next couple of years, they remain a specialty polymer and will not be commoditised for at least a decade. Buyers will likely need to commit to long-term offtake agreements to secure access for the foreseeable future.

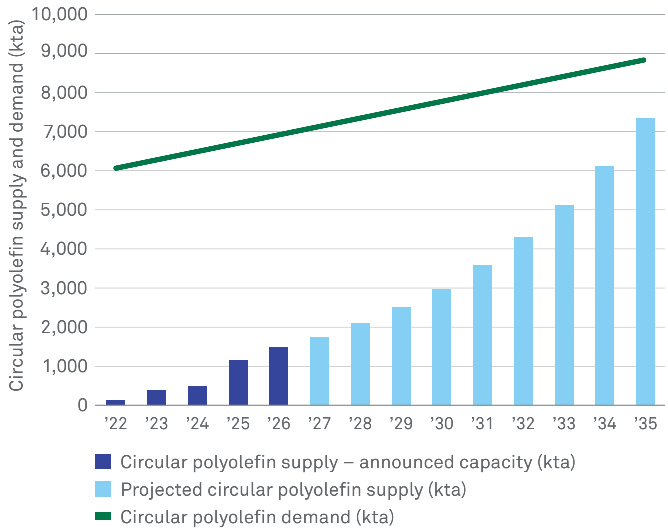

Figure 5. **Projected circular polyolefin supply and demand. See Methodology and Assumptions for more detail.**

CONCLUSION

This white paper highlights that circular polyolefins produced through advanced recycling are no longer an academic curiosity or theoretical exercise by the chemical industry to retain its license to operate. Billions of dollars of investment are flowing into this industry currently to build more than one million tonnes of capacity by 2025 [PlasticsEurope 2021, ACC 2022]. With over twenty different advanced recycling technologies and most of the major international petrochemical manufacturers actively involved, we expect the industry to continue to develop and provide a real circular solution for food grade plastics to complement mechanical recycling. However, it is expected to take more than a decade before supply of circular polyolefins will begin to approach latent demand. Capacity will only grow in regions that have a well-developed circular economy policy, a well-regulated waste management sector and an existing virgin polyolefin manufacturing base.

REFERENCES

American Chemistry Council (ACC), *The potential economic impact of advanced recycling and recovery facilities in the United States*, Report, April 2022

M. Bachmann, C. Zibunas, J. Hartmann et al., *Towards circular plastics within planetary boundaries,* Nature Sustainability, 2023, https://doi.org/10.1038/s41893-022-01054-9

California Department of Resource Recycling and Recovery (Calrecycle), *Plastic Minimum Content Standards (AB 793)*, https://calrecycle.ca.gov/bevcontainer/bevdistman/plasticcontent, 2020

Chemical Market Analytics (CMA), *Polyethylene World Analysis edition 2023*, December 2022

R. J. Conk et al., *Catalytic deconstruction of waste polyethylene with ethylene to form propylene*, Science, 2022, Vol. 377, 1561-1566

Department of Climate Change, Energy, the Environment and Water (DCCEEW), *Australian Packaging Covenant*, www.dcceew.gov.au/environment/protection/waste/plastics-and-packaging/packaging-covenant, 2022

Ellen MacArthur Foundation (EMF), *The Global Commitment 2022*, Progress report, 2022

European Commission (EC), *European Green Deal: Putting an end to wasteful packaging, boosting reuse and recycling*, Press release, November 2022

HM Revenue & Customs (HMRC), *Introduction of Plastic Packaging Tax from April 2022*, Policy paper, July 2021

International Sustainability & Carbon Certification, *ISCC PLUS System Document*, v3.3, August 2021

Joint Research Centre (JRC), *Environmental and economic assessment of plastic waste recycling*, Technical Report, 2023

L. Mann, *Mechanical recycling of polyethylene*, Qenos white paper, March 2022

M. McDermott (Wood Mackenzie), *Europe polyolefins: assessing the outlook for resin and recycling*, SPE Annual Conference: Plastics and the Circular Economy, November 2022

Z. Peng, T. J. Simons, J. Wallach, A. Youngman, *Advanced recycling: opportunities for growth*, McKinsey & Company article, May 2022

PlasticsEurope, *European plastics manufacturers plan 7.2 billion Euros of investment in chemical recycling*, Press release, May 2021

S. Singh, *India 'getting more mature' in plastics recycling*, Plastics News, March 2023

Sphera on behalf of the Consumer Goods Forum, *Life cycle assessment of chemical recycling for food grade film*, v1.6, July 2022

N. M. Wang et al., *Chemical recycling of polyethylene by tandem catalytic conversion to propylene,* Journal of the American Chemical Society, 2022, Vol. 144, 18526-18531

J. Wassenaar, *Circular advanced recycling of plastics through pyrolysis*, Qenos white paper, March 2022

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Qenos Pty Ltd

471 Kororoit Creek Rd
Altona Victoria 3018 Australia

Phone 1800 063 573
ABN 62 054 196 771

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