Trends in plastics recycling

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Trends in plastics recycling and consequences for drinking water sector

Azoulay et al. (2019)

Summary

Plastics are a hot topic nowadays, with certain types of polymers more easily reused than others. With reuse, new recycling strategies are required, which may have consequences for the drinking water sector. Currently the vast majority of plastics in the Netherlands are recycled mechanically, however chemical recycling is expected to grow to account for 10% of plastic recycled in the Netherlands by 2030. Plastic recycling done in Belgium and Germany are here not yet taken into account. This means that the rivers Rhine and Meuse could already be carrying chemicals from these processes when entering the Netherlands. Chemical recycling may offer benefits over mechanical recycling, in terms of closing the loop in plastic production and processing difficult to recycle waste, including contaminated plastics. However, careful attention should be paid to potential new emissions routes, including emissions to wastewater. The recycling industry would benefit from a clear, streamlined set of regulations, focused on the exposure risk of specific applications of recycled plastics. The water sector, including the drinking water sector, should be present as a stakeholder in these discussions to ensure the protection of water quality.

Consequences for you

	Low	Medium	High	Brief explanation
Impact		■		Impact on water quality possible if water sector not involved in regulation of emissions from (new) recycling techniques. Clear regulations focused on risk of exposure necessary in plastics industry to ensure a safe circular economy.
Certainty	■			The development of new recycling techniques, in particular chemical recycling, and their emissions is still uncertain as few chemical recycling facilities operate in the Netherlands at the moment. This is expected to change in the coming decades.

Trend description and background

Introduction

Plastics are a ubiquitous part of everyday life and can pose a risk to health at every stage of their lifecycle, from production to use, recycling and (re)use (Azoulay et al., 2019). Risks to human health arise from both the chemical used during production and recycling to the plastic particles themselves. The rising use of plastics over the last several decades has put a spotlight on the need to reuse and recycle of plastics of all kinds. Certain types of polymers are easily reused while others are more difficult. However with reuse, new production strategies are required since the quality of the raw material is different, and less well controlled. This raises the question of whether recycling of plastics leads to emissions of contaminants with consequence for the drinking water sector.

Plastic Recycling Methods

Plastic recycling reprocesses waste or scrap plastic into a (new) products, or to its constituent components to be used as raw materials in the creation of new products (Merrington, 2011). However, with increasing plastic use and recycling rates, the concern arises about the impact of different plastic recycling schemes and emissions to the environment.

Plastics can be recycled either mechanically, where plastic materials are ground to granulate and melted, or chemically, where plastic is converted into smaller molecules suitable as feedstock for new petrochemicals or plastics (Al-Salem et al., 2009). Plastics which cannot be recycled are either incinerated for energy recovery or landfilled, though landfilling in general is not practiced in the Netherlands (Broekhuizen, 2016).

Mechanical recycling is the most common form of plastic waste recycling (Ragaert et al., 2017). In mechanical recycling, plastics must be collected, sorted, washed and ground into a flakes or granulate. Challenges in mechanical recycling include processing difficulties due to coatings and paints, phase separation caused by contaminants, difficultly ensuring a consistent, high-quality product and high price fluctuations for the end product. Moreover, plastics are often downcycled when using mechanical recycling techniques, as the product is of lesser quality than the original polymer (Janssen et al., 2016).

Wastewater from mechanical recycling is produced as a result of separation, washing and quenching techniques (Al-Salem et al., 2009). Density separation is used to separate different plastic polymers based on their density; PP[1] and PE will float in water, while PET, PS, ABS, PC and PVC will sink (also known as float-sink separation, Wang et al., 2015).

Plastics may be washed several times during processing, each serving a different purpose (Ragaert et al., 2017);

- Pre-wash – used to separate rocks, metals and glass from plastic (e.g. rotating drum washers)
- Friction washing – used to remove organic waste from the plastic, before or after shredding
- Rinsing – removal of final debris and or soaps used during friction washing

Depending on the type of plastic, during the friction washing step additive, such as caustic soda or surfactants may be added (Al-Salem et al., 2009).

Quenching involves using water to cool plastic which has been extruded and granulated after processing. Analysis of wastewater from these different washing steps show differences in contaminant concentrations, where the highest measured in the friction washing steps with additives (Santos et al., 2005).

[1] Plastic abbreviations: acrylonitrile-butadiene-styrene (ABS), Bis(2-Hydroxyethyl) terephthalate (BHET), expanded polystyrene (EPS), polycarbonate (PC), polyethylene (PE), polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS) and Polyvinyl chloride (PVC).

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Chemical Recycling techniques are more tolerant to mixed and contaminated waste streams than mechanical recycling techniques (Solis et al., 2020). As a result, there has been increased interest in chemical recycling in recent years as it has the potential to produce higher quality products ('up-cycling') and reduce the chemicals needed for fuel and virgin plastics (Ragaert et al., 2017). However, this comes at the expense of higher energy inputs and resulting higher recycling costs (Solis et al., 2020).

Chemical recycling techniques include solvolysis, depolymerisation, catalytic pros lysis and gasification (Error! Reference source not found.).

Solvolysis uses a solvent to dissolve polymers, separating them from additives and other materials. Solvolysis has been used to recycle EPS, commonly used as an insulating material in the construction industry which has been treated with bromated flame-retardants. The solvolysis process can separate the bromated flame retardants from the polymers, producing clean PS (KIDV, 2018).

Depolymerisation converts a polymer to a monomer through chemolysis with a chemical reagent, for example glycolysis and hydrolysis, (World Economic Forum Ellen MacArthur Foundation and McKinsey & Company, 2016). In plastics, depolymerisation of condensation polymers like PET, and nylon is possible. For PET, the challenge has been to separate the monomers from the colorants and additives present. Depolymerisation of PET produces BHET, a precursor to PET (Crippa et al., 2019).

Pyrolysis is the thermal decomposition (thermal cracking) of plastics at high temperatures in the absence of oxygen (Munir et al., 2018). Catalytic cracking produces a lighter fraction of liquid fuel compared to thermal cracking, while hydrocracking produces a highly saturated liquid product, which can be used directly as fuel without further processing (Munir et al., 2018). Addition of hydrogen (hydrocracking) also allows removal of heteroatoms of chlorine, bromine and fluorine in plastic waste (Munir et al., 2018).

Gasification of plastic waste produces syngas (H_2, CO, CO_2, CH_4 and N_2) (Lopez et al., 2018). Gasification is more flexible for mixtures of plastic waste than pyrolysis. While gasification is used commercially for coal, only small-scale pilot plants have been built for plastics and the viability of gasification of plastics is dependent on the price of oil (Krebbekx et al., 2018; UNEP, 2009).

Wastewater from chemical recycling can be produced from a number of processes, including from water-cooled condensers, waste steam or hot water and waste water from wet scrubbers and byproducts of chemical reactions (UNEP, 2009). Wastewater treatment would typically occur on-site and the water (partially) reused. Examples of treatments would include flocculation/coagulation to removal organics and inorganics, (advanced) oxidation to treat PAHs, phenols and metals and aerobic biological treatment for acids from oxidation to biomass and CO_2 (Mehrjouei et al., 2014; Schultz et al., 2004).

Limited literature is available on wastewater quality produced in plastic recycling facilities. Wastewater from a plastic pyrolysis plant can contain a range of aromatics hydrocarbons, aldehydes, furans and phenols (Mehrjouei et al., 2014). The wastewater from gasification of plastics can contain oil and grease, polycyclic aromatic hydrocarbons (PAHs), inorganics, metals and phenols (Schultz et al., 2004).

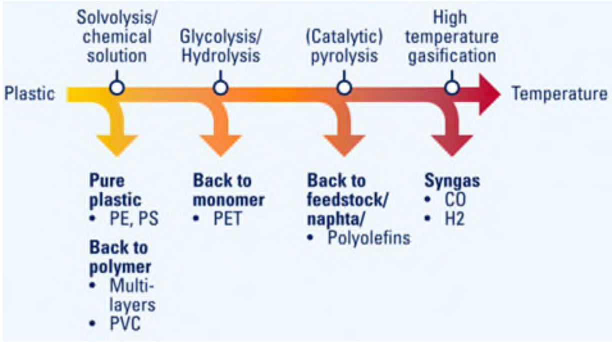

Figure 1 Chemical recycling techniques and the associated products (Krebbekx et al., 2018)

Relevance

Plastic Recycling in the Netherlands

In 2018, the Netherlands produced an estimated 523 thousand tons (KT) of plastic packaging waste, of which 272 KT (52%) was recycled, with an additional 61 KT used for energy recovery (Afvalfonds Verpakkingen, 2019). After an initial decline in 2017 due to the import ban on plastic waste to China, plastic waste collection stabilized in 2018 (Afvalfonds Verpakkingen, 2019). Recycling of Dutch plastic waste takes place mainly in the Netherlands and Germany (Afvalfonds Verpakkingen, 2019), with the amount of plastic waste exported abroad decreasing every year since 2016 (CBS, 2019). In Germany, chemical recycling makes up only a small percent of total recycling (Broeren et al., 2019).

Currently chemical recycling takes place in only a few pilot plants in the Netherlands, see Box 1 (KIDV, 2018). However, the Dutch Circular Economy Transition Agenda aims to have 10% of all plastics in the Netherlands chemically recycled by 2030, amounting to some 250 KT (Minsiterie van Infrastructuur en Waterstaat, 2018). Europe has set targets for recycling plastic waste at 75% for 2030, currently it is set at 22.5% (Broekhuizen, 2016).

The Netherlands Institute for Sustainable Packaging (KIDV) reviewed the potential for upscaling chemical recycling techniques in the Netherlands (KIDV, 2018). The KIDV found that pyrolysis and gasification were promising techniques which could be used in the short-term to process plastics which are currently difficult to recycle mechanically. At the moment, solvolysis at is not economically viable, though it does offer advantages for multi-layered packing materials and contaminated plastics. Finally, depolymerisation of PET is a promising technique as it can produce food-grade raw material, which is not possible using mechanical recycling techniques. Krebbekx et al. (2018) estimated the chemical recycling capacity from Dutch waste streams for pyrolysis at 94 KT and glycolysis (depolymerisation) at 13 KT per year.

Chemicals of Concern

Chemicals of concern in plastics include brominated flame-retardants, plasticisers, heavy metals (e.g. cadmium, lead), pigments, heat and UV stabilizers and antioxidants (Broekhuizen, 2016; Janssen et al., 2016). While the use of these substances have been phasing out over time, there remains a stock of plastics with these chemicals which must be processed. The use of plastics containing substances of very high concern (SVHC) are restricted under REACH (Broekhuizen, 2016).

A balance between the benefits of plastic recycling, in terms of CO_2 reduction, energy savings, and the application of plastics which may contain SVHC must be found. For example, in the case of PVC containing cadmium or lead, the current legislation requires labelling and limits the use of PVC for non-drinking water related purposes, such as cable ducts, window frames, doors and gutters (Janssen et al., 2016).

Separating materials containing SVHC is challenge for the mechanical plastic recycling industry, as most of the

Box 1. Dutch Chemical Recycling Plants (KIDV, 2018)

Ioniqa Depolymerisation of PET. Recycling plant in Rotterdam. Capacity: 10 KT per year producing BHET.

CuRe Technology Polyester Rejuvenation Technology. Pilot plant in Emmen. Capacity: 25 KT producing BHET/PET

Waste-to-Chemicals (W2C) Gasification of unrecoverable plastic waste. Consortia of Air Liquide, Enerkem, Nouryon, the Port of Rotterdam and Shell. Capacity: target 200 KT producing syngas.

BEWiSynbra Group Solvolysis of EPS. Pilot plant Etten-Leur. Capacity: target 60 KT producing PS.

IGE Solutions Amsterdam Pyrolysis of unrecyclable plastic waste, Port of Amsterdam. Capacity: target 33 KT producing fuel.

waste comes as a heterogeneous mixture, with many sources and polymers present. Tracing the origin of plastics at the beginning of the recycling chain is essential to separate out plastics which may contain SVHC, such as plastics from electronics, agriculture or end-of-life vehicles (Broekhuizen, 2016). However, identifying and testing on-site is not always feasible while testing at a later stage means the chemicals have already been mixed into the recycled product.

On the chemical recycling side, some techniques can eliminate hazardous chemicals, for example solvolysis can separate bromated flame retardants from the plastic monomers, and be treated separate (KIDV, 2018). A similar process to handle flame retardants is being developed for depolymerisation techniques (Ragaert et al., 2017).

An additional challenge for the plastic recycling industry is the complex legislative landscape. At different stages during recycling, plastics may be considered waste, raw materials and/or products, with different legislation applying at each stage (Janssen et al., 2016). In addition, during the processing of plastic waste, there is no clear definition for when the plastic waste reaches the so-called 'end of waste' and crosses over to a plastic product. The associated regulations for waste (Waste Framework Directive 2002/68/EC) and products (REACH) leave some legal ambiguity up to the recycling companies (Broekhuizen, 2016). Finally, under the National Waste Management Plan 3 (LAP3), chemical recycling techniques which produce fuel (e.g. pyrolysis, gasification) are classified as chemical conversion, and not recycling, which has consequences for incentives programs and contribution to recycling targets (KIDV, 2018).

As it stands now, recycling companies in the Netherlands must also comply with emission legislation (lozingsvergunningen). However, considering the plethora of chemicals in plastics, the emission legislation and monitoring is likely not equipped to evaluate the right parameters. This problem is not unique, as this holds for many production processes, but may be even more relevant for plastic recycling as the source material is heterogeneous, when compared to normal petrochemical industry. The recycling industry would benefit from a clear, streamlined set of regulations, focused on the exposure risk of specific applications of recycled plastics, drafted in consultation with different stakeholders in the plastic manufacturing, recycling, handling industry but also with the water sector in general (Janssen et al., 2016).

Conclusions

- The drinking water sector should be aware of developments of new plastic recycling techniques in the Netherlands.
- While chemical recycling does not currently play a large role in plastic recycling in the Netherlands, there is ambition to grow to 10% of all plastic recycled in the coming decade.
- Chemical recycling may offer benefits over mechanical recycling, in terms of closing the loop in plastic production while also processing difficult to recycle waste, including contaminated plastics.
- However, with an increase in frequency of chemical recycling, careful attention should be paid to potential new emissions routes, including emissions to wastewater.
- The legal and regulatory landscape is complicated for plastic recyclers and the industry may not be equipped to monitor parameters of interest for the drinking water sector, or the water sector in general.
- Therefore, to stimulate more sustainable plastic recycling and at the same time ensure safety, simplified legislation is needed with input from relevant stakeholders which included the water sector
- Early cooperation of the water sector, including the drinking water sector, with the plastics industry can prevents future water quality issues associated with plastic recycling and prevent contamination which may that might impede innovation in a later stage.

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More information

Afvalfonds Verpakkingen. (2019). *Monitoring Verpakkingen*. Retrieved from www.afvalfondsverpakkingen.nl

Al-Salem, S. M., Lettieri, P., & Baeyens, J. (2009). Recycling and recovery routes of plastic solid waste (PSW): A review. *Waste Management*, *29*(10), 2625–2643. https://doi.org/10.1016/j.wasman.2009.06.004

Azoulay, D., Villa, P., Arellano, Y., Gordon, M., Moon, D., Miller, K., & Thompson, K. (2019). *Plastic & Health - The Hidden Costs of a Plastic Planet*. Retrieved from www.ciel.org/plasticandhealth

Broekhuizen, M. P. M. J. F. A. Van. (2016). *Waste handling and REACH*. Retrieved from http://rivm.openrepository.com/rivm/bitstream/10029/620916/1/2016-0159.pdf

Broeren, M., Lindgreen, E. R., & Bergsma, G. (2019). *Verkenning chemische recycling - update 2019*. Retrieved from https://www.cedelft.eu/en/publications/download/2607

CBS. (2019). Less recyclable plastic waste sent to China. Retrieved June 10, 2020, from Centraal Bureau voor de Statistiek website: https://www.cbs.nl/en-gb/news/2019/11/less-recyclable-plastic-waste-sent-to-china

Crippa, M., & Morico, B. (2019). *PET depolymerization : a novel process for plastic waste chemical recycling*. https://doi.org/10.1016/B978-0-444-64337-7.00012-4

Janssen, M. P. M., Spijker, J., Lijzen, J. P. A., & Wesselink, L. G. (2016). *Plastics that contain hazardous substances : recycle or incinerate?* 56. Retrieved from https://www.rivm.nl/bibliotheek/rapporten/2016-0025.pdf

KIDV. (2018). *Chemical recycling of plastic packing materials Analysis of opportunities for upscaling*. Retrieved from https://kidv.nl/media/engelse_kidv_publicaties/chemical_recycling_of_plastic_packaging_materials_analysis_and_opportunities_for_upscaling.pdf?1.0.1

Krebbekx, J., Duivenvoorde, G., & Haffman, S. (2018). *Roadmap towards increasing the sustainability of plastics packaging*. Retrieved from http://www.rethinkplastics.nl/wp-content/uploads/2018/08/Materiaalverduurzamingsplan-Kunststof-verpakkingsindustrie_Engels_digitaal-V2.pdf

Lopez, G., Artetxe, M., Amutio, M., Alvarez, J., Bilbao, J., & Olazar, M. (2018). Recent advances in the gasification of waste plastics. A critical overview. *Renewable and Sustainable Energy Reviews*, *82*(July 2017), 576–596. https://doi.org/10.1016/j.rser.2017.09.032

Mehrjouei, M., Muller, S., & Moller, D. (2014). Treatment of Pyrolysis Wastewater Using Heterogeneous Advanced Oxidation Processes. *Environmental Progress & Sustainable Energy*, *33*(1), 178–183. https://doi.org/10.1002/ep.11778

Merrington, A. (2011). Recycling of Plastics. *Applied Plastics Engineering Handbook*, 177–192. https://doi.org/10.1016/B978-1-4377-3514-7.10011-X

Minsiterie van Infrastructuur en Waterstaat. (2018). *Transitie-agenda circulaire economie - Kunststoffen*. Retrieved from https://www.rijksoverheid.nl/documenten/rapporten/2018/01/15/bijlage-3-transitieagenda-kunststoffen

Munir, D., Irfan, M. F., & Usman, M. R. (2018). Hydrocracking of virgin and waste plastics: A

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detailed review. *Renewable and Sustainable Energy Reviews*, *90*(April), 490–515. https://doi.org/10.1016/j.rser.2018.03.034

Ragaert, K., Delva, L., & Van Geem, K. (2017). Mechanical and chemical recycling of solid plastic waste. *Waste Management*, *69*, 24–58. https://doi.org/10.1016/j.wasman.2017.07.044

Santos, A. S. F., Teixeira, B. A. N., Agnelli, J. A. M., & Manrich, S. (2005). Characterization of effluents through a typical plastic recycling process: An evaluation of cleaning performance and environmental pollution. *Resources, Conservation and Recycling*, *45*(2), 159–171. https://doi.org/10.1016/j.resconrec.2005.01.011

Schultz, C. L., Smyrnios, K. X., Carrafa, G. P., & Schultz, N. C. (2004). *Gasification Of Plastic Waste As Waste-To- Energy Or Waste- To- Syngas Recovery Route*. https://doi.org/10.4236/ns.2013.56086

Solis, M., & Silveira, S. (2020). Technologies for chemical recycling of household plastics – A technical review and TRL assessment. *Waste Management*, *105*, 128–138. https://doi.org/10.1016/j.wasman.2020.01.038

UNEP. (2009). *Converting Waste Plastics into a Resource Compendium of Technologies*. Retrieved from http://wedocs.unep.org/handle/20.500.11822/8638

Wang, C. qing, Wang, H., Fu, J. gang, & Liu, Y. nian. (2015). Flotation separation of waste plastics for recycling-A review. *Waste Management*, *41*, 28–38. https://doi.org/10.1016/j.wasman.2015.03.027

World Economic Forum Ellen MacArthur Foundation and McKinsey & Company. (2016). *The New Plastic Economy - Rethinking the future of plastics*. Retrieved from http://www.ellenmacarthurfoundation.org/publications

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