Exploration chemical recycling - Extended summary

What is the potential contribution of chemical recycling to Dutch climate policy?

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Background

This document presents an extended summary of the (Dutch) report '*Verkenning chemische recycling; Hoe groot zijn – en worden – de kansen voor klimaatbeleid?*', prepared for the Dutch Ministry of Economic Affairs and Climate Policy in 2018. The original full-length report (in Dutch) containing all background information is available online.

Extended summary

Introduction

Chemical recycling is considered an important solution to make the life cycle of plastics more sustainable by Dutch policymakers. For example, the Dutch circular economy transition agenda for plastics envisions that by 2030, 10% of all plastics used in the Netherlands will be chemically recycled (I&W/EZK, 2018). Chemical recycling is viewed as an interesting addition to the present mechanical recycling of plastics, since it can process different plastic waste streams and produce high-value resources for the chemical industry.

The goal of this study is to provide a first estimate of the potential climate change benefits of the chemical recycling of plastic waste streams. We first assess which plastic waste streams exist that are not suitable for high-value mechanical recycling but could be chemically recycled. We estimate the annual volumes of these streams in the Netherlands and neighbouring countries, and combine the available amounts of material with preliminary carbon footprint results for several innovative chemical recycling technologies.

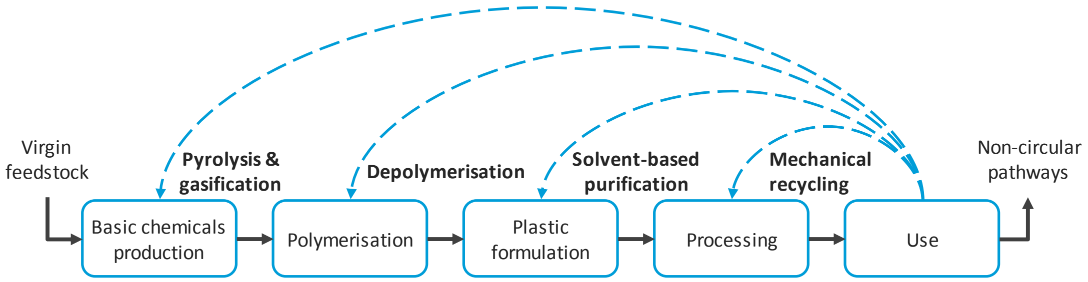
We focus on three specific plastic waste streams: losses from mechanical recycling systems, monostreams that are difficult to recycle mechanically (PET trays and bromine-containing EPS) and mixed plastics (DKR 350). Since these streams cannot (easily) be mechanically recycled into high-value products, chemical recycling could be a useful addition to the existing range of waste treatment technologies. This means that chemical recycling is not considered a replacement for mechanical recycling.

Chemical recycling

During mechanical recycling, waste plastics are extruded into plastic granulate, which can be reprocessed directly into new products. In contrast, chemical recycling converts the waste plastics into more basic materials, as used earlier on in the plastic production chain. Four main chemical recycling types are distinguished here: pyrolysis, gasification, depolymerisation and solvent-based purification. This is illustrated in Figure 1. Within these four main types, different technologies (e.g. focusing on specific inputs/outputs or chemical processes) are being developed.

Chemical recycling can offer different technological benefits over mechanical recycling. For example, some technologies can utilise a wider range of input materials, opening up the possibility of recycling mixed plastic waste streams. Similarly, some chemical recycling technologies can remove impurities from the plastic waste input to create higher quality products. Finally, when chemical recycling is used to produce basic chemicals, a wide range of new plastics (or other products) can be created. However, when waste plastics are broken down into very basic materials, more processing steps are required to convert the outputs of chemical recycling back into plastic products, which can require more energy compared to mechanical recycling. This may also result in worse carbon footprint results in comparison to mechanical recycling, although the size of these differences depends on the technology.

Figure 1 - Comparison of chemical and mechanical recycling technologies



Based on Crippa et al. (2019).

Available plastic waste volumes

Table 1 provides an overview of the volume of plastic waste streams that could be used as inputs for chemical recycling in the Netherlands in 2020 and 2030. For 2030, conservative and optimistic scenarios are created, based on assumptions regarding for example the growth in plastics consumption and post-consumer sorting efficiency. In addition, the optimistic scenario assumes that a part of the plastics discarded in Belgium, Germany and the United Kingdom is imported to the Netherlands. The table shows that by 2030, the Netherlands is estimated to produce a plastic waste volume of around 260 to 330 thousand tonnes (kilotonne; kt) per year (yr) that could be treated in chemical recycling technologies. If import from neighbouring nations is possible as well, the total volume may exceed 1,000 kt/yr.

Table 1 - Volume of waste plastic available for chemical recycling in the Netherlands, kt/yr

	2020	2030		
		Conservative	Optimistic	
			Netherlands	Import
Recycling losses	97	107	161	558
PET trays	32	36	40	0
DKR-350	101	112	126	583
Bromine-containing EPS	7	8	9	0
Total	**237**	**263**	**336**	**1,141**

Carbon footprint of different plastic waste treatment technologies

Each of the identified waste streams can be treated with different technologies, ranging from incineration to (in some cases) mechanical recycling to various forms of chemical recycling (gasification, pyrolysis, depolymerisation and solvent-based extraction).
For applicable technologies, information on the carbon footprint of waste treatment was gathered from previous research.

The carbon footprints for chemical recycling technologies are derived from screening life cycle assessment (LCA) studies, based on information about the mass and energy balances of the treatment technology. Data for these screening LCAs was gathered from various companies and complemented with information from (scientific) literature and expert judgments. The sources used include CE Delft (2017), TNO (2017) and information from confidential CE Delft projects. The carbon footprints of the reference technologies (mechanical recycling and incineration with energy recovery) are derived from CE Delft (2018) and internal data.

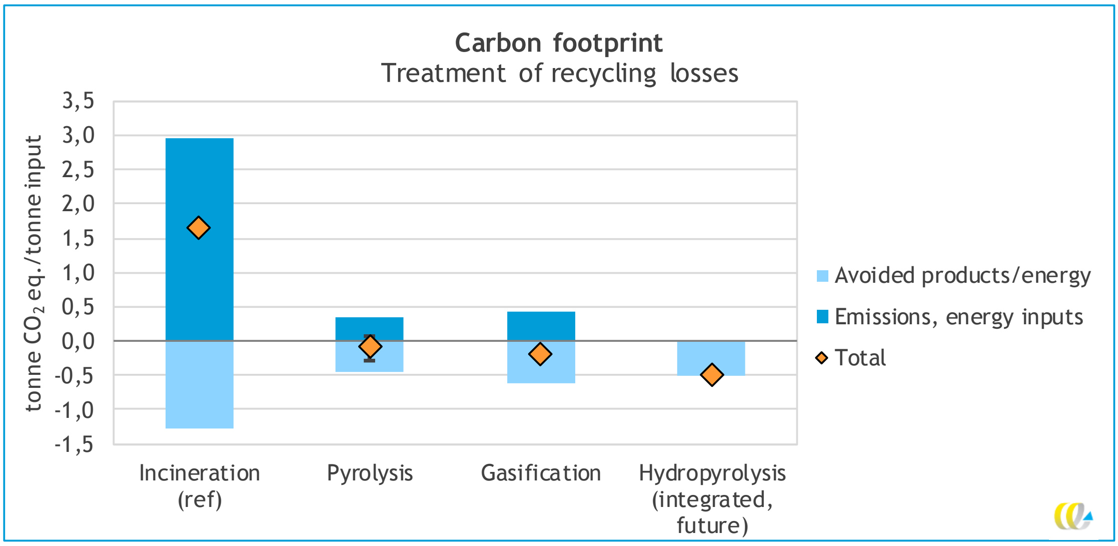
The carbon footprints indicate the impact on climate change of treating one tonne of plastic waste using various technologies. They are expressed in tonne CO_2 equivalents (eq.) per tonne of waste input. The carbon footprints consists of two parts:
- **Emissions and energy inputs**: the carbon footprint of the direct process emissions and emissions linked to production and supply of the energy/material inputs of the process.
- **Avoided products/energy carriers:** this includes the carbon footprint of conventional production processes of the useful outputs produced by the waste treatment technologies. For example, incineration with energy recovery generates electricity. This means that less electricity needs to be generated in conventional power plants, so these avoided emissions are credited to the waste treatment process (incineration with energy recovery in this example).

Furthermore, note that emissions related to the collection and sorting of the waste plastics are not included. Other environmental impacts than climate change have not been considered.

All carbon footprints are derived for the Dutch situation, meaning they are based on for instance the current Dutch electricity mix and the average Dutch energy efficiency of waste incinerators. Since many chemical recycling technologies are still in development and have not yet been implemented at industrial scale, there are uncertainties in the results and they should be considered as indicative.

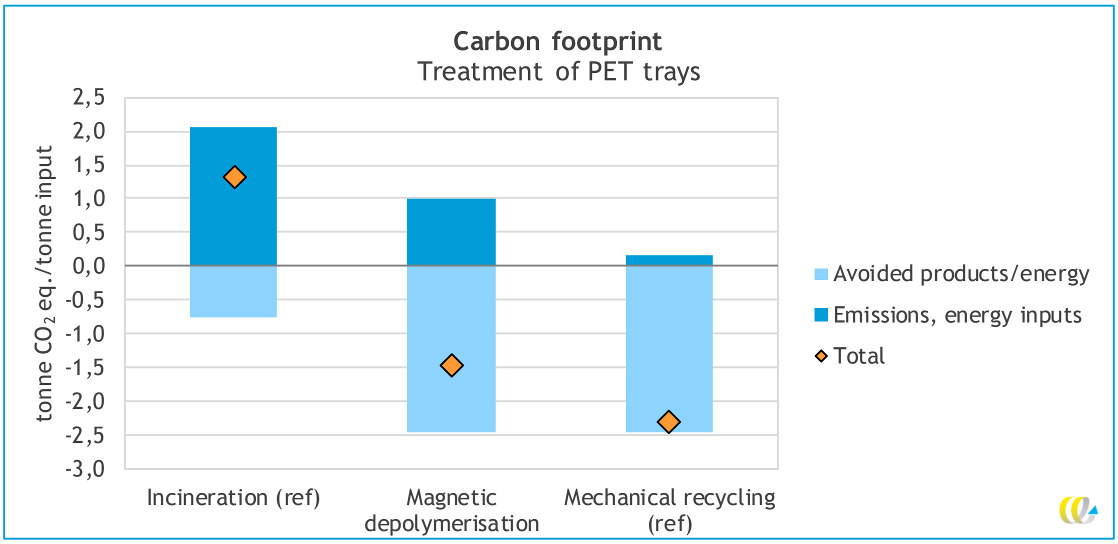
The carbon footprint results for the treatment of the losses from mechanical recycling, PET trays and mixed plastics (DKR 350) are shown in Figure 2, Figure 3 and Figure 4, respectively. Since the estimated volumes of bromine-containing EPS are minor (Table 1), the carbon footprint results are not shown here.

Figure 2 – Carbon footprint of treating recycling losses with various technologies, tonne CO_2 eq./tonne input



Recycling losses are currently incinerated. Chemical recycling can reduce the carbon footprint by up to about 2 tonne CO_2 eq./tonne input, although integrated hydropyrolysis is still in development and the results for this technology are therefore more uncertain.

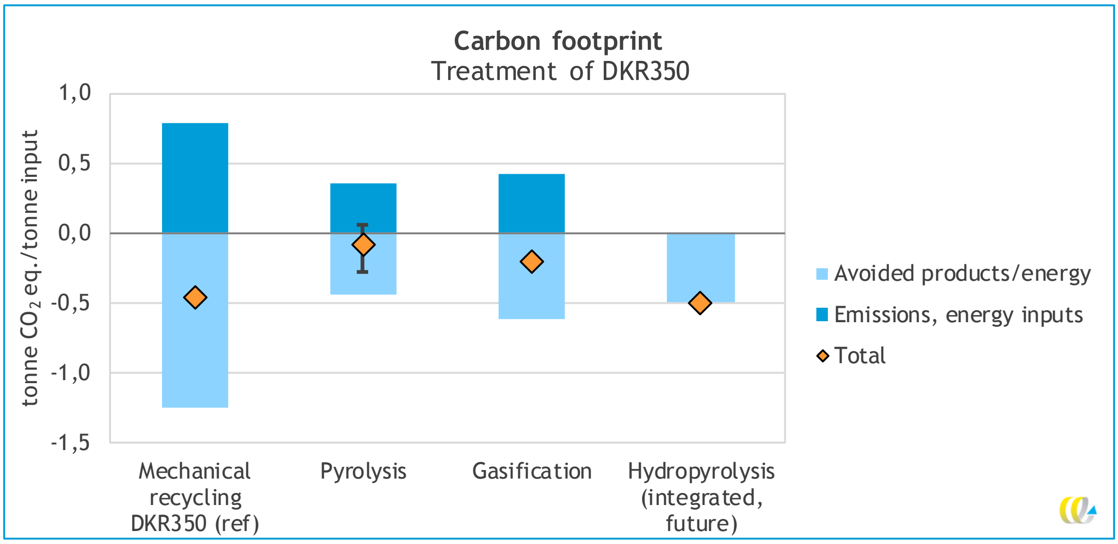
Figure 3 - Carbon footprint of treating PET trays with various technologies, tonne CO_2 eq./tonne input



PET trays are currently stored in the Netherlands, as it is difficult to mechanically recycle them. Alternatively, the PET trays could be incinerated, but that would mean the materials are lost.
This means there is no reference technology that is fully appropriate. The results shown here for mechanical recycling correspond to conventional/existing mechanical recycling of PET in the Netherlands. The carbon footprint of chemical recycling, in the form of magnetic depolymerisation, comes close to (conventional) mechanical recycling but has a higher carbon footprint.

To estimate the total potential contribution of chemical recycling to climate change impact reduction (in the next section), mechanical recycling was (conservatively) used as a reference.

Figure 4 - Carbon footprint of treating DKR 350 with various technologies, tonne CO_2 eq./tonne input



It is estimated that DKR350 can be treated in the same chemical recycling technologies as recycling losses. However, the reference is different, as DKR350 is currently mechanically recycled. It is estimated that hydropyrolysis can reduce the carbon footprint of DKR350 waste treatment slightly.

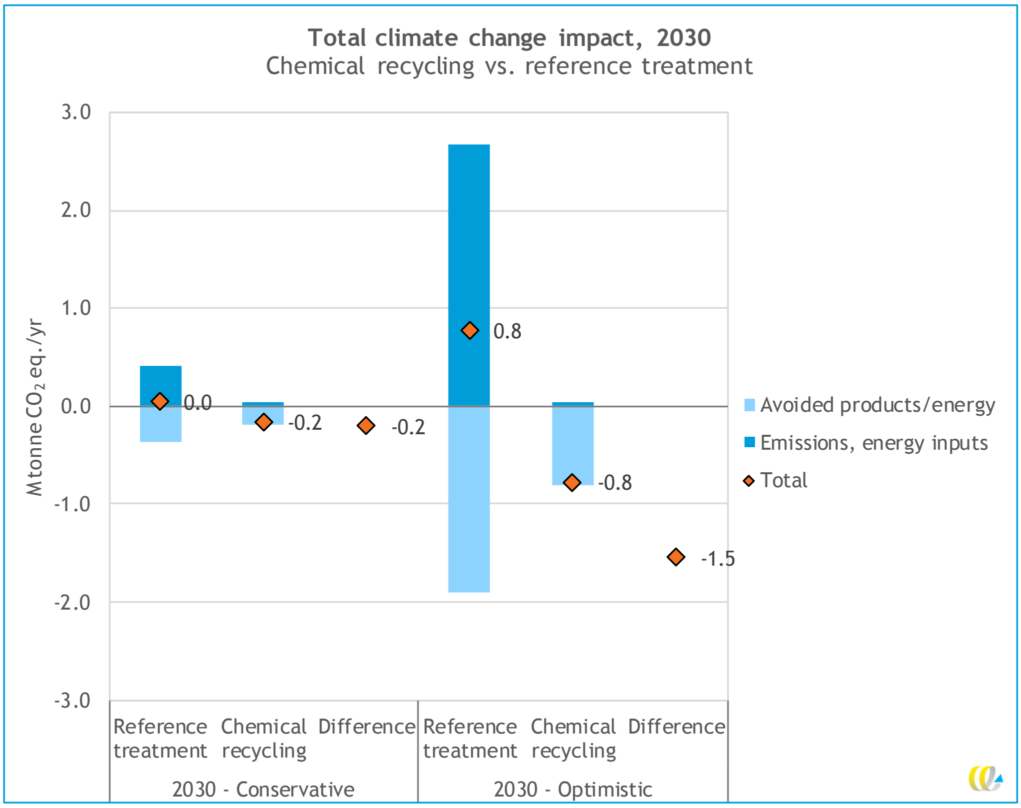
Potential contribution of chemical recycling to climate change policy

To estimate the total possible contribution of chemical recycling to reducing the climate change impact, the estimated waste volumes (Table 1) are combined with the carbon footprint results (as shown in the figures above). We assume that instead of being treated in the reference technology[1], the entire volume is instead treated in the chemical recycling technology with the lowest carbon footprint.

Figure 5 shows the total climate change impact in 2030 of treating the four selected plastic waste streams in either the reference technologies or in the (best scoring) chemical recycling technology. Results are expressed in million tonnes of CO_2 eq. per year (Mt CO_2 eq./yr).

In the conservative scenario, the use of chemical recycling instead of the reference technologies for these four streams reduces the (worldwide) climate change impact by 0.2 Mt CO_2 eq. In the optimistic scenario, the total plastic waste volumes are substantially larger (Table 1). Therefore, the total climate change reduction increases to 1.5 Mt CO_2 eq. Of this total reduction, about 1.0 Mt CO_2 eq. is estimated to occur within the Netherlands (not shown in figure). The remainder takes place abroad.

Figure 5 - Climate change impact of treating selected waste streams in either reference technologies or in chemical recycling technologies, Mt CO_2 eq./yr



[1] The following references are used. Recycling losses: incineration with energy recovery; PET trays: mechanical recycling; DRK 350: mechanical recycling; bromine-containing EPS: incineration with energy recovery. Note that at present, mechanical recycling of PET trays is not possible, which makes this a conservative approach from the point of view of chemical recycling.

Study limitations

A few assumptions and limitations should be noted here:

- The study focuses on the Netherlands. Results for different regions, with e.g. different electricity mixes and energy efficiencies of waste incinerators, may differ.
- We assume the studied technologies can directly be utilised to process the selected plastic waste streams at large scale.
- Not all waste streams that are potentially suitable for chemical recycling have been included. The potential of chemical recycling to contribute to climate change reductions may therefore become larger if other waste streams are also considered.
- We have assumed that the various outputs of chemical recycling (e.g. syngas) can be sold on the market (thereby avoiding conventional production processes).
- To estimate the climate change impacts in 2030, several possible changes have not been taken into account, including changes in the electricity mix and technological improvements.
- The carbon footprints for the new technologies are first estimates. They should be further evaluated once more (large-scale) facilities become operational.

Conclusions and policy recommendations

The analysis shows that chemical recycling can make a substantial contribution to the goals of the Dutch government to reduce climate change impacts. If plastic waste streams can be imported from neighbouring countries, the worldwide climate change reduction may exceed 1 Mt CO_2 eq. by avoiding the current (reference) treatments.

The climate change benefits differ per technology and waste stream. Due to the range in available technologies and their differing carbon footprints, chemical recycling should not be viewed as a single treatment option. Generally, technologies with lower carbon footprints have more specific requirements for the feedstock inputs. The climate change reductions of ‘short loop’ such as depolymerisation and dissolution (sometimes called ‘monomer recycling’) are comparable to mechanical recycling per kg of material input. In contrast, gasification and pyrolysis (also called ‘feedstock recycling’) can deal with a wider variety of inputs, but offer lower climate change impact reductions. The carbon footprint of these ‘longer loop’ technologies lies in between that of mechanical recycling and incineration with energy recovery (based on Dutch efficiencies).

Chemical recycling technologies are generally not fully commercialised yet. To stimulate their further development, a level playing field with mechanical recycling could be beneficial. If, for example, the environmental impacts of a chemical recycling technology are similar to mechanical recycling, it should be treated the same in policy as well. This is important for waste treatment policies and permits, for monitoring and reporting of recycling figures and also for producer responsibility schemes which support recycling.

Finally, the climate change impacts of plastics can be further reduced by increasing recycling rates overall (through both mechanical and chemical recycling). To increase the available volumes of waste plastics, both source separation by consumers and post-consumer separation by machines should be stimulated.

Literature (extended summary)

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