



Chain of Custody Model Implications for Chemical Recycling

Support to an Implementing Act on
Recycled Content in
SUP Beverage Bottles

January 2023

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PDF	ISBN 978-92-68-04607-4	doi:10.2779/42915	KH-03-23-249-EN-N
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Luxembourg: Publications Office of the European Union, 2023

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1.0 Introduction

The aim of this briefing report is to provide a first analysis of the expected development of the chemical recycling technologies that are relevant for the recycling of SUP beverage bottles up to 2030. The implications of different chain of custody models and allocation rules are discussed and (where possible) quantified for both PET and non-PET beverage bottles.

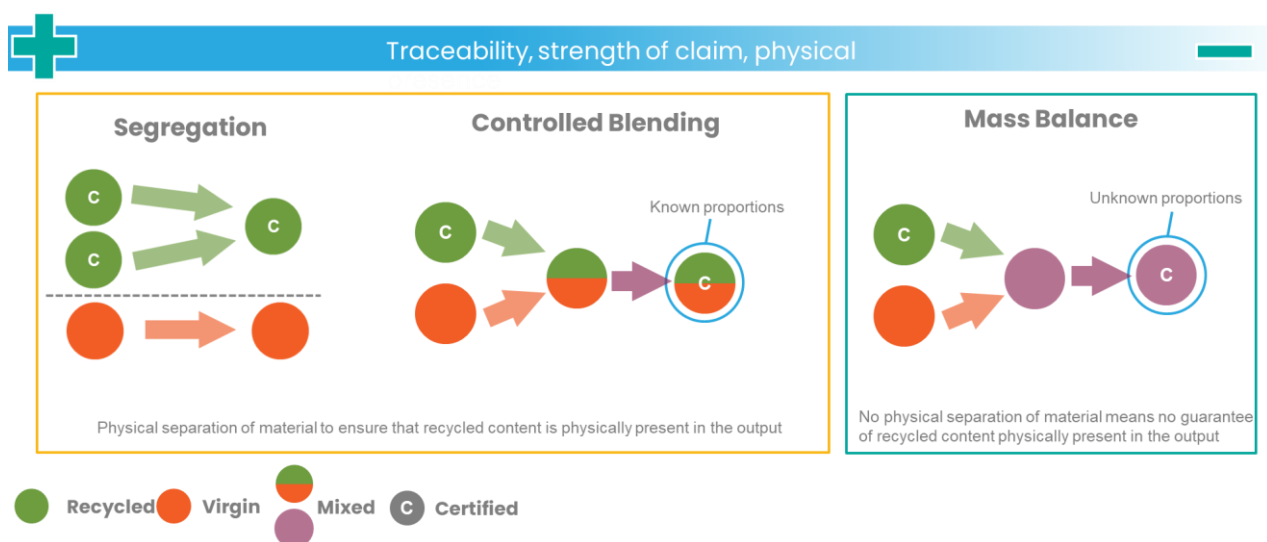
The following sections provide a brief overview of the key concepts that are discussed later. For a fuller explanation of these, the reader should also refer to the full report: *Study to Develop Options for Rules on Recycled Plastic Content for the Implementing Act Related to Single-Use Plastic Bottles Under Directive (EU) 2019/904*.¹

1.1 Chain of Custody

Figure 1-1 shows the relevant chain of custody (CoC) models according to ISO 22095. The most important models are controlled blending and mass balance. Controlled blending involves a quantity of recycled and virgin material mixed in known proportions, whereas mass balance involves mixing where it is unknown what is contained in an individual product. The proportions are only known across a time period and therefore are considered an average across that time.

Mass balance therefore requires a specific ruleset in order to be implemented. There is no agreed and established ruleset at the EU level (or within any other governmental policy) currently and therefore there are various options available that will affect the calculation method.

Figure 1-1 - Chain of Custody (CoC) According to ISO 22095

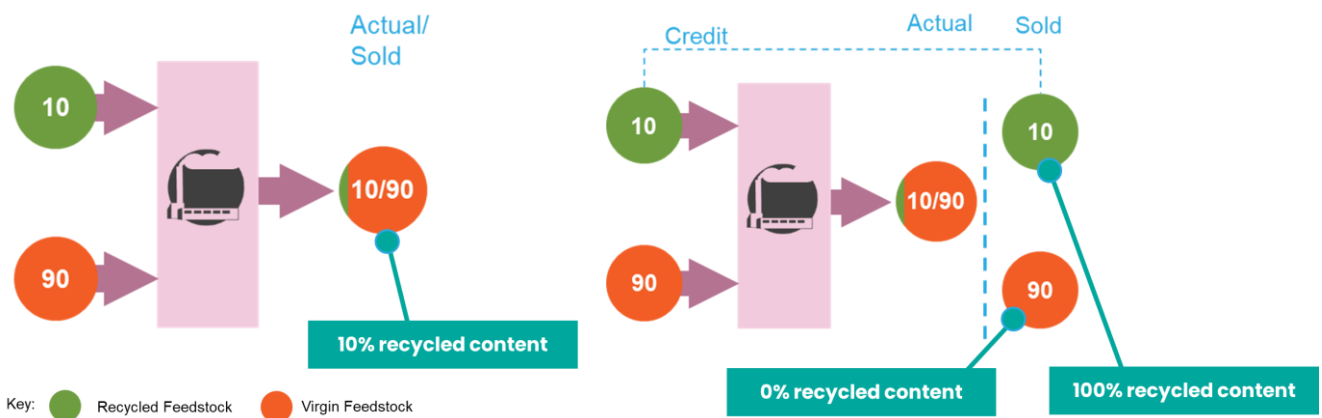


¹ <https://op.europa.eu/en/publication-detail/-/publication/43084f4a-03e7-11ed-acce-01aa75ed71a1/language-en>

1.2 Mass Balance Systems

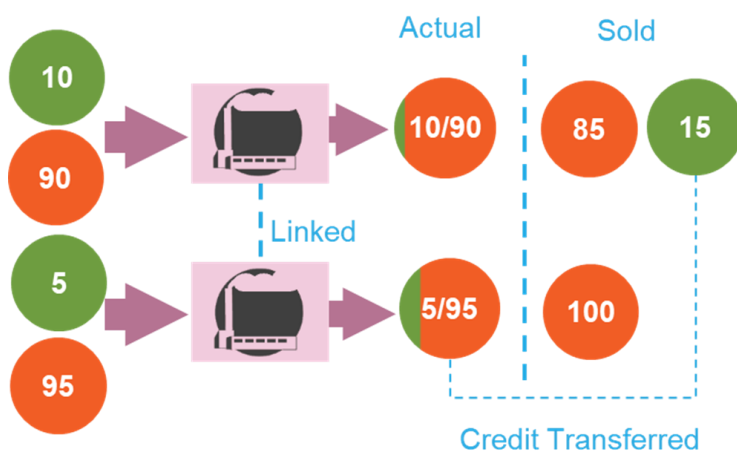
Figure 1-2 shows the two main mass balance systems; rolling average and the credit method (also both referenced in ISO 22095). The key difference is what proportion of recycled content is being claimed in the output. When a rolling average is used, the recycled content is proportional to the inputs. With the credit method, the recycled input can be assigned a credit and therefore that amount of the output can be sold as 100% recycled content. The latter is the preferred method of the chemicals industry.

Figure 1-2 - Mass Balance Systems: Rolling average (L) and Credit Method(R)



An extension to the credit method is restricted credit transfer (RCT) which is shown in Figure 1-3. This allows the generated credits to be moved between facilities that produce the *same outputs*.

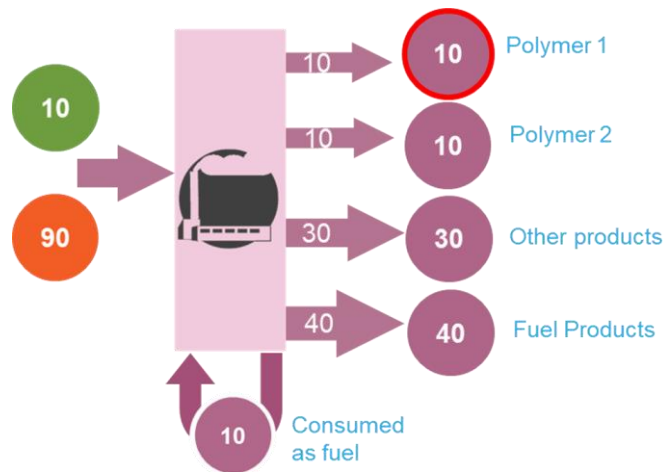
Figure 1-3 – Restricted Credit Transfer



1.3 Mass Balance Allocation

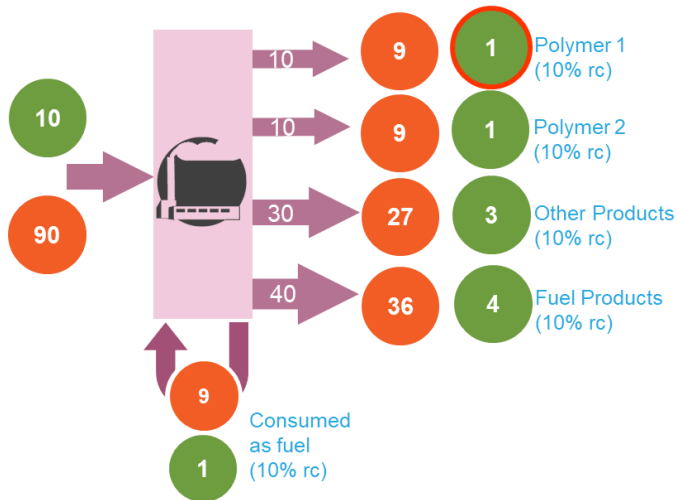
Some chemical recycling processes have multiple outputs. The main example of this is pyrolysis oil – produced from waste plastic – that is fed into a stream cracker which produces many different hydrocarbons. As the inputs are mixed and there is no way of knowing which atoms become present in the outputs, an allocation process is required. Figure 1-4 shows the key variations of this in a simplified form. The important aspect of allocation is that the method determines how much recycled content can be claimed in a particular output. In these examples, a particular polymer has a market demand for recycled content, but the claim can vary between 10% - 60% recycled content for the same input of recycled material into the process.

Figure 1-4 – Allocation Methods

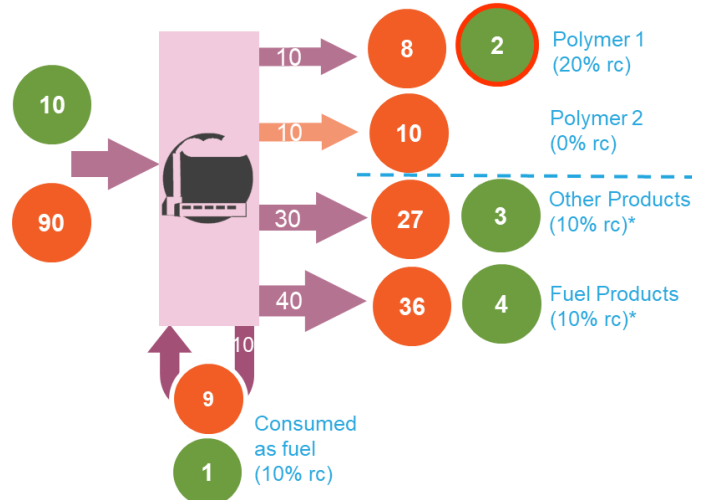


The manufacturer only wants to make a recycled content claim on 'polymer 1' as there is a market demand

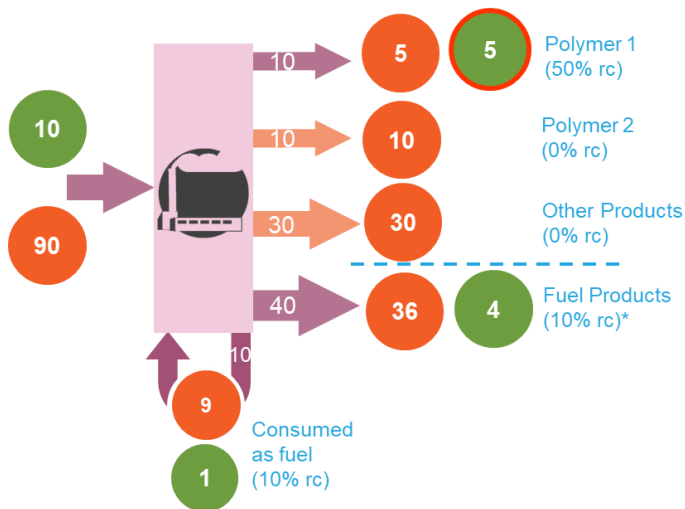
Proportional



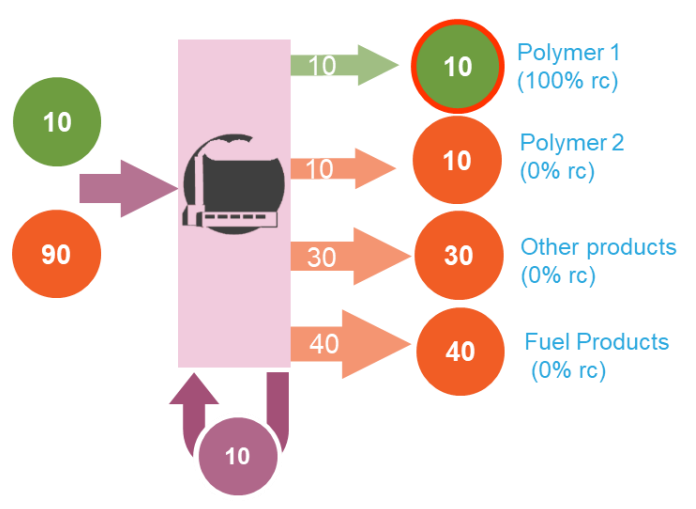
Polymers Only



Fuels Excluded



Free



Key: ● Recycled Feedstock ● Virgin Feedstock

2.0 Mass Balance by Bottle Material

2.1 PET

Chemical recycling of PET is primarily achieved by chemical depolymerisation – a process by which the PET monomers are chemically extracted. The only outputs are the targeted monomers (typically MEG and TPA) and therefore a mass balance approach is not strictly necessary.

According to Plastics Europe,² 0.8Mt of chemical depolymerisation **input capacity** is expected by 2030 and this equates to an output capacity of 0.7Mt (a loss rate of 13%). This estimate is for all allocation approaches as the choice of allocation does not affect chemical depolymerisation technologies.

To put this into perspective, it is estimated that 3.34Mt of beverage bottles will be placed on the EU market by 2030.³ The entire output capacity of PET depolymerisation could therefore be used to incorporate 24% recycled content across the whole PET beverage bottle market. However, it is unlikely that beverage bottles will receive the entire capacity due to other products beginning to see demand for this material also. The principal competition is likely to come from other packaging in the form of PET food trays. These packaging types are typically not recycled in high volumes due to technical and commercial challenges that make the material less attractive than beverage bottles – these include higher contamination rates from food and less separate collection (i.e. no equivalent to deposit refund schemes) which lead to difficulties in providing a high quality food grade output. This also means that incorporating recycled PET content is not common particularly for food contact applications. PET depolymerisation can potentially help to overcome some of these issues due to the virgin grade outputs that are produced.

- Chemical depolymerisation of PET does not require a mass balance method and therefore the rules will not affect the uptake of this technology.
- The increase in the availability of chemical depolymerisation of PET is not likely to have a large effect on PET beverage bottle recycling.

2.2 HDPE

The other material commonly used in beverage bottles is HDPE which currently represents around 3% of the market by mass. There are currently no authorised recycling processes for HDPE that can provide a food grade output. This means that whilst HDPE bottles can be recycled, they are unlikely to contain any recycled content, and there is no clear path for doing so in the future. The recast *Regulation on Recycled Plastic Materials and Articles Intended to Come into Contact with Food* (2022/1616⁴) seeks to address this issue, but as it was only introduced late in

² Chemical recycling Mass balance and pyrolysis, Plastics Europe, November 2021

³ Ecnomia modelling for impact assessment on the revision of the PPW Directive.

⁴ <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32022R1616>

2022, it is unclear at this stage whether it will lead to authorised *mechanical* recycling processes for H/LDPE. Any recycling process that is not already considered suitable (i.e. some PET recycling and closed-loop system) will need to apply the procedure for registering as a “novel recycling technology”. The Regulation allows novel recycling technologies to conduct operations without a formal European Food Safety Authority (EFSA) approval whilst still adhering to specific safety criteria. This is designed to remove the administrative barrier of requiring a formal opinion from EFSA to operate.

As recycled plastics that are taken back to their constituent monomer are exempt from the requirements of EU 2022/1616, some forms of chemical recycling are likely to play a role in incorporating recycled content in polyolefins. Such processes will require a mass balance method in order to calculate the recycled content in the monomer (most commonly, ethylene and propylene). A controlled blending CoC would be insufficient to allow such technologies to contribute. The rules around what can be counted as recycled content and the calculation method are therefore of particular importance to bottles made from HDPE.

The Plastics Europe survey from November 2021⁵ found that members would reduce their planned investment in chemical recycling technologies by 15% if the *fuels excluded* method was chosen over the *free allocation* method. No further scenarios were tested and therefore it is unclear what impact other more-strict allocation methods would yield.

The same survey found that whilst investment and the amount of treated waste would reduce, by 15%, the output of recycled plastic would reduce by 30% due to stricter allocation rules. This would therefore assume losses⁶ of 44% using a *fuels excluded* allocation. This loss rate is an average of the amounts reported to Plastics Europe and will vary depending upon the type of value chain employed. Table 2-1 shows an example of the reported potential input tonnages back calculated using assumptions around yield losses at various stages for both free allocation and fuels excluded. For reference, proportional allocation is also shown with the same output (1.9mt) as fuels excluded which demonstrates that 9.7mt of input would be needed to produce this amount. For all examples it is assumed the credit method would also be used.

Table 2-1 – EU Pyrolysis Development by Allocation Method

Allocation Method>>	Free	Fuels Excluded	Proportional
Plastic Waste Input into pyrolysis (Mt)	4.4	3.75 (-15%)	9.7
Pyrolysis efficiency (losses)	30%		
Input into hydro treatment(Mt)	3.1	2.6	6.8
Hydro treatment losses	4%		
Input into Steam Cracker (Mt)	3	2.5	6
Steam Cracker Allocation Losses	1%	26%	71%
Monomer/polymer Output (Mt)	2.9	1.9 (-37%)	1.9

⁵ Chemical recycling Mass balance and pyrolysis, Plastics Europe, November 2021

⁶ The term ‘losses’ in this context includes both the physical losses in the system due to process inefficiencies and the accounting losses due to the method applied. The accounting losses still exist as recycled content, but within other outputs of the steam cracker. For example, recycled content could be claimed in the fuels, but the *fuels excluded* method prevents that amount from being allocated (transferred) to the monomer outputs. These are deemed as losses in this context as it is claimed by the chemical companies that there is no marketable value in fuels containing recycled content.

Losses (physical and accounting)	33%	51%	80%
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The loss rate of 44% is somewhat consistent with the results in Table 2-1 that result in losses of 51% using a *fuels excluded* allocation. This model assumes 30% is lost in the pyrolysis process and that a hydrotreatment process is used to remove impurities which results in a further 4% losses. If a refinery is used in place of hydrotreatment, the overall losses would rise close to 90% – this is because the majority of the output of a refinery (~75%) is used as a fuel. It is argued by the petrochemical industry that the fuels-exempt model is therefore impossible to implement in a value chain that relies on a refinery.

Given the calculated losses (51%) are close to the industry estimate for potential losses (44%), this would suggest that the vast majority of the planned capacity at the time of the survey did not intend to use refineries to upgrade the pyrolysis oil. Indeed, the use of a refinery in this context is unlikely to present a long-term prospect due to the need to reduce reliance on fossil fuels and therefore on the need for refineries in the future.

It is estimated that 71kt⁷ of polyolefin beverage bottles will be placed on the EU market annually by 2030, almost all of which are made of HDPE. With 30% recycled content, around 21kt of recycled HDPE would be required. To put this into context, if 1.9Mt of polyolefin chemical recycling is in place by 2030, beverage bottles would take only 1% of this capacity.

To put this into the context of the Commission’s proposal for a Packaging and Packaging Waste Regulation⁸, it is estimated that 5Mt of food grade polyolefin packaging will be on the market by 2030.⁹ This means that with current output capacity estimates, the 1.9Mt of recycled polyolefins could result in recycled content of 38%. This does not account for any demand from other sectors which might reduce this availability. For a fuels excluded allocation method, 75% of this Mt will also have to be collected and recycled to achieve this recycled content (as per the losses shown in Table 2-1). A recycled content of 10% in food grade polyolefin packaging would require around 500kt of recycled plastic which is around 25% of the predicted output capacity.

- There is considerable uncertainty round how both mechanical and chemical recycling can contribute to food grade recycled content by 2030.
- This is due to development of both types of technology being very immature with potential yet to be realised
- However, the very low volume requirements to fulfil the SUPD target for non-PET bottles is likely to mean that material will be available, particularly from chemical recyclers as only 1% of predicted capacity will be needed.

3.0 Restricted Credit Transfer (RCT)

⁷ Eunomia (2021) for DG Environment, Assessment of options for reinforcing the Packaging and Packaging Waste Directive’s Essential Requirements and other measures to reduce the generation of packaging waste, unpublished draft report

⁸ [Proposal for a Regulation on packaging and packaging waste.pdf \(europa.eu\)](https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021PC0100&from=de)

⁹ Eunomia modelling for impact assessment on the revision of the PPW Directive.

The use of RCT is cited as an important part of the business case for chemical recycling as it allows identical recycled materials to be moved electronically rather than physically. It works on the assumption that recycled outputs are identical and indistinguishable from virgin outputs and therefore determining where the recycled content ends up can be considered an accounting exercise. The counter argument to this is that transparency and credibility may be reduced in such a system and may not be entirely necessary.

For the purposes of the SUPD, HDPE bottles and to a lesser extent LDPE labels are where the demand for chemically recycled material may be driven from. This means that RCT would primarily be used where there is more demand for recycled content in the ethylene output from a steam cracker in a particular location and not in another; the credits can then be transferred to the one with the demand. From analysing existing voluntary schemes and the feedback from Member States in this project it is clear that a world-wide system is not desirable. Voluntary schemes have several different boundaries which demonstrates the difficulty in coming to consensus around this topic. For EU implementation it makes sense to set the boundary at the EU as a minimum and it has also been suggested that this is further restricted to within countries. The main argument for implementing such a system is to reduce transport distances, although this has yet to be quantified by the chemicals industry so the reality of this is unclear. The following provides some context for the implications of RCT for the large chemical companies that own and operate steam crackers in the EU.

In 2021 there were 38 steam crackers situated in the EU producing ethylene as a product with 21,000kt of ethylene capacity in total and around 84% of that realised as production in 2020. Around 23% of production was used for HDPE in 2020 and a further 40% for LLDPE/LDPE. The remainder is used as chemical build blocks for other polymers.¹⁰

There are 19 companies that own and run ethylene steam crackers within the EU (see Table 3-1). Of those, 10 have facilities in more than one country and only one company (Dow) has facilities in three countries. The scope for the benefit for the implementation of RCT with an EU level boundary is therefore limited to these 10 companies (representing 74% of the total capacity). It is unclear which, if any, of these companies would intend to make use of RCT in practice as they are all in the trial phase of implementation without fully established value chains for chemical recycling at present. If the boundary is restricted to in-country, 6 companies would be able to take advantage of RCT (green boxes in Table 3-1).

The three largest producers (Dow, Lyondell Bassell and Ineos) also have the largest distances between facilities with 1,000–1,800 km. All of the remainder have 250–600 km between two facilities. It should also be noted that only 14 out of 27 Member States have ethylene production and therefore transport will still be necessary to and from these countries. Equally, each individual company may also have to ship to at least another 24 Member States, therefore the benefit of RCT may be minimal in practice. Also, given the demand for recycled (poly)ethylene is likely to be high throughout the EU due to the increasing number of recycled content targets, it is also possible that the need to electronically move the material around may not be necessary.

Finally, the shipping of both the sorted plastics and the processed pyrolysis oil should be taken into account. This can only be moved physically and the benefit of a centralised credit in one

¹⁰ All raw data from Cefic - <https://www.petrochemistry.eu/about-petrochemistry/chemicals-facts-and-figures/european-market-overview/> - further analysis by Eunomia.

plant may be negated by the additional transport of the input material. This will also heavily depend upon where the plastic waste comes from and the location of pyrolysis plants – the latter is particularly uncertain given that both centralised and decentralised systems are being trailed by various operators.

- The need for RCT has yet to be proven by industry
- Relatively few companies are likely to benefit from it
- The true benefit is difficult to quantify given the complexity of the value chain which is continually evolving.
- A decision to include RCT is likely to rest upon an intuitive desire to either provide maximum flexibility or credibility in the system rather than strong supporting data for either approach.

Table 3-1 - EU Installed Ethylene Capacity, 2021 (ktonne)

Green box = companies with more than one plant in country

	Austria	Belgium	Netherlands	Czechia	Finland	France	Germany	Hungary	Norway	Poland	Portugal	Slovakia	Spain	Sweden	Total	Proportion	Countries Operated in
Dow			1,825				565						675		3,065	15%	3
Lyondell Basell						470	1,440								1,910	9%	2
Ineos							1,155		650						1,805	9%	2
BASF		1,080					620								1,700	8%	2
Total		1,160				525									1,685	8%	2
Sabic			1,310												1,310	6%	1
Shell			910				310								1,220	6%	2
Repsol											410		804		1,214	6%	2
BP							1,073								1,073	5%	1
Borealis					400									640	1,040	5%	2
OMV	500						450								950	5%	2
MOL								660				220			880	4%	2
Naphtachimie						740									740	4%	1
PKN Orlen										700					700	3%	1
Unipetrol				544											544	3%	1
ExxonMobil						425									425	2%	1
Versalis						380									380	2%	1
A.p. Feyzin						250									250	1%	1
Klesch							110								110	1%	1
Total	500	2,240	4,045	544	400	2,790	5,723	660	650	700	410	220	1,479	640	21,001	100%	

 Source: derived from <https://www.petrochemistry.eu/about-petrochemistry/petrochemicals-facts-and-figures/european-market-overview/>

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