Post-Consumer Plastic Packaging Waste – How to Increase the Yield and Reduce the Cost –

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Recycling schemes for post-consumer plastic packaging waste are politically motivated, create environmental benefits for the society and increase the business costs in general. These recycling schemes are shaped by the local presence of converting industries that are able to use the recyclates as raw materials. Choices for recycling schemes should therefore be based on the expected compliance, efficiency (the lowest environmental impacts for the least costs) and the present local industry.

1. Political context in the Netherlands

Up to 2008 the Netherlands primarily recycled post-industrial plastic packaging waste (PPW) and had implemented a deposit refund system for the majority[1] of the large PET bottles from the households (which was mandatory by decree). The post-industrial PPW recycling scheme had grown autonomously; it was simply cost efficient for businesses to recycle their PPW. This is organised by a multitude of collection services, sorting facilities and converting industries. According to the association of the involved companies (NRK) the amount of post-industrial PPW collected amounted 173 kton and the amount of produced recyclates amounted to 157 kton/a [1]. The largest deposit refund system (SRN) collects roughly 25 kton of PET bottle waste annually and produces about 20 kton of RPET regranulate. Additionally two small independent deposit refund systems (Aldi and Lidl) do not publically report their results.

In 2006 a new packaging waste law [2] came into force in the Netherlands. This law introduced producer responsibility for all types of packaging waste in the Netherlands and set a number of recycling targets for packaging waste in the future. In the subsequent framework agreement of 2007 between the ministry, the association of municipalities and the representatives of the producers of packed goods the recycling targets for all the plastic packaging waste were redefined as gradually increasing from 38 % in 2009 to 42 % in 2012 [3].

[1] For PET bottles filled with water and soda drinks, but not those filled with juices, etc.

Conflicts and issues arose when it was discovered that the newly introduced producer responsibility contradicted largely with the municipal caring duty for organising waste management. These conflicts have still not been resolved completely. In 2008 the first tests were performed with the separate collection of PPW from households resulting in 8 kton of collected PPW. In 2009 more municipalities started to contribute to this Nedvang system and the amount rose to 23 kton and in 2010 almost all municipalities contributed and 83 kton post-consumer PPW was collected [1]. This fast rise of this separate collection system for PPW from households is a large success for the operational organisation Nedvang.

Another issue that impeded the implementation of the Nedvang separate collection system in 2007 to 2009 was the opinion of several municipalities that a comingled collection of MSRW together with PPW followed by the automatic separation of the PPW from the MSRW would be more efficient than separate collection. As political compromise two existing material recovery facilities in Friesland and Groningen were allowed to recover plastic packaging waste from MSRW and entitled to obtain a fee for the produced plastic concentrates. These recovered plastic concentrates were supplied to sorting companies. In January 2011 a newly build recovery facility in Wijster for PPW became available, but this facility was not granted a fee for the recovered PPW. Nevertheless, during 2008-2011 a very lively debate on source separation versus post-separation dominated the Dutch waste symposia and this slowed decision making process down within municipalities on the introduction of PPW collection schemes.

2. Plastic packaging waste in the Netherlands

According to the Dutch taxation office 454 kton plastic packaging materials were brought on the market [1]. This number stems from company statements, which according to the environmental inspection agency have hardly been verified by the taxation office [4]. In 2010 roughly 9.2 ± 1 % of the MSRW was PPW [5], this corresponds to 360 kton wet and dirty or roughly 275 kton PPW dry and clean. The amount of PPW generated by companies

Table 1: Composition of plastic waste present in the MSRW of Rotterdam households in January 2011; the objects were first sorted by NIR and secondly manually; the percentages have been calculated from weights of the sorted fractions including attached moisture and dirt

	PET	PE	PP	PVC	PS	Total
	%					
Bottles	3.26	1.29	0.02		0.02	4.59
Flasks	1.73	3.65	0.62	0.09		6.09
Rigids	6.29	0.86	7.48	0.38	1.20	16.21
Flexibles	0.07	36.01	4.41	0.11	0.04	40.64
Laminated flexibles	0.26	2.53	1.21	0.00		4.00
Non-packaging plastics	1.47	5.29	5.01	1.84	1.00	14.61
Undesired plastic packaging		0.03	0.01	0.09	0.60	0.73
Residual plastics						13.14
Total	**13.08**	**49.65**	**18.75**	**2.51**	**2.87**	**100.00**

Undesired plastics are: kit-tubes (PE), chewing gum and drug strips (PP, PVC) and expanded PS objects.

Residual plastics are mostly: black coloured packages and a small amount of PC, PLA objects.

can then be resolved from the difference between the total amount and the amount in the MSRW, which would yield roughly 178 kton, including the 28 kton PET bottles from the deposit refund system.

The composition of Dutch PPW present at the households was estimated from sorting analysis of MSRW from the city of Rotterdam in January 2011 [7]. This city, as exemption, has not implemented a separate collection system for PPW, yet. Although this large city cannot be expected to be representative for the whole of the Netherlands, it is the only available detailed analysis of the composition of PPW at the households.

3. Dutch PPW recycling chain in 2010

The last year from which all the data up to the municipal level is present is 2010. In 2010 a mature deposit refund system for large PET bottles for water and soda was present, the source separation system of Nedvang was emerging and expanding to 360 of the 418 municipalities and plastic recovery was performed at two recovery facilities on behalf of 55 municipalities.

Within the deposit refund system about 28 kton large PET bottles were put on the Dutch market (1.69 kg/cap.a). The percentage of bottles that are returned to the shop was estimated to be 95 % and the conversion yield from bottles to PET milled goods was estimated to be 77 %. Hence this system will yield after counting and re-processing 20.5 kton PET milled goods (1.24 kg/cap.a), 2.3 kton polyolefin mixture (0.14 kg/cap.a) and 3.8 kton waste. In 2010 about half of the PET milled goods were used for the production of fleece garment and the other half for new PET bottles.

In 2010 360 of the 418 municipalities co-operated with Nedvang in the source separation system for PPW. The municipal collection responses were found to be greatly dependant on the urbanisation degree [1-5], the type of PPW collection system (curb side or drop off) and the presence of a so-called diftar system for MSRW, this means a system in which the citizen has to pay for the amount of MSRW it offers for collection. The averaged municipal collection responses per category have been summarised in Table 2. In total 83 kton of PPW was collected in 2010.

These averaged responses show that the collection was successful for a newly erected system for most types of municipalities with the exception of the most urban ones. In general municipalities with a diftar system for the MSRW had higher PPW responses than non-diftar municipalities and curbside collection systems yield more PPW than drop-off systems. Compared to the theoretical maximum of 18.3 and 15.5 for diftar and non-diftar municipalities, respectively, it is clear that the non-diftar municipalities still have the largest challenge to raise the responses[2].

The composition of the source separated PPW was studied by detailed sorting analysis PPW samples of 4 different municipalities; urban & diftar, urban & non-diftar, rural & diftar and rural & non-diftar. Diftar municipalities were found to have more residual waste in their PPW (13 and 30 %) than non-diftar municipalities (2 and 7 %). These composition have been averaged and are shown in Table 3.

[2] The theoretical maximum response was calculated from the amount of PPW present at the households and correcting it for the amount of moisture and dirt present in diftar and non-diftar communities. Since PPW collected in diftar communities contains more moisture and dirt, this theoretical maximum is also higher.

Table 2: Collection responses of PPW and the amount of connected inhabitants for various types of municipalities categorised in urbanisation degree 1-5, type of PPW collection system and the presence of a diftar system for MSRW

Urbanisation degree	Type of PPW collection system	Diftar		Non-diftar	
		Response	Inhabitants	Response	Inhabitants
		kg/cap.a		kg/cap.a	
1	Curb side	0	0	0	0
1	Drop-off	0	0	1.9	2,220,107
2	Curb side	9.4	282,214	4.6	1,605,122
2	Drop-off	9.7	302,120	3.4	2,496,010
3	Curb side	10.7	618,432	5.8	1,483,160
3	Drop-off	3.0	143,374	4.2	808,220
4	Curb side	11.7	1,399,668	6.4	1,069,145
4	Drop-off	7.3	345,776	4.2	486,568
5	Curb side	11.3	601,864	6.8	521,173
5	Drop-off	7.3	195,905	4.2	175,707
Total			**3,889,353**		**10,865,212**

Table 3: Average composition of the source separated PPW; the percentages have been calculated from weights of the sorted fractions including moisture and attached dirt

	PET	PE	PP	PVC	PS	Total
	%					
Bottles	6.00	2.60	0.05		0.05	8.70
Flasks	3.28	7.93	2.25			13.45
Rigids	9.08	1.20	8.85	1.58	2.60	23.30
Flexibles	0.08	20.78	4.43	0.58		25.85
Laminated flexibles	0.20	1.72	0.38			2.30
Non-packaging plastics	0.22	1.02	1.49	0.97	1.18	4.88
Undesired plastic packaging					0.68	0.68
Residual plastics						7.93
Residual waste						12.93
Total	**18.84**	**35.24**	**17.44**	**3.12**	**4.51**	**100.00**

In 2010 the source separated PPW was transported to four different German sorting facilities in Porta Westphalica, Sinn, Kerpen and Borken. The PPW is sorted into the following fractions PET, PE, PP, Film and Mixed plastics according to the DKR 328-1 (PET, 90 % bottles), 324 (PP), 329 (PE), 310 (Film) and 350 (MKS). For the PET packaging waste this means that the sorted PET should contain 90 % bottles and flasks while the input material consists out of roughly 50 % bottles and flasks and 50 % trays. The PET-trays should be added to the Mixed plastic fraction. Nedvang has reported the averaged sorting results of the four sorting facilities for 2010, see Table 4.

This clearly shows that the largest losses in the sorting facilities is due to insufficient sorting of PE, PP and FILM. This material is lost to the Mixed plastic fraction. The composition of the sorted fractions have been studied in detail and these measurements reconfirm the sorting inefficiencies.

Table 4: Sorting results with source separated PPW as Nedvang publishes and what would be expected for ideal sorting

	Nedvang 2009	Nedvang 2010	Sita R'dam 2011	Ideally sorted
	%			
PET bottle	6	5.6	8	10
PE	5	4.7	10	11
PP	4	3.3	7	11
Film	19	17.4	17	36
MKS	49	45.4	46	19
Rest	17	23.6	12	13

Nedvang 2009: Presentation at VMK, Nedvang 2010: KplusV evaluatierapport bronscheiding en nascheiding

Table 5: Reprocessing yields of various sorted fractions; the Sorting companies Sita and Nehlsen have supplied samples of fractions made from source separated PPW and the sorting companies Tönsmeier and DELA have done so for recovered plastics; Yield in terms of recovered mass [kg dry and clean output/kg wet and dirty input]

Fractions	Source separated PPW fractions	Recovered PPW fractions
	%	
PET	73 – 77	70 – 75
PE	82 – 92	75 – 86
PP	79 – 88	70 – 77
FILM	55 (95 ns)	50 – 55
MKS	70 – 80	68 – 74

ns: not-sieved; most film fractions were sieved prior to washing, some of the source separated film fractions were relatively clean and did not need to be sieved.

The sorted fractions were traded to re-processing companies which convert the fractions into milled goods and agglomerates, under the supervision of Nedvang and DKR. The re-processing yields of the various companies are not being disclosed and hence we have determined the yields ourselves in the laboratory[3]. These yields are summarised in Table 5.

The collected technical data of the has been used to calculate the overall recycling chain yield (from collection to milled goods and agglomerates). From the 83 kton (5.11 kg/cap.a) of collected source separated PPW in the Netherlands 69 kton (4.14 kg/cap.a) was sorted into recyclable fractions, which resulted in the production of 54 kton (3.27 kg/cap.a) milled goods and agglomerates, a graphical description of the recycling chain is presented in Figure 1.

In 2010 55 of the 418 municipalities supplied their MSRW to 2 material recovery facilities (Omrin and Vagron). Omrin produced roughly 5 kton of PPW and Vagron produced 2.6 kton rigid PPW and 1.6 kton of flexible PPW. In total this amounted to 9.2 kton of PPW or 6.6 kg/cap.a, which was sorted and re-processed into 3.96 kg/cap.a of milled goods and agglomerates. The recovered plastics are slightly more polluted than the source separated PPW and the sorting yields are therefore slightly less good. In order to achieve the same DKR specifications, the sorting companies will have to put more effort in sorting the recovered PPW than the source separated PPW, which reduces the yield slightly. The reprocessing yields of recovered sorted fractions are listed in Table 5 and are similar but slightly lower than those from separate collected sorted fractions.

[3] These results are published later this year.

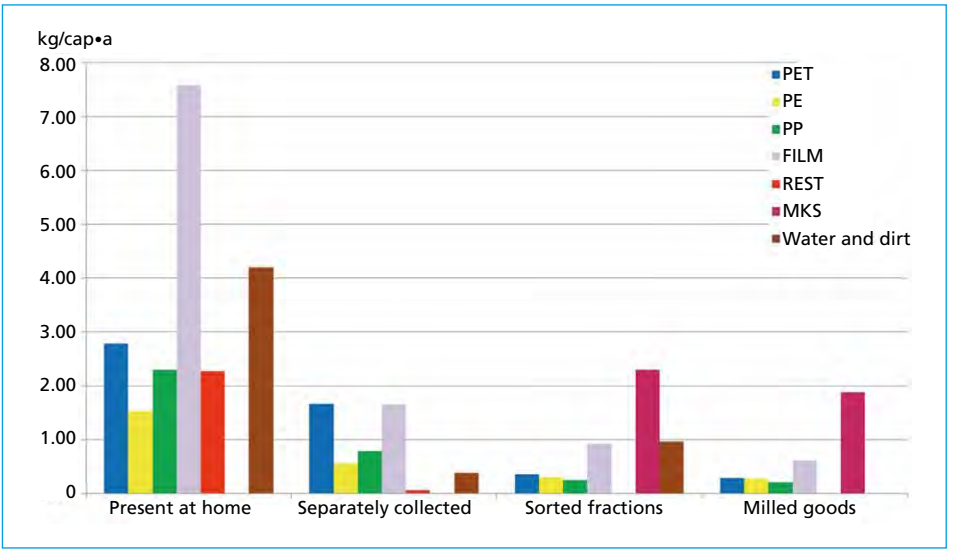

Figure 1: Schematic description of the PPW recycling chain for source separated PPW; from the civilians up to the milled goods and agglomerates

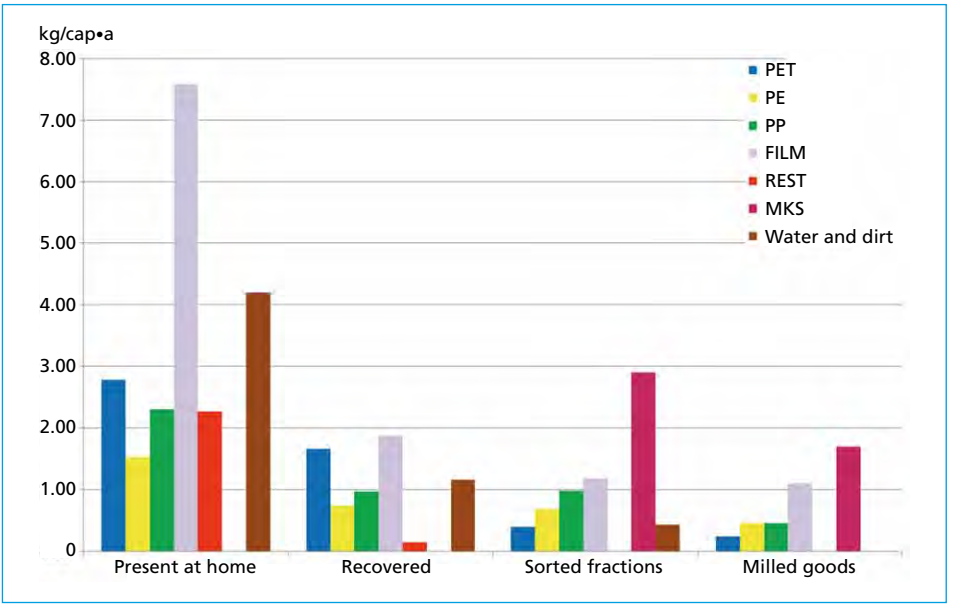

Figure 2: Schematic description of the PPW recycling chain for recovered PPW; from the civilians up to the milled goods and agglomerates

In summary, the three different recycling schemes for post-consumer PPW in the Netherlands have yielded in 2010 the following amounts of milled goods and agglomerates; deposit refund 22.8 kton (1.38 kg/cap.a), source separation 54 kton (3.27 kg/cap.a) and recovery 5.7 kton (3.96 kg/cap.a). The deposit refund system was mature. The source separation system benefited from existing infrastructure in Germany to sort and reprocess PPW and

was established fast. The recovery system was new and suffered in 2010 from several quality related issues. The recovered PPW quality did not always match the expectations of existing German sorting companies that had to adjust their facilities to produce sorted fractions that either complied with DKR specifications or almost complied with these specifications. The latter fractions had to be sold as a lower quality grade sorted fractions which resulted in slightly lower prices.

4. Cost of recycling PPW

Recycling of post-consumer PPW costs money. The precise amount depends on the chosen perspective, allocation choices and fluctuating revenues for the produced recyclates. The Dutch deposit refund system for large PET bottles costs 30-50 mln EUR/a, or roughly 1,500 EUR/ton collected material [6]. The societal costs amount to 2.42 EUR/cap.a. The larger contributing factors are the wages of supermarket employees, equipment costs, the administration costs involved with the redistribution of money. A large contribution to the uncertainty is formed by the revenues from the sold bales of PET bottles which have varied largely over the past years.

The costs of the source separation system for PPW comprise of collection fees for the municipalities (487 EUR/ton), transport costs (35 EUR/ton for the total network), cross docking fee (25 EUR/ton), sorting fees (125 EUR/ton), export permit costs (15 EUR/ton) and balance between the revenues given for the sorted fractions that can be sold and those that require a processing fee to get recycled (15 EUR/ton on average). Hence the total costs for the Dutch source separation system for PPW amounted to about 702 EUR/ton collected material or 58.2 mln EUR in 2010. The societal costs amount to 3.90 EUR/cap.a.

The costs of the recovery system for PPW comprise of the fee for municipalities (390 EUR/ton recovered PPW), transport costs (40 EUR/ton for the total network), sorting fees (130 EUR/ton), export permit costs (15 EUR/ton) and balance between the revenues given for the sorted fractions that can be sold and those that require a processing fee to get recycled (30 EUR/ton on average). Hence the total costs for the Dutch recovery system for PPW amounted to about 600 EUR/ton recovered PPW or 5.5 mln EUR in 2010. The societal costs amount to 4.55 EUR/cap.a.

This means that the cost efficiency of the three Dutch PPW recycling schemes in 2010 were: 1.70 EUR/kg for deposit-refund, 1.06 EUR/kg for source separation and 0.96 EUR/kg for recovery (all in terms of costs per total amount of output products).

5. Improving the recycling schemes for PPW

The source separation and the recovery system for post-consumer PPW were young systems in 2010 in the Netherlands with room for improvement. The objective of the stakeholders is to achieve a cost-neutral recycling chain; meaning that the costs of the recycling chain equal the revenues of the sold milled goods and agglomerates. Since the overall costs of recycling PPW in Netherlands amounted just over 100 million Euro in 2010, this is a large challenge. Nevertheless, various model calculations have shown that cost-neutrality can be approached in future, but will require many improvements of all members in the recycling chain. These improvements encompass: Raising the responses, Lowering the specific costs, Improving sorting and re-processing, Redesign for recycling and Adding the PET bottles of the deposit refund system to the source separation system. Figure 3 shows that cost neutrality can be achieved when all these improvements to the PPW recycling scheme are conducted simultaneously by all chain partners.

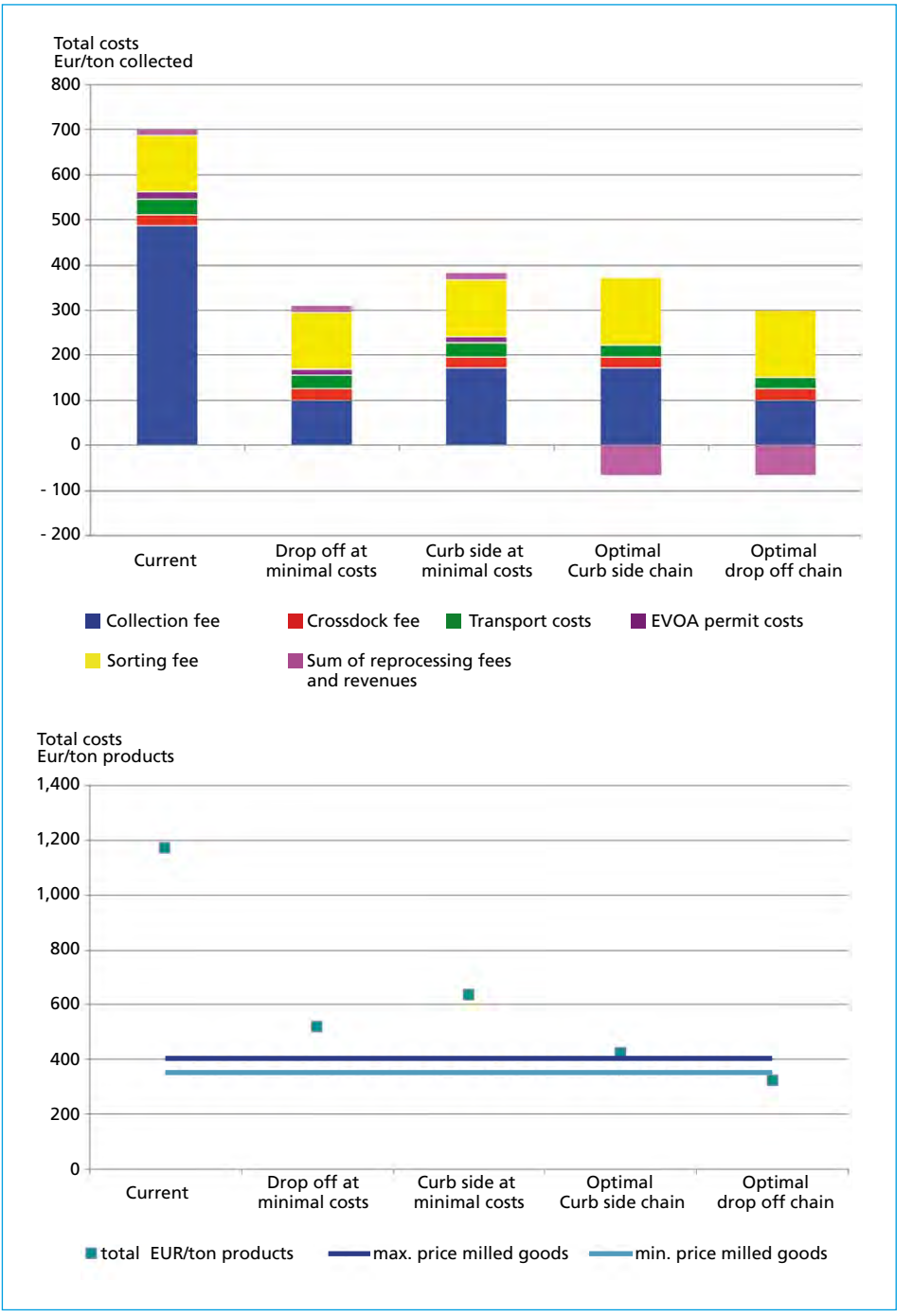

Figure 3: The cost structure of the current source separation system in the Netherlands and how it can be improved when the collection is performed at minimal costs and when several design changes are made to the currently applied packages

Raising the responses

Although the official numbers are not available yet, the total amount of collected PPW via the source separation system is expected to have risen to about 100 kton in 2011. This is mostly due to a rise in collection responses of rural and semi-urbanised municipalities. The largest cities are still lagging behind both in offered collection facilities and in obtained responses. Based on the experience in other European countries the threshold percentage for post-consumer PPW is expected to be about 55 to 60 %, which would imply that the total collected amount of PPW for source separation should be able to mature to 130-140 kton in the Netherlands.

Also the output of the recovery facilities can be improved. In January 2011 a new recovery facility opened in Wijster. It was engineered with the intention to recover a maximum amount of PPW from the MSRW. This facility was able to recover about 8.4 % of the Rotterdam MSRW as plastic packaging concentrates, wherein the PPW content was 13 %. The initial products contained much residual waste and hence the net recovery rate was only 5.3 %, which translates into a response of 17.9 kg/cap.a [7]. This recovery facility did not receive a fee from the Afvalfonds and the operator decided to change the settings of the facility into the production of relative smaller amounts (approx 6 kg/cap.a) of more pure PPW. This material is sorted by German sorting facilities and the sorted fractions are sold to re-processors. This example shows that there is a inverse relationship between the quantity and the quality of the PPW recovered and that it is a good alternative for urban centres where source separation is not easily implemented.

Lowering the specific costs

The largest cost factors for the recycling of PPW are the fees given to municipalities for the separate collection of PPW (487 EUR/ton) and the recovery fee for PPW (390 EUR/ton). Based on detailed logistical collection models and general economic information provided by waste collection companies, we have been able to calculate the minimal collection costs under Dutch conditions to be about 100 EUR/ton for a drop-off system with underground press containers, 171 EUR/ton for a kerbside collection system and roughly 200 EUR/ton for a recovery system [8]. These calculated specific costs are sensitive for local conditions (traffic jams, distances between connections and cross-docking stations) and the real collection costs can be higher. Nevertheless, there are plenty of business opportunities to make the PPW collection more cost effective. Including for instance the merging of the PET bottle deposit refund system with the source separation and recovery systems. The rise in the amount of PPW per household would already render a 10 % reduction in collection costs.

Improving sorting and re-processing

Sorting facilities have relatively large losses of PE, PP and FILM material to the mixed plastic fraction. Although all these fraction contribute to the recycling target, an improvement in the ratio between valuable fractions and the mixed plastic fraction would reduce the overall costs of the chains. Up to now the additional effort of the sorting facilities caused higher sorting fees and did not result in an overall improved financial balance. Nevertheless, the process can be designed to achieve better sorting results [9]. Furthermore, it is expected that future packaging design improvements will make the sorting and re-processing more efficient.

Redesign for recycling

The FMCG industry itself can also contribute to improved recycling chain yields and lower costs, although the relationships between the applied packaging designs and the effects on the recycling chain are far from simple. Here we will limit ourselves to a few clear examples.

PVC-packages

Most rigid PVC packages can be substituted without loss of performance by equivalent packages made from PET and PP. The PVC stretch films can be substituted by PE and EVA based systems. The producers of goods in PVC packages are for a large part well defined (drugstores, DIY stores, toys, X-mas cards) and partially more diffuse (cheaper imported products). PVC packages distribute themselves in a complex manner over the various products and waste streams in both the source separation and recovery recycling chains.

In case all the PVC would be substituted into PP and PET a maximum of a 2 % improvement in the overall recycling yields is expected, due to slightly higher sorting yields and re-processing yields and concomitant reductions in the amounts of waste formed.

PS packages

The amount of PS varies from 2 to 5 % in various PPW streams; the majority are rigid trays, cups and beakers, a smaller part is formed by non-packaging waste from electronics and appliances and finally also foam (EPS). Two aspects make PS packages difficult; the current sorting facilities are not well able to deal with EPS and therefore demand that it is not collected and many rigid PS packages are brittle and are fragmented during the sorting and handling. Therefore most sorting companies do not aim to sort PS from the PPW mix and currently it is distributed in complex manner over all products and waste streams. Two improvements can be followed; include EPS in the PPW recycling system and adapt collection logistics and sorting companies, or try to replace PS by PP. A substantial part of the rigid PS packages could be substituted without loss of performance by PP. We estimate that the replacement strategy could result in a 2 % improvement of the overall recycling yield.

Black packages

About 10-15 % of the Dutch PPW are black packages; roughly half rigids and half flexibles. These black plastics mostly end up in the REST fraction and therefore do not contribute to recycling. A large portion of the black rigid packages are used for fresh products (PP, PET) and could be designed to have a colour that allows for NIR sorting. A very small fraction of black flasks are used for motor oils and these are not desired in the recycling chain. The redesign of trays to different colours than black can really make a clear improvement in the overall recycling yield of about 5 %.

Transparent PET trays

Dutch PPW contains about 10 % of PET based trays, of which about one third are pure PET trays, another one third are PET-PE multilayer trays and the rest are more complex compositions and coloured trays. Currently the sorting companies aim for PET at DKR 328-1 (90 % bottles) and most of the PET trays end up in the MSK fraction. This means that valuable pure PET trays are lost without revenues, which worsen the economics of the recycling system and does not yield recycled raw materials for making RPET trays. Since the NIR sorting technique can not successfully differentiate the pure PET from the other PET trays, an option would be to mark the pure PET trays with an easily measureable marker, for instance a UV-marker, this would simplify the PET sorting operation, lower the overall recycling costs and increase the share recycled packages in the portfolio of recycled products. Basic cost model calculations show that this design change could lower the overall recycling costs with about 50 EUR/ton output.

6. Conclusions

The source separation of plastic packaging waste in the Netherlands has developed rapidly and is a large success in terms of achieved recycling targets and reduced environmental impact. However, the costs for the recycling of post-consumer PPW had already doubled in 2010 and is expected to rise further with expected increased responses in 2011 and 2012. In order to render a cost neutral recycling scheme for post consumer plastic packaging waste it is vital that all the stakeholders collaborate. With a concerted action such a cost neutral recycling system could be approached.

In the recent past, the national debate focussed on the means of collection (deposit refund, source separation and post separation).The achieved recycling results in the past years have shown that not the system itself but the performance of the system is critical. Especially the collection step in the recycling chain has been found to be critical and it really depends on local conditions whether or not a curb side collection system or post-separation is practically feasible and economic executable. This insight has shaped the new decree for the period 2013-2022 in which municipalities and packaging industries get freedom of system choice, the municipalities themselves become responsible for the sorting and the reprocessing and in return the recycling targets are gradually increased to 52 %.

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