FINAL REPORT SUMMARY

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Ecological balance sheet for recycling polyurethane foam cans using the PDR method

PRODUKTE DURCH RECYCLING

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Customer:
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PE INTERNATIONAL AG

Nomenclature

Abbreviation	Explanation
ADP	Abiotic Depletion Potential
AP	Acidification Potential
EP	Eutrophication Potential
GWP	Global Warming Potential
MDI	Methylene diisocyanate
NMVOC	Non-Methane Volatile Organic Substances
ODP	Ozone Depletion Potential
POCP	Photochemical Ozone Creation Potential
PU	Polyurethane

Brief summary

The objective of the study is to conduct an ecological comparison of predominantly material-based recycling of polyurethane foam cans according to the "PDR system" and other recycling methods.

The scope comprises the part of the PU foam can lifecycle that is in the area of responsibility of the disposer. This means the comparison looks at the end of the life cycle of the PU foam cans starting at the collection point until the start of the new life cycle of the materials and energies recovered in the recycling process. In order to be able to isolate this part of the system from other life cycles of secondary raw materials, credit notes are issued for all materials and energies that enter a new life cycle after treatment. The functional unit of the study is the recycling of the average composition of a PU foam can with a weight of 241 g, including a percentage for transport packaging.

In the closed *PDR system*, the cans are dismantled into their separate constituents so they can be recycled according to material as far as possible. Only those parts that cannot be recycled according to material are sent to the energy recovery system. In particular, special steps are taken to recover the contents of the cans, the prepolymer mixture and propellant mixture, and to recycle these materials. For modelling the *PDR system*, very few unimportant preceding chains are cut off and very few allocations are required.

In contrast to the *PDR system*, the competitor system, with its mixed material recycling and combustion, incinerates the prepolymer mixture and propellant mixture contents of the can. As regards the system limits, allocations and assumptions, the competitor system only differs slightly from the *PDR system*.

The predominantly material-based recycling of PU foam cans in the *PDR system* is far superior to the combination of material-based recycling and incineration of the competitor system. In the *PDR system*, higher environmental costs are necessary in the impact categories acidification, eutrophication (over-fertilisation) and greenhouse effect to recycle the material flows than in the competitor system; however this drawback is more than compensated by the higher credits. In the photochemical ozone creation (summer smog potential) impact category, the *PDR system* is also superior in terms of costs. Not only are the costs lower than in the competitor system, the credits are higher. The *PDR system* is also much more beneficial to the environment for the consumption of primary energy.

Sensitivity examinations have shown that also those parameters that have a large influence on the final result do not result in any change of the final result when varied. The ecological benefit of the *PDR system* as compared with the competitor system is so large that the result of the study is not changed by this variation.

Therefore, PDR should concentrate next on improving the environmental performance to optimise the transport of the cans to PDR for material-based recycling.

1 Detailed summary

1.1 Summary of the task and objective of the study

The objective of the study is to conduct an ecological comparison of predominantly material-based recycling of polyurethane foam cans using the *PDR method* and other recycling methods.

Two methods have been selected from the variety of possible processes: The predominantly material-based recycling in the *PDR system* and a 'competitor system' with a combination of material-based recycling and incineration of the residue fractions.

The scope comprises the part of the PU foam can life cycle that is in the area of responsibility of the disposer. This means the comparison looks at the end of the life cycle of a PU can starting at the collection point through to the start of a new life cycle of the materials and energies recovered in the recycling process. In addition to the packaging, the *PDR system* can also recycle the propellants and prepolymers from the most common 1C cans on the market, and also the propellant from 2C cans. Thereby, the material-based and energy-based costs required for the recycling are also taken into account. The reference year for the study is 2011.

The target group for the study is primarily PDR itself. The study should also be made accessible to the interested public.

The study and reporting are oriented to the principles of life cycle assessments defined in the DIN ISO 14040 and DIN ISO 14044 standards.

1.2 Summary of special aspects of the method

The study comprises the part of the PU foam can life cycle that is in the area of responsibility of the disposer, In order to be able to isolate this part of the system from other life cycles of secondary raw materials, credit notes are issued for all materials and energies that enter a new life cycle after treatment. This process represents an expansion of the system space. The granted credits are itemised separately and are not offset against the treatment costs.

1.3 Summary of the system description, actual examination framework

The functional unit of the study is the recycling of the average composition of a PU foam can including a percentage for transport packaging, as delivered after collection. In 2011, an average PU foam can weighed 241 g (without transport packaging).

The system boundary of this examination is the 'end-of-life' part of the product life cycle of a PU foam can. In addition to partially emptied 1C cans and 2C cans from the German post-user market, PDR also accepts nonconforming goods or goods that have exceeded their shelf life (so-called special items) directly from manufacturers/retailers. Once in the collection point, the used PU foam cans are the responsibility of the disposal company and this responsibility remains until the secondary raw materials recovered from the treatment process are used in new products. All steps, from the collection of the used cans to their recycling, treatment and reuse or recycling and re-use or further use to their use again in new products, are thus part of the system, likewise the elimination of constituents that cannot be recycled. The energy balance of the "PDR system" reference scenario is shown in Figure 1-1. Material-based and energy-based operating equipment within the energy balance are balanced including their manufacture.

At the beginning of the recycling process, the PU foam cans are moved from the returned box by hand and cleaned. They are sent to the automatic treatment system via a conveyor belt. The cans are dismantled into their separate components in a closed system:

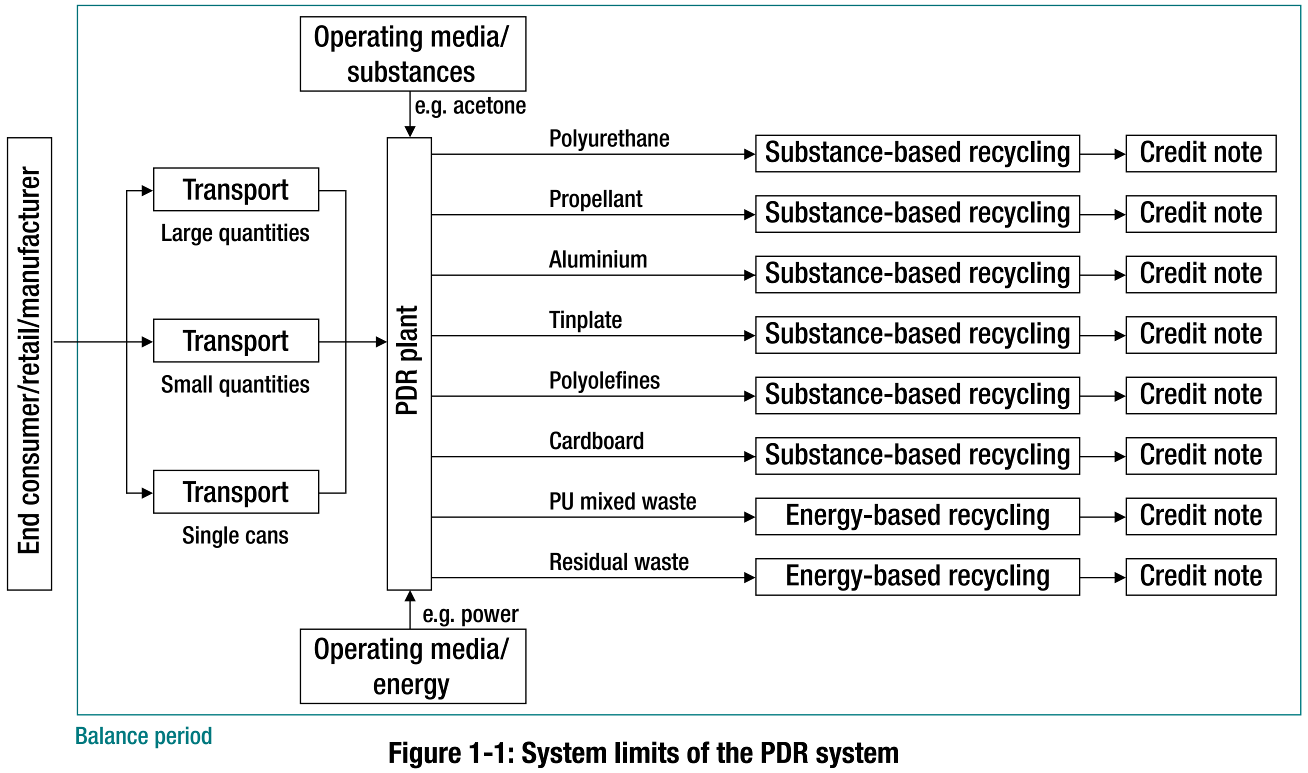

Figure 1-1: System limits of the PDR system

- The tinplate and aluminium pieces are melted again in smelting companies after they have been cleaned.
- Any residual propellant is completely extracted, liquefied at ultra low temperatures and later used again when filling technical products.
- A solvent is used to recover the prepolymer mixture. After a filtering and distillation process, the prepolymer mixture is used as a substitute for polyols and isocyanates for technical applications.
- The plastic caps are ground and sent to a plastics processing company.
- Defective returned cartons are sent to the paper industry as a raw material for recycling cartons. Useable cartons are reused.

This ecological balance sheet looks at the issue of whether possible competitive companies or PDR itself with its method of recycling the materials of the used packaging of PU foam cans into materials or incinerating these parts, could act in a more ecological manner than PDR currently does with its predominately material-based recycling system. For this reason, many aspects of the *PDR system* could be used in the "competitor system" comparison scenario. Therefore, the system limits of the competitor system largely correspond to those of the presented *PDR system*.

In order to prevent uncontrolled escape of the propellant into the environment, the PU foam cans must also be punctured in a controlled way in an inert gas atmosphere in the competitor system. The escaping propellant is collected and can be incinerated in a hazardous waste incinerator.

The prepolymer mixture can be hardened technically in a chamber sealed from the environment. Once hardened, the materials are safe and can be incinerated for energy recovery in a waste incinerator.

Analogous to the predominantly material-based recycling by PDR, a "competitor system" comparison scenario is presented in which the constituents of the PU foam can that can be recycled into separate constituents are compared with a material-based recycling approach. This concerns the following material flows: aluminium scrap, tin plate scrap, polyolefins (protective caps on the cans) and cartons (packaging of the cans).

With regard to the system limits, allocations and assumptions, the competitor system only differs slightly from the *PDR system*.

1.4 Summary of the material balance

The model for both systems is established in the software for holistic life cycle assessments 'GaBi 5' from PE INTERNATIONAL. The model is structured on a set of free parameters that are listed in the environment report of PDR.

The *PDR system* is far superior to the competitor system with regard to primary energy consumption.

1.5 Summary of expected impact

This study considers the greenhouse effect (GWP 100), acidification (AP), over-fertilisation (EP) and photochemical ozone creation (POCP) impact categories.

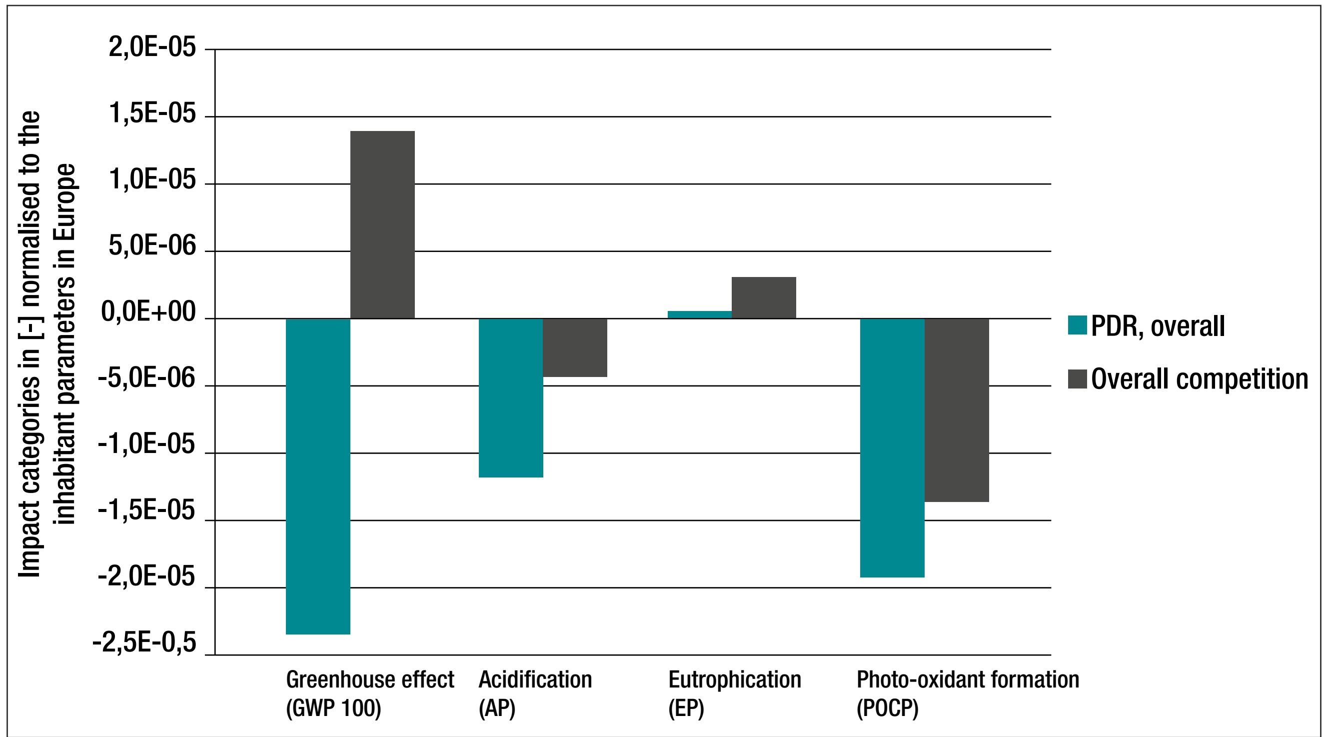

Figure 1-2: Evaluation of system comparison; impact categories normalised to Europe in 2010 per functional unit

The predominantly material-based recycling of PU foam cans in the *PDR system* is superior in all four impact categories to the combination of material-based and energy-based recycling of the competitor system.

In the *PDR system*, higher environmental costs are necessary in the acidification, over-fertilisation and greenhouse effect impact categories to recycle the material flows than in the competitor system; however this drawback is more than compensated by the higher credits. The *PDR system* is also superior in with regard to costs for the photochemical ozone creation impact category. Not only are the costs lower than for the competitor system, the credits are higher.

1.6 Assessment summary

The results of this study in the individual impact categories show the clear environmental benefit of the *PDR system* in the individual impact categories as compared with the examined competitor system. Therefore no weighting is applied because it does not bring any additional insights for the results of the study.

1.7 Summary of sensitivity of important parameters

The sensitivity was examined of those parameters that are expected to have a large influence on the final results and estimates were made where there was a large amount of uncertainty.

The results of the sensitivity examinations show that also those parameters that have a large influence on the final result do not result in any change of the final result when varied. The environmental benefit of the *PDR system* as compared with the competitor system is so large that the result of the study is not changed by this variation. The *PDR system* still outranks the competitor system from an environmental point of view despite the higher costs for transport, higher credits for energy-based recycling and higher emissions in the plant in Thurnau.

1.8 Summary of conclusions

The PDR recycling method allows the objectives and requirements of the Waste Management and Product Recycling Act (KrW-/AbfG dated 27/09/1994, § 5 and § 6) to be achieved. As the examination period records the year 2011, no reference could be made to the Waste Management and Product Recycling Act which came into force on 01/07/2012. Therefore, the reference to the new Waste Management and Product Recycling Act alone does not bring different results because the content of the referenced regulations of the §§ 5 and 6 KrW, /AbfG completely comply with the provisions of the §§ 7, 8 KrWG, if relevant. The process is technically feasible and economically reasonable. PDR has developed a market for the material fractions (prepolymer and propellant mixtures) created during the recycling process. The study documents that the predominantly material-based recycling of PU foam cans has environmental advantages over the combination of material-based recycling and incineration of a competitor system

The use of solvents to recover prepolymer mixtures as a material flow for material-based recycling is worthwhile in light of the fact of the high credits for the material-based recycling of the prepolymer mixture.

The propellant mixture is already fully marketed, the transport channels have been optimised in recent years and the emissions in the Thurnau plant have been reduced thanks to the thermal-regenerative after-burning process. The efficiency per can has been improved, both in relation to the materials used as well as the energy required.

Therefore, PDR should primarily concentrate on improving the environmental performance to optimise the transport of the cans to PDR for material-based recycling.