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Ecology and Economy of Plastic Recycling

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Starting Position

Everybody on the Symposium talks on biodegradable polymers. The topic of my paper will deal with undegradable commodity plastics and its recycling.

It will be of general interest to compare both environmental concepts in the beginning of this paper.

Historically, we discussed mainly the environmental problem of littering and disposal. A special topic was – and still is – the disposal in marine environment. The answer seemed to be biodegradable polymers visibly disappearing quickly but with an unknown environmental fate of the short chain remnants. Meanwhile, several different scientific concepts have been developed but none of them had the big commercial success so far. Nevertheless the scientific community continues to discuss this direction intensively.

Today, the view on environmental problems has broadened considerably. The concept of sustainability has been developed recognizing the responsibility of our present generation to keep sufficient resources of any kind which are not endless for the following generations. But sustainability includes economic and social aspects as well and it is our task now to mirror individual decisions towards this goal of substainable development of our society in general.

Let us first discuss the ecological goals of this concept. Present main topics are:

saving of resources
minimization of emissions including disposal
avoidance of hazardous substances

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The public emphasis concentrates presently on minimization of emissions if you consider the debate on global warming or on dioxins in the past. But saving of resources will become more important in the future if the limited availability of fuel for instance gets more public awareness again.

Non-degradable and partially also degradable plastics are derivatives of fuel and we have to discuss what is the better sustainable concept to use this fuel economically.

	Non-degradable	Degradable
Source	**Fuel**	**Fuel / biomass**
Resource demand	**80 - 140 MJ/kg**	**unknown**
Resource saving by recycling	**20 - 60 MJ/kg**	**-**
Emissions		
production phase	**concentrated in plants**	**concentrated in plants**
disposal phase	**concentrated in recycling facilities**	**dispersed in landscape CO_2 / CH_4 etc.**
Hazardous substances	**influence known and regulated**	**little knowledge**
Economy	**reasonable cost**	**more costly**

Which plastic route is more sustainable?

Meanwhile we have developed a good insight into the environmental behaviour of commodity plastics which I am going to describe in a moment. According to my knowlege, rather little is known on the environmental behaviour of degradable polymers from a sustainable point of view. It should be the task of the European Degradable Polymer Society (EDPS) which will be constituted here in Stockholm these days to initiate more scientific activities towards this goal.

The influence of commodity plastics on environment

The Association of Plastic Manufacturers Europe started a programme on life cycle analysis of most of the common plastics some years ago already. Meanwhile, the data for most polymers for resource demand and emissions have been evaluated and published based on the average of data of all European production sites. The results for resource demand are shown in the following figure.

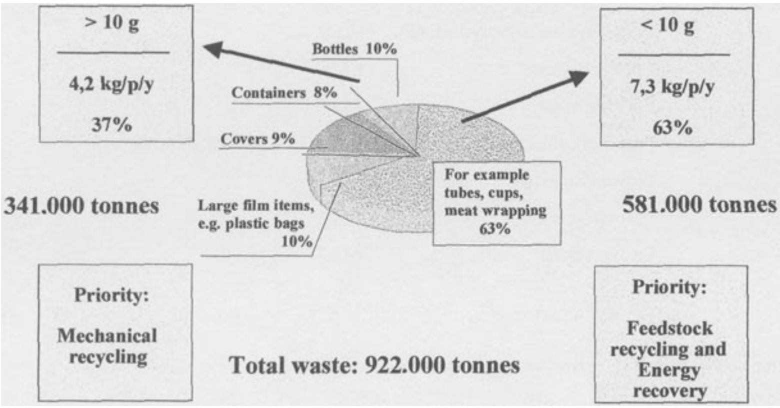
Polyethylene	**85.8**	**(83.0 - 88.5)**
Polypropylene	**80.0**	
Polystyrene	**102.2**	**(96.2 - 105.3)**
ABS	**95.2**	
Polyvinyl chloride	**66.8**	**(65.0 - 74.9)**
Polyethylene terephthalate	**83.8**	
Polybutadiene	**84.5**	
Polyurethane	**104.9**	
Polymethylmethacrylate	**111.7/133.4**	**(beads/sheet)**
Polycarbonate	**116.3**	
Polyamid 6.6	**143.6**	
Epoxy resins	**141.7**	

Production of plastics – gross energy requirements (MJ/kg)

More difficult is the question on hazardous substances. This only partially is a topic of the polymer itself, except for the chlorine issue, but it is mainly a question of additives needed for processing and stabilization. This is a very complex subject - if you only consider the issue of possible endocrine effects of substances and a topic on its own. I therefore would like this to remain unanswered today. We will concentrate on the two first topics only in this paper.

But what is the influence of waste and recycling and recovery on the environment? Plastics production in Europe is around 25 mio. t/y in Europe and around 11.0 mio. t in Germany. Thus, Germany is a major producer and this might be the reason why concepts for collection and recycling and recovery of industrial scrap and postconsumer waste have been advanced earlier than in the rest of Europe. Unfortunately the concept for collection being established in the household area, known as Duales System Deutschland, is a very costly system. We spend today more than 2 billion German Marks in order to recycle 500.000 t/y of plastic. This raised the question if the ecological benefit is justifying these tremendous costs. APME / VKE / VCI and DSD initiated a life cycle analysis on the topic in 1992. The first results were published in 1995. Meanwhile we have gathered data for all important recycling routes and this will be presented now.

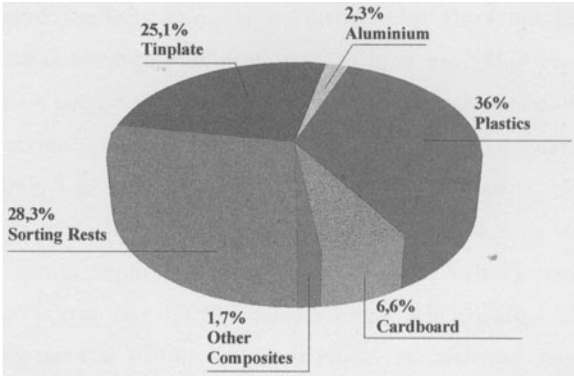
Typically plastic packagings are light-weight packagings: 60% of all plastic packagings weigh less than 10 g, and their light weight reflects their outstanding performance. Only 10 weight % of the total packaging consumption fall to the share of plastic packagings, while these packagings protect 42% of all goods in private households (70% thereof food packagings).



Source: GVM 1993

Plastics packaging – domestic household use 1991, Germany (kt/y)

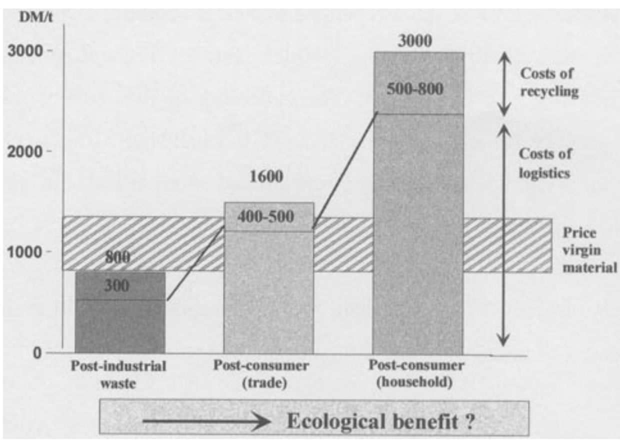
The stringent requirements of the German Packaging Ordinance - i.e. to collect 80%, to sort 80%, and to channel 64% into material recycling - forced the Dual System from the very start to sort, unlike in other countries, not only large plastic packagings (such as bottles and huge bags) but also small packagings (e.g. bags for chips, yoghurt cups) and utilise those packagings in material recycling, because large packagings (weight > 10 g) merely account for 37% of the total market input of plastic packagings. Consequently, also unlike in other countries, no bring system was possible in Germany, but a high-cost kerbside collection system had to be built up. Since it would have been too exacting for private households to cope with several containers for waste collection, the idea of the Yellow Bag - intended not only for plastics but also for composite packagings and metal tins - was born. However the possibility to frequently abuse the Yellow Bag for ordinary waste disposal was overlooked so that actual contents of the Yellow Bag are now composed as follows.



Source: Dieter-Eckart Uhlig
"Handbook of Sorting Technology"

Contents of the yellow bag, 1995

Regional analyses (Dresden, Lahn-Dill district) repeatedly confirm this picture. Given such framework conditions, it becomes obvious why some two thirds of the total costs incurred in collection and sorting arise in the collection of light-weight and contaminated - and therefore difficultly utilisable - waste, whilst just one third of the total costs fall to the share of recycling.



Dependence of waste management costs on waste quality plastics packaging

Today total costs in the cycle management of plastic packagings from private households exceed DM 2 billion per year, i.e. more than 50% of the total costs of the Dual System. Referred to the final outcome- i.e. 535,000 tons of recycled plastics - this results in a price of roughly DM 4/kg of plastic. The total amount is covered by the payment of DM 27 per person, i.e. a private household consisting of 4 persons pays annually some DM 100 alone for the disposal of 40 kg/household of purchased, mainly small-size plastic packagings. By contrast the annual fee payable for the remaining waste (4 x 283 kg = 1,132 kg/household) varies around DM 520 p.a., depending on the municipality. The plastic materials thus obtained are three times as expensive as the purchase of new products (DM 1.20/kg approx.) Therefore the following questions are obvious:

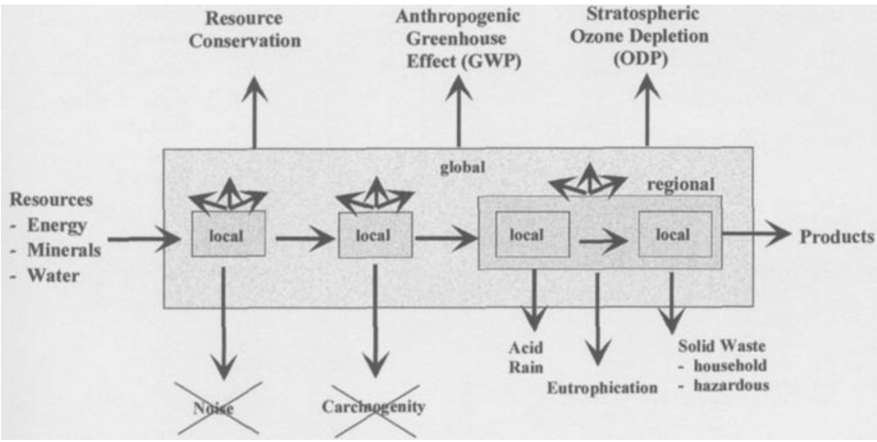
- What are the advantages to the environment to justify such extra cost?
- Is there a savings potential which makes it possible to reach the same or almost the same ecological result at lower cost?

The work on such an analysis started some 6 years ago with an eco-balance for all recycling routes available for plastic packagings, as demanded i.a. in the European Packaging Directive. A first interim result was published in 1995. Commissioned by DSD, VCI, APME and VKE, three reputable technical institutes (University of Berlin, University of Kaiserslautern, Fraunhofer Institute „Process Technology and Packaging", Freising) carried out a detailed study. The collection of data was monitored by the technical surveillance association Rhineland (TÜV Rheinland). Representatives of the German Federal Environmental Agency (Umweltbundesamt) attended as guests the panel meetings accompanying the project.

The parameters prescribed in the German Waste Management and Recycling Act were used as parameters to assess potential influence on the environment:

- Resource reduction;
- Minimisation of emissions, examining in detail:
  - Potential effect – on global warming
  - Potential effect – on acidification
  - Potential effect – on eutrophication
  - Potential effect – on waste generation

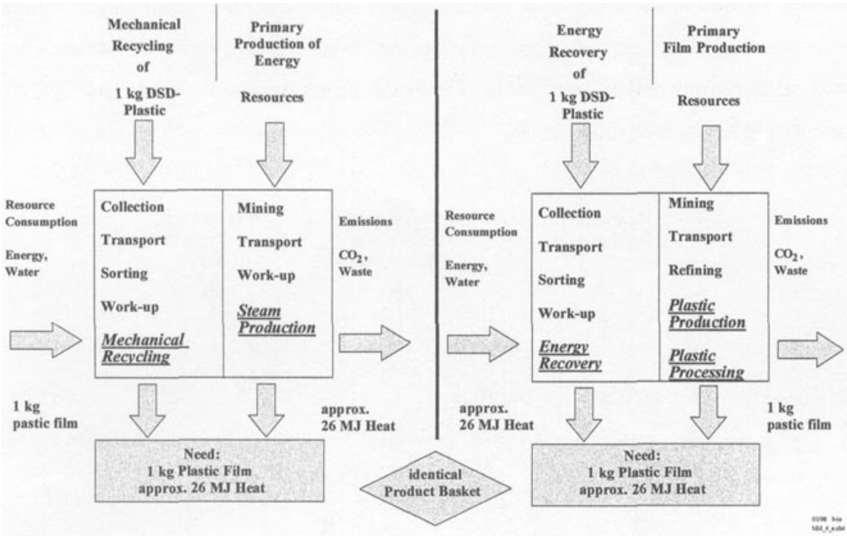
For reasons which will be explained in a later part of this paper, it was not possible to sufficiently examine the equally important aspect of eco-toxicity. It must also be mentioned that in the analysis of process chains with significant geographical distanees between the various process steps, only the inclusion of global forms of influence in an eco-balance really makes sense whilst locally occurring events are much less significant and should be assessed only locally.



LCA – data assessment

Initially the essential task in the study was to develop a conclusive scientific method allowing a comparison of different processes leading to different end products. These efforts were guided by the question whether it makes more sense in ecological terms to obtain one or several products from 1 kg of waste, or if it is more useful to generate the corresponding quantity of heat. The solution was a so-called „basket of benefit" („Nutzenkorb") consisting of all „benefit factors" („Nutzengrößen") made available in recycling processes (products, heat, electricity).

The starting point was the deliberation that human society needs products and heat as well as electricity to satisfy its needs. If these „benefit factors" cannot be obtained from waste, conventional methods are followed and they have to be created from primary resources. This approach allows the ecological assessment of recycling chains against process chains creating the same „benefit factors" from primary resources. Thus the question can be answered in what way a „basket of benefit" of a given composition can be created in the environmentally soundest manner.



Product basket method

This is the direct answer to the question about the most sustainable method to obtain - in their entirety - these „benefit factors" in the prescribed quantitative shares.

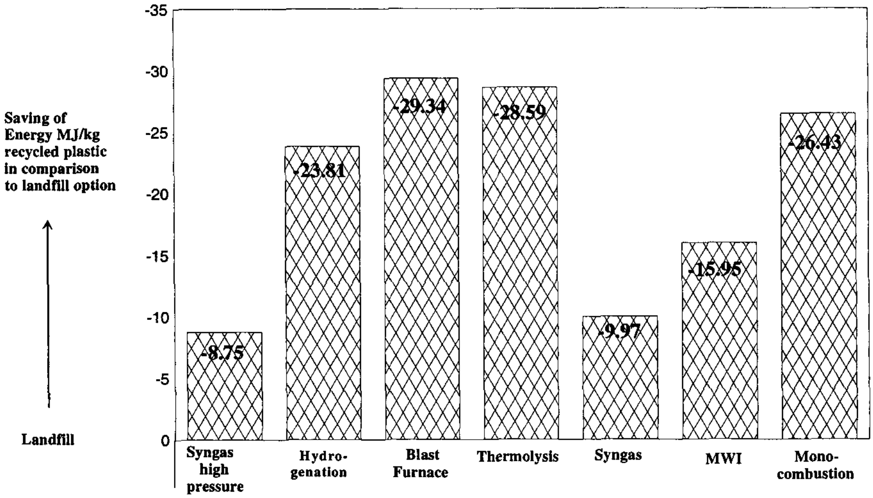
Any change in the weighting of „benefit factors" in the „basket of benefit" would influence the total result, if such a change affected the flow of quantities in waste recovery. Further details on the „basket if benefit", the collection of the various data and their evaluation can be taken from the recently published summary of the study.

In 1997 the study was awarded the Océ-van der Grinten-Prize. So far the study has brought the following findings (status 1995):

1. Mechanical recycling, feedstock recycling, and energy recycling all make sense for plastics from ecological aspects. However in the various recycling routes the potential for savings differs with regard to the examined environmental parameters.

2. The reason underlying these differences in the savings potential is the varying ecological efficiency of recycling routes, i.e. which ecological efforts are linked with the respective recycling route.

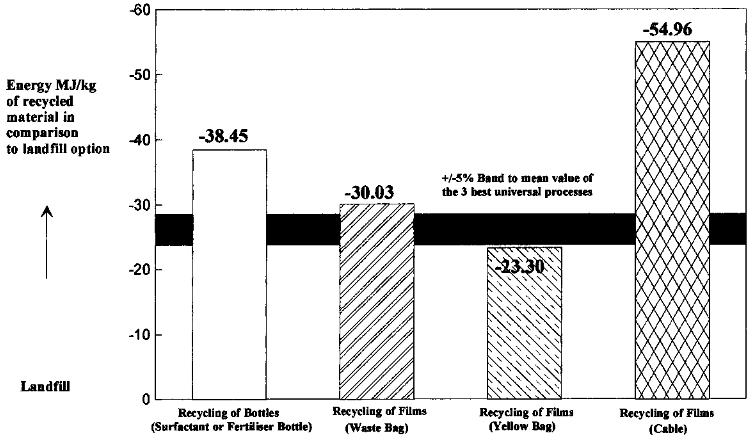
3. The so-called „universal processes" of feedstock recycling and energy recovery (i.e. processes in which, possibly after physical pre-treatment, all types of plastic waste from private households can be recycled) yield certain savings in environmental parameters.



Ref: Study by German Institutes 1995

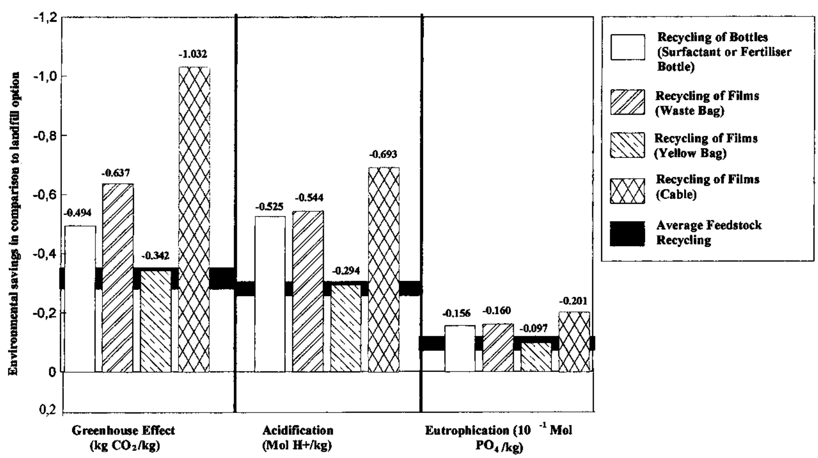
Feedstock recycling in comparison to landfill, saving of energy

Mechanical recycling processes can be more or less advantageous than the mentioned „universal processes". Therefore the term „mechanical recycling" as such is no ecological assessment and becomes an ecological assessment only after the efficiency of the process is taken into consideration. The term „efficiency" comprises the ecological cost of the recycling route as well as the efficiency with which the identified aim - i.e. substitution of the primary commodity - is reached, expressed by the degree of substitution.



Resources assessable in terms of energy in MJ/kg utilised in mechanical recycling (reference scenario: landfill)

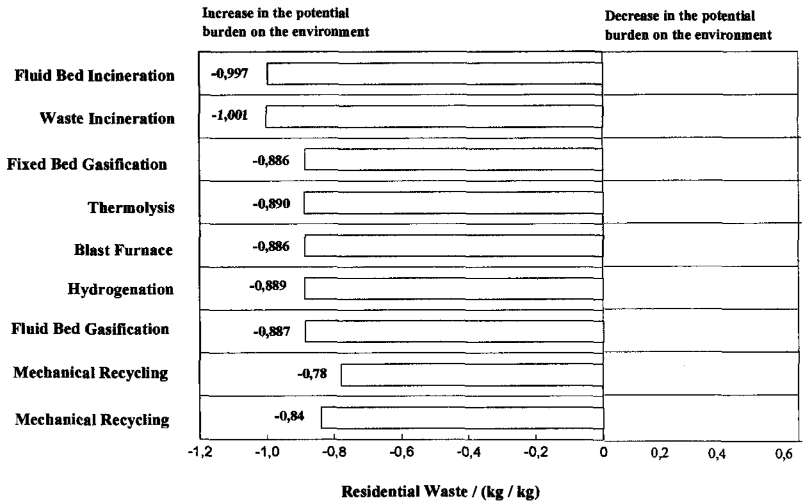
4. In ecological terms, the effects of plastic recycling are most apparent in resource reduction - i.e. the consumption of energy and connected emissions are reduced - which essentially corresponds to the savings potential in global warming.



Greenhouse effect, eutrofication and acidification (reference scenario: landfill)

The potential to influence acidification and eutrophication, respectively, differ between the various processes only slightly when compared with the parameters above.

5. Waste incineration is the most effective method of waste reduction. All other recycling routes involve more waste in the total recycling chain than waste incineration.



Residential Waste (reference scenario: landfill)

Findings so far published met with great interest in society at large. In addition to a public presentation in Bonn in 1995, a VCI workshop was held to discuss the study in detail.

The main point of criticism was the lack of information about eco-toxicity. Eco-tox data - e.g. on heavy metals, dioxins, etc - were collected if available. However the data situation, especially for mechanical recycling - was insufficient so that no comparison could be made. Moreover several proposals for aggregation exist due to the complexity of the matter. An uniformly accepted procedure is still lacking, such a system remains to be elaborated as scientific findings progress. For these reasons the collected individual data were not evaluated.

At present a „Critical Review“ according to ISO 14040 is being prepared. The review will be made by experts who did not participate in the study discussed here. Results are expected for 1998.

Another demand is to extend the study to recycling routes not yet examined, such as:

- Mechanical recycling of mixed plastics to obtain products substituting goods made of wood or concrete. Here thick-walled sections for the production of various articles (park benches, landing-stages, bank stabilisations) make a good example. Roughly one third of the quantities utilised in 1996 in Germany by DKR in mechanical recycling provided such target products.

	Germany		Export	
	Virgin Resin	Wood/Concrete	Virgin Resin	Wood/Concrete
Film	**49.378**	**14.197**	**28.139**	**2.321**
Bottles	**35.542**	**0**	**0**	**0**
Cups	**9.595**	**95**	**0**	**0**
Mixed Plastics	**3.943**	**23.049**	**1.480**	**1.600**
Total	**98.458**	**37.341**	**29.619**	**3.921**
Grand total	**135.799**		**33.540**	

Source: DKR

Mechanical recycling of DSD/DKR waste, substitution of virgin resin vs wood/concrete (in t/y, 1996)

In 1996 merely two thirds - i.e. some 100,000 t approx. - substituted plastics as primary commodities, and up to now only this form of mechanical recycling has been examined.

- Energy recovery in a cement kiln.
- Energy recovery in a waste incineration plant fulfilling not only disposal tasks but also offering an optimised energy utilisation throughout the year. The waste incineration plant examined in the main study served merely as a reference scenario for a

examined in the main study served merely as a reference scenario for a comparison of recycling routes and was in the upper third of plants currently operated in Germany.

Meanwhile the following examinations have been conducted with the described results by the Fraunhofer Institute „Process Technology and Packaging", Freising:

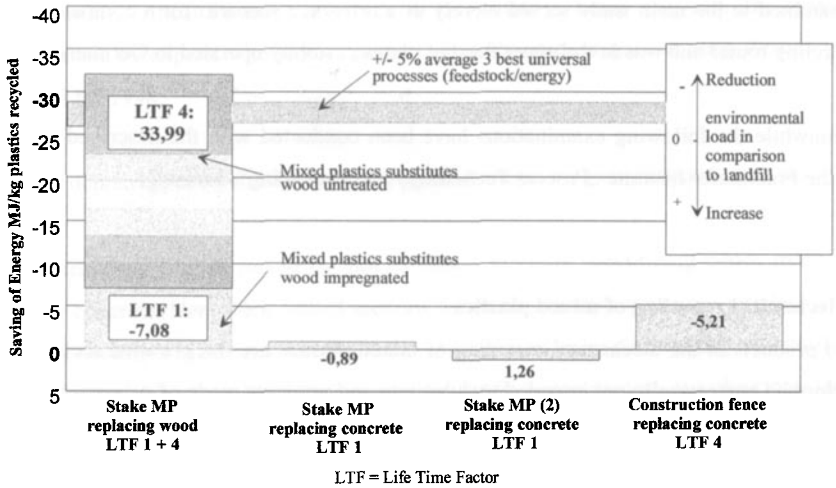
- **Mechanical recycling of mixed plastics**

End products in the mechanical recycling of mixed plastics are thick-walled sections or preformed parts usually not intended to substitute end products made of primary plastics but end products made of wood or concrete. The decisive criterion in the case of wood substitution is the life cycle ratio (LCR) of the compared products made of mixed plastics or wood, respectively. Only above a certain limit value (in the examined case LCR = > 3.3) - i.e. a clearly longer life cycle of the plastic product as compared with the wooden product - is the level of resource reduction in feedstock recycling/energy recovery reached.

The situation is similar where acidification and eutrophication are concerned. Advantages are found only with regard to waste minimisation.

In the case of concrete substitution, assessement criteria are the life cycle ratio as well as the weight ratio between concrete and plastic recyclate. However ecological savings found in the examined cases are invariably much lower than savings possible through feedstock recycling/energy recovery, so that here mechanical recycling is obviously unsuitable to reach ecological objectives.

Based on this study it is concluded that in the mechanical recycling of mixed plastics the ecological level of the universal processes in feedstock recycling/energy recovery is reached only in exceptional cases (LCR > 3.3).



Mechanical recycling of mixed plastics (MP) – (DSD-system)
Saving of energy consumption in comparison to landfill

Products of mechanical recycling substituting	Influence parameters	Ecological break even point mechanical vs feedstock / energy recovery
Plastic	Substitution factor	ca. 0,7 - 1,0
Wood	Life time ratio	ca. 3,3 [a]
Concrete	Weight ratio	ca. 7 - 28 [b]

a. at weight ratio 0,75
b. at life time ratio 4 - 1

Plastic waste from household packaging
Ecological comparison: mechanical vs feedstock / energy recovery

• Energy recovery in a cement kiln

Plastic waste can be used as substitute fuel for coal in a cement kiln. The incineration occurs at 2000°C and the heat is used completely for heating the kiln.

The life-cycle-analysis carried out shows a significantly better resource saving potential than feedstock recycling (29 – 33 MJ/kg vs 26 – 30 MJ/kg) correspondingly, the saving potential for eutrophication or for acidification has also improved.

The use of plastic fuel in a cement kiln represents an environmentally interesting alternative to feedstock recycling.

• Energy recovery in a waste recycling facility with an optimised, all-year energy utilisation concept

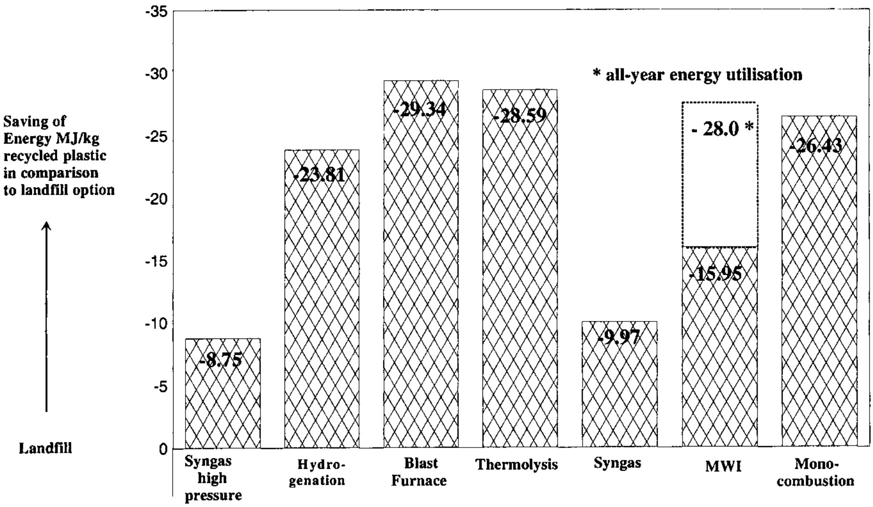
Waste incineration plants in Germany used to be planned and operated primarily as waste treatment plants. Main objectives were to ensure reliable disposal and a minimum of released emissions. The utilisation of generated energy was just a relevant secondary aspect, mainly because of the costs. At many locations there is no or only little demand for thermal energy so that process heat is made available only to cover own requirements. The rest of the generated quantities of steam is transformed into electricity, due to usually low pressure levels, with a relatively low efficiency. Co-generation concepts or the complete utilization of the generated steam as heating steam can be realised only in exceptional cases, i.e. where local conditions are particularly favourable. This situation is specific to Germany and differs strongly from conditions in various other European countries where the inclusion of waste incineration plants in energy supply structures has been given higher priority for some time. In an extra study two plants (Paris, Burgkirchen) were examined, because these plants implement optimised energy recovery concepts.

It is not possible to describe here all the details of the extra study, but the following points are worth mentioning: From aspects of environmental protection, energy recovery of plastic waste in such plants is, in principle, not less favourable than feedstock recycling but on condition that

- Waste heating and power plants with high total energy efficiency ratios are available;
- The recycling plant is well integrated in power and heat grids;

- Local consumers are supplied with heat throughout the year if possible, or the energy from own generation is used mainly as heat in the recycling plant;
- Mostly coal as primary fuel is substituted in the supply of energy.

If these conditions are met e.g. the savings potential for resources in energy recycling improves to the level reached in feedstock recycling.

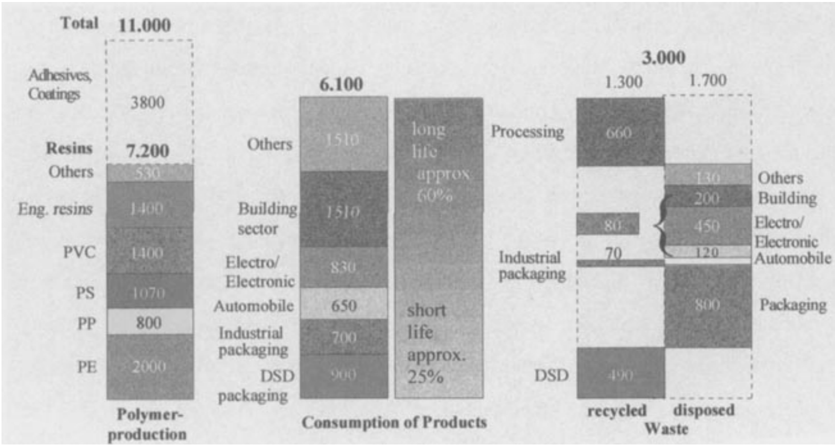


Ref: Study by German Institutes 1995

Feedstock and energy recycling in comparison to landfill – saving of energy

Summing up it is concluded that the mechanical recycling of mixed plastics makes little sense from ecological aspects, and in the described borderline cases energy recovery is on the same footing with feedstock recycling.

We have used these data to evaluate the total environmental savings by the amount of plastics recycled in 1995 in Germany. From the total production of 11 mio. t in 1995 we have to delete the amount for lacquers, adhesives, fibre raw material which are included in the official statistics.

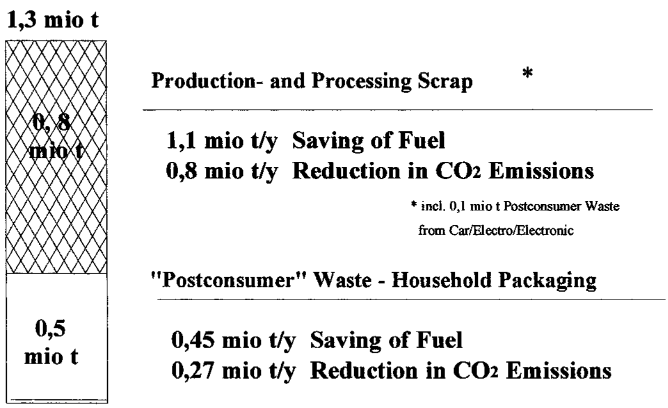


Production, use and waste of plastics in Germany 1995 (kt/y)

We end up with the consumption of finished plastic products of around 6.1 mio t out of which 3 mio. t turned to waste. Approximately 40% of the total is being recycled today already, certainly the majority being industrial scrap.

Using the environmental data collected we calculate that we save by recycling today

- 1 mio. t/y emissions
- 1.5 mio. t/y fuel

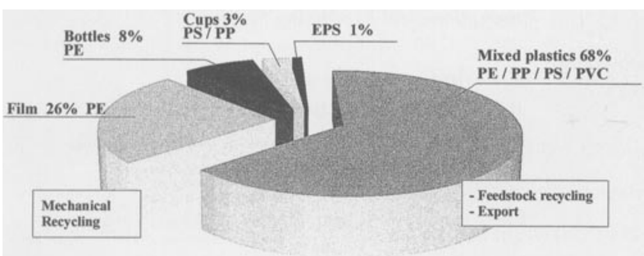


Recycling and recovery of plastic waste – ecological impact

The environmental savings of incinerating of the waste for disposal has been neglected so far as well as the demand for the primary production. Thus the total environmental impact of plastics products has not been evaluated yet. But, this at the same time would have to take into acocunt the environmental savings by using plastics in cars or by using plastics in insulation as well as in other applications. Thus the total impact of plastics is still open. Nevertheless, we recognize from the figure that the recycling of scrap which is economically profitable at the same times make the major savings contributions and that the recycling of the postconsumer waste from household which is rather costly as we have discussed make much smaller contributions. This raises the question of the economic impact of ecological savings. In other words, do the environmental savings justify the tremendous costs in the household area. We have made the following calculations:

Initially it must be realised that we are talking about various disposal scenarios for an annual consumption of roughly 800,000 tons of plastic packagings from private households. To produce such a quantity of plastics, just under 2 petroleum equivalents - i.e. 1.6 million tons/y - are needed. To allow a comparison: The entire demand for petroleum in Germany amounts to 110 million t/y so that we consider disposal scenarios for some 1.5% of the annual petroleum requirement. Against this background very little can be done wrong.

According to DSD, out of the total quantities placed on the market in 1996, 535,000 tons - i.e. 66% - were channelled into recycling operations.



	1994	1995	1996	1997
Plastic packaging collected	546.500 t	731.385 t		
Plastic packaging recycled	461.100 t	504.000 t	535.000 t	615.000 t *
- feedstock recycling	52.000 t	99.000 t	251.000 t	359.000 t
- export	256.000 t	233.000 t	102.000 t	53.000 t

Ref.: DKR Cologne

* thereof 34.000 t from previous year

Plastics packaging waste from yellow bag collections

As the next step, the following assumptions are made to determine maximum environmental effects and possible differences in those effects.

In case A it is alleged that all plastic goods are made from virgin material and plastic waste remains part of the household waste and is channelled - together with residual waste and in compliance with the German technical instruction on residential waste (TA Siedlungsabfall) - into thermal treatment. In this case the entire collected quantity (750,000 t) undergoes thermal treatment. Using the ecological savings of the study for each recycling route, this leads to resource savings in comparison to landfill of:

-300,000 t/y fuel oil.

At the same time the potential effect on global warming goes up by

+643,000 t/y in CO_2 equivalents[1]

In case B it is alleged that waste is collected separately but very little sorting is done, because in this case the entire quantity is channelled into feedstock recycling. The following savings potential is calculated from ecological mean values obtained in the 3 best processes available in mechanical recycling:

- Fuel oil -382,000 t/y, or
- Greenhouse potential -159,000 t/y in CO_2 equivalents

The scenario of an optimised energy recovery is almost fully congruent as far as resource savings are concerned (-360,000 kt/a of fuel oil). However the situation is more complex with regard to the potential effect on global warming and depends on individual framework conditions.

In case C it is alleged that the same quantity channelled into recycling is entirely (100%) utilised in the ecologically most favourable method available in mechanical recycling (conduit production), resulting in the following theoretical savings potential:

- Fuel oil -715,000 t/y, or
- Greenhouse potential -546,000 t/y in CO_2 equivalents

[1] Example: 750,000 t/y x –15.95 DM/kg energy savings : 40 MJ/kg (H_u fuel) = 300,000 t/y

Since the practical implementation of case C is impossible for numerous reasons, in case D a more realistic scenario is assumed with 40% mechanical recycling and 60% feedstock recycling. In mechanical recycling 2/3 of the amount is intended to substitute virgin resins, and roughly 1/3 is intended to substitute wood and concrete. For the sake of simplicity, the ecological effect of the latter is equalled with feedstock recycling - a rather positive view as previously described.

The following savings potential is calculated in this scenario:
If a degree of substitution of 1:1 is achieved for the primary commodity:
-470,000 t/y of fuel oil, or
-262,000 t/y in CO_2 equivalents.

If a degree of substitution of 0.7 is reached:
-413,000 t/y of fuel oil, or
-218,000 t/y in CO_2 equivalents

In scenario E it is alleged that - complying with the demand voiced by some politicians - the share of mechanical recycling is raised to 60%. The following savings potential is calculated based on assumptions analogous to scenario D:

If a degree of substitution of 1:1 is achieved for the primary commodity:
-514,300 t/y of fuel oil, or
-313,400 t/y in CO_2 equivalents.

If a degree of substitution of 0.7 is reached:
-428,700 t/y of fuel oil, or
-248,000 t/y in CO_2 equivalents.

	Saving Potential Resources, measured in t/y fuel oil	Saving Potential Greenhouse Effect, measured in t/y CO_2 Equivalents
Case A: Traditional Waste Management/ Waste in MWI	- 300.000	+ 643.000
Case B: 100% Feedstock Recycling	- 382.000	- 159.000
(Case C: 100% Mechanical Recycling) hypothetic, as beyond means	(- 715.000)	(- 546.000)
Case D: 40% Mechanical Recycling 60% Feedstock Recycling	- 413 - 470.000	- 218 - 262.000 *
Case E: 60% Mechanical Recycling 40% Feedstock Recycling	- 428 - 514.000	- 248 - 313.000 *

* according to efficiency of virgin resin substitution

Ecological comparison on different recycling scenarios for plastic waste in the household area (based on: 750.000 t waste collected – 535.000 t recycled)

The differences in the savings potential between case D and case E are +15,000 t/y of fuel oil in the lower borderline case and +44,000 t/y of fuel oil in the upper borderline case, i.e. differences are in the vague zone of these calculations.

The ongoing discussions about those differences during the present amendment to the German Packaging Ordinance have the character of religious wars. Looking at the real differences, especially in scenarios D and E, one may wonder whether politicians have identified the right priorities.

This question is even more justified when relating the values calculated here to the present total emissions in Germany.

	kg CO_2/kg	for 535.000 t/y recycled plastic packaging waste (mio. t CO_2 /y)
Scenario A: 100% Municipal waste incinerator	+ 0,858 *	+ 0,643 *
Scenario B: 100% Blast furnace	- 0,348 *	- 0,159 *
Scenario C: 100% best mechanical recycling (pipe processing)	- 1,032 *	- 0,546 *

* Deviation in comparison to Scenario Landfill
\+ = Increase / - = Decrease

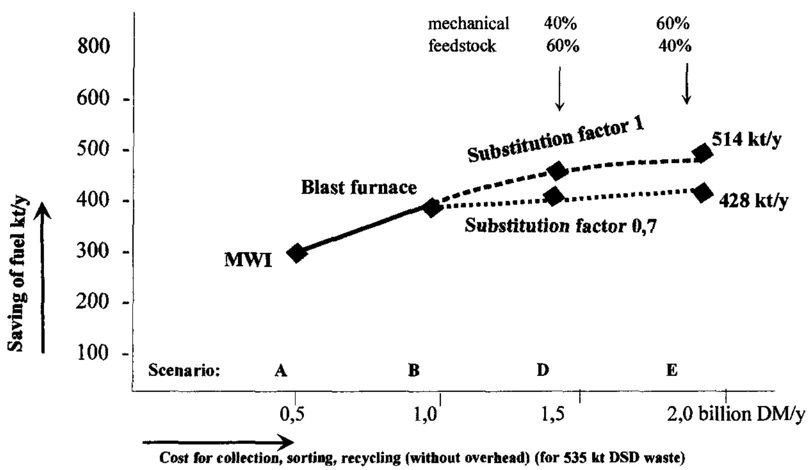
Comparison		
Energetical use of oil	104 mio. t/y	326,0
Total emissions Germany		888,0 *
CO_2-formation by respiration	80 mio. persons	20,0

* OECD-calculation (FAZ 25.06.97)

Plastic waste scenarios – influence on "global warming potential"

Economic consequences of plastics recycling

An evaluation of scenarios A to E with known average costs of collection, sorting, and recycling or disposal in results in the following picture:



Ecology vs economy for different strategies of recycling and recovery

Cost differences are large whilst added ecological benefits are small.

In case D total costs including systems overhead are in the region of DM 2 billion so that the search for favourably priced alternatives should begin soon. However it should be stressed that favourably priced alternatives must not reduce savings benefitting the environment, or reductions must be negligible.

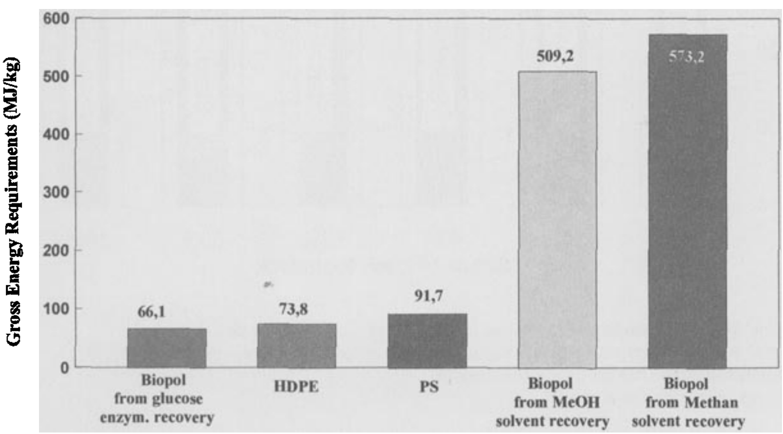
Analysing the costs of the Dual System it emerges that more than two thirds of the total costs fall to the share of logistics, i.e. collection and sorting. This situation results from the joint collection of several material flows so that we practically have a second waste collection system.

At present a public discussion starts. The logistics of DSD should be adapted to these environmental findings.

Biodegradable polymers in comparison

Let us return to the biodegradable polymers now for the rest of the paper.

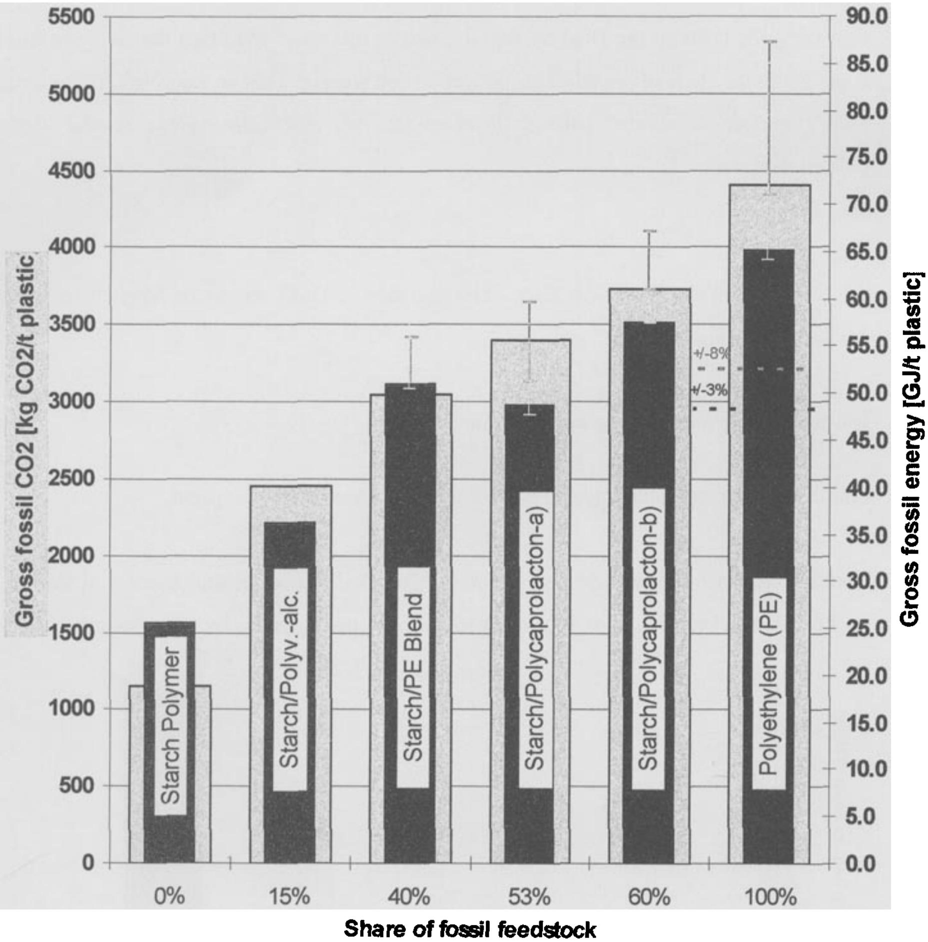
Comparable environmental data as shown for commodity plastics are scarce – at least to my knowledge. I am aware of an investigation on Biopol polymers by Fraunhofer Institute.



Ecological comparison of production of Biopol vs commodity resin

The main result being that the environmental overall effect strongly depends on the feed for the fermentation process.

A comparison of starch modified polymers with commodity plastics has recently been carried out by the Fraunhofer Institute Karlsruhe.



Notes:

- Gross fossil CO2: CO2 equivalents of captured carbon of fossil origin are included.
- Gross fossil energy: Energy equivalents of captured carbon of fossil origin are included.
- Energy for transportation has not been accounted for.
- Brocken lines: Incineration of w aste PE

Gross fossil energy and CO_2 for plastics with differing shares of fossil inputs

Apparently there is an environmental benefit for starch based polymers in comparison to polyethylene if all polymers are deposited. But this advantage becomes rather small if the heat content of polyethylene is recovered as it should be done today and in the future.

Summarizing this paper I would like to state:

- We have gathered a lot of knowledge on the ecological behaviour of commodity plastics.
- The concept of biodegradation considers one environmental aspect only, i.e. littering. It should be re-evaluated under the more general aspect of sustainability.
- Life cycle investigations on degradable polymers should be initiated .