Evaluation of system costs for the use of plastics with regard to disposal costs

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Abstract

In this paper we evaluate the real costs for the use of plastics regarding costs for disposal. These costs are until now not sufficiently reflected in the consumer prices. This causes massive competitive disadvantages for renewable raw materials, even though these are produced with significantly lower energy consumption and disposal costs. Plastics waste has no recycling potential and should be regarded as waste for disposal.

Keywords

Plastics, Recycling, Disposal, System costs, Antimony

1 Introduction

Plastics are increasingly present in our everyday world. People, who are concerned with waste in some way, will see these plastics again when they are no longer usable - as waste. Our motivation for this paper springs from some observations about plastics during our dealings with waste.

The company EcoEnergy has been operating the demonstration plant for the SCHU-BIO®-Process for wet mechanical separation of waste since 2005.

In the process biogenic, native organic matter is separated from the fossil organics, the plastics.

Chemical analysis of these fractions shows a definite decrease of pollution in the native organics fraction and increased pollution in the fractions containing plastics.

A second clue, indicating the pollution of plastics, appeared when we investigated possible RDF fuels, applicable for co-combustion until up to 25 % of the thermal output in a coal fired power plant. We established suitable input criteria for co-combustion, not only regarding plant emission but also quality of desulphogypsum and fly ash. In the end, only material blends with little or no plastics could meet the input criteria.

These findings lead us to investigate further and analyze the system costs for the use of plastics with regard to disposal costs.

2 Production of Plastics

Naphtha is produced from crude oil and is the raw material for production of plastics.

Until the Fifties nahptha was used directly as fuel. The development of higher compression for combustion engines lead to the need for more knock-proof fuel with higher octane number. Naphtha became a by-product from crude oil distillation.

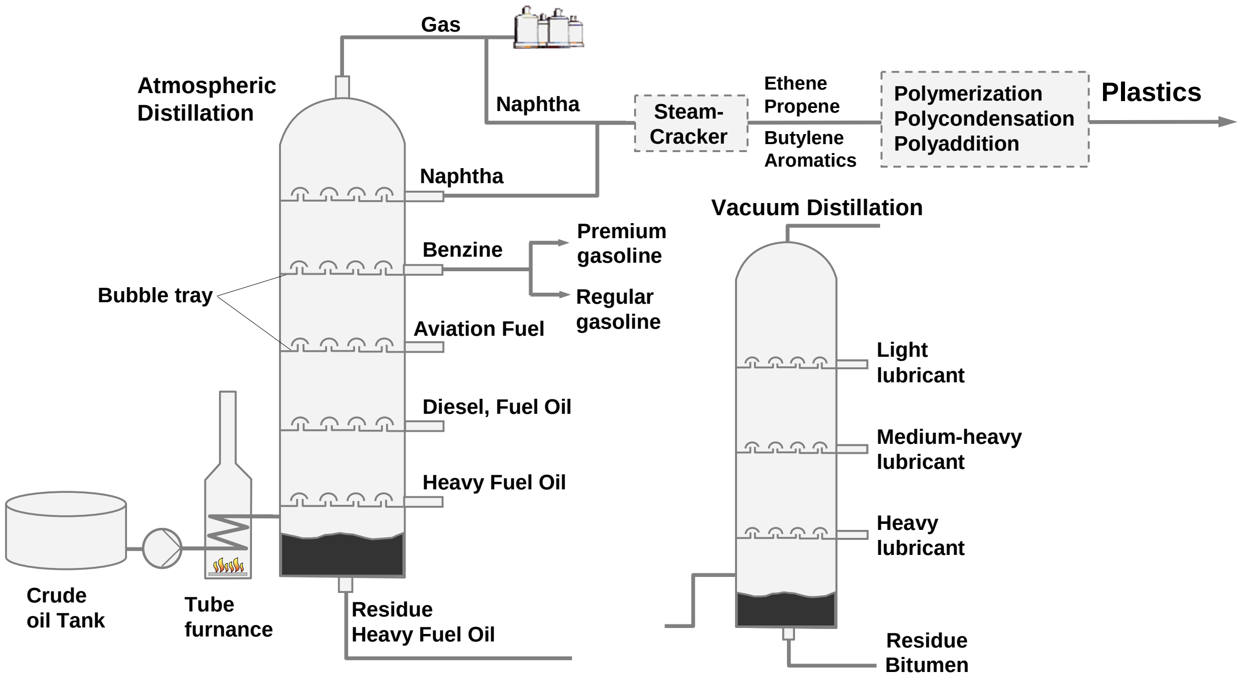

Figure 1: Distillation of crude oil and plastics production

Modern refineries produce about 9 % Naphtha from crude oil. When the production is aimed more at benzine and diesel instead of heavy fuel oil, naphtha yield is at about 12 %.

In Germany crude oil consumption is at about 120 million t per year and 20 million t plastics are produced. Additionally needed naphtha is imported via product pipeline from Rotterdam. The precursors for plastics, especially ethane, are produced from naphtha using a steamcracker (see figure 2).

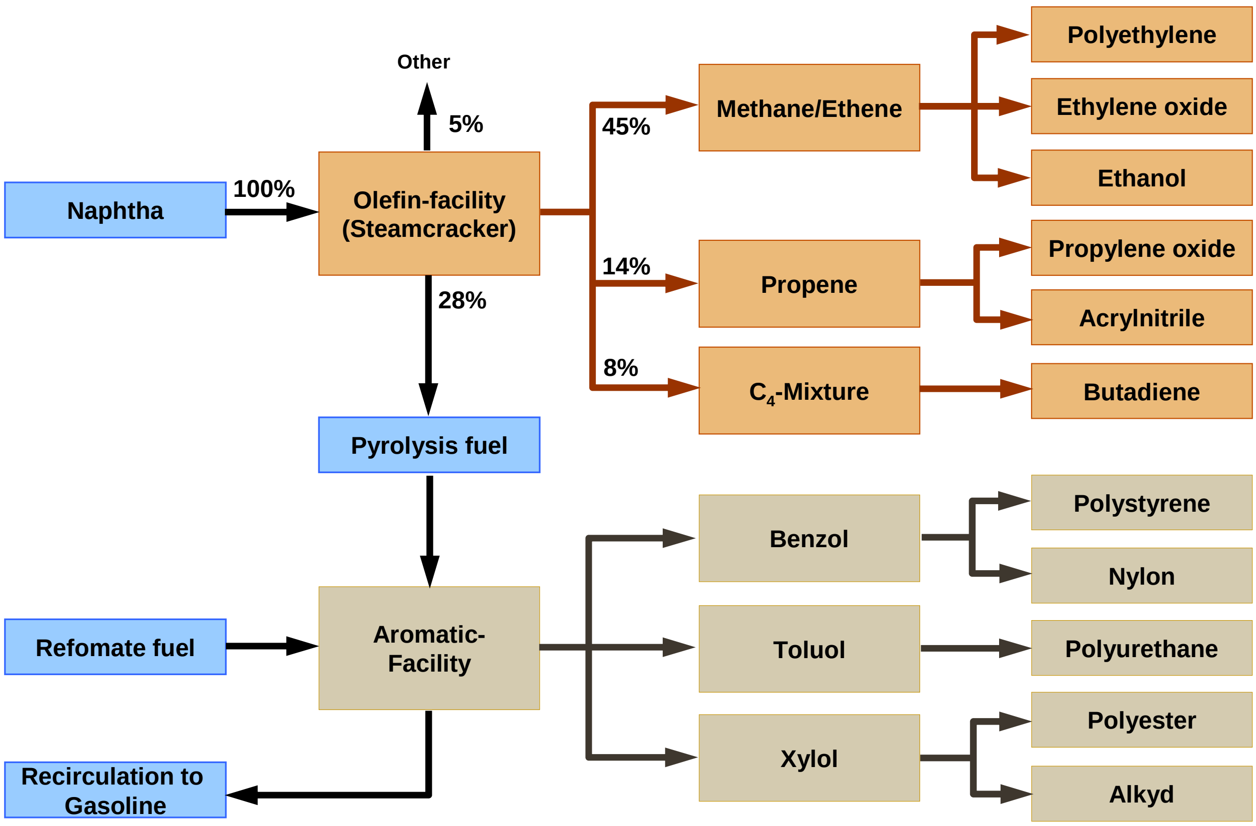

Figure 2: Products from Naphtha-steamcracker

Percentage distribution of the produced fractions depends on the crude oil properties. The precursors for plastics production are therefore not produced on demand from the consumer market for plastics but according to crude oil quality and to the technical conditions of the refinery.

Consequently refineries can only run when the produced naphtha is processed to plastics. Recently, in March 2009, the steamcracker of BASF in Ludwigshafen, Germany, was shut down because of the drop in demand for plastics.

Crude oil tanks in the USA are full, but the stored gasoline is decreasing because of the decreased demand for plastics. Demand for plastics dropped by 20 % to 70 %, depending on the sort. Logistics of the by-products are crucial for operating a refinery since these, like f. ex. naphtha, are generated in a substantial amount. For example, benzene storage capacity can not be increased easily, because it is a hazardous substance. If there is not enough demand for benzene, the refinery has to shut down. Therefore, production of polystyrene from benzene can not be stopped. To secure the demand for the produced plastics, the price can be adapted until they are cheaper than the corresponding natural material.

Another example is PVC, already much discussed in waste industry. PVC contains 57 % chlorine and is produced from chlorine gas and hydrochloric acid. Formerly there was a surplus of chlorine gas from sodium electrolysis in the chemical industry because sodium hydroxide was needed for production processes. PVC production consumed chlorine gas as well as naphtha and provided a way out of a disposal problem. Today, the situation is reversed because of the increased demand and acceptance of PVC.

3 Costs of raw plastics production

Many refineries are still burning off naphtha. For production of plastics precursors, naphtha is split via steamcracker into different short-chain hydrocarbons.

Naphtha is difficult to combust, because it is a very heterogeneous material. Gas turbines for naphtha need external combustion chambers and have to be equipped with explosion protection. In addition, they have a short lifetime and need to be replaced after 3 to 5 years. Naphtha is easily inflammable and transportation is a logistic challenge. Consequently, plastics production plants are often installed near a refinery.

Table 1: Up-to-date fuel costs in comparison with naphtha

Fuel	**Procurement Costs (customary units)**	**Energy content**	**Energy-based Procurement Costs**
Naphtha	332,00 €/t	43,50 MJ/kg	27,48 €/MWh
Crude Oil	49,60 US$/bbl	42,80 MJ/kg	22,26 €/MWh
Heavy Fuel Oil Power plant	167,00 €/t CE	41,80 MJ/kg	20,50 €/MWh
Light Fuel Oil Industry	303,00 €/t CE	41,80 MJ/kg	37,20 €/MWh
Natural Gas Industry	22,33 €/MWh	-	22,33 €/MWh
Natural Gas Power Plant	21,84 €/MWh	-	21,84 €/MWh
Anthracite	112,50 €/t	29,32 MJ/kg	13,81 €/MWh
Pulverized Lignite	112,00 €/t CE	21,00 MJ/kg	13,75 €/MWh
Waste Wood	-1,00 €/t	15,00 MJ/kg	-0,24 €/MWh
Wood, dry, finlely chopped	30,00 €/fm	15,00 MJ/kg	11,08 €/MWh
Straw, dry	60,00 €/t	17,00 MJ/kg	14,95 €/MWh
Grain, whole Plant	90,00 €/t	17,00 MJ/kg	22,42 €/MWh
Grain	120,00 €/t	17,00 MJ/kg	29,90 €/MWh
Vegetable Oil	500 €/m³	37,00 MJ/kg	52,88 €/MWh
Biogas from corn silage (Basis: Biogas recovery)	22,00 €/t	-	23,20 €/MWh

* CE = coal equivalent (anthracite)

The use of naphtha for plastics production is more profitable than using naphtha for power generation. During the last few years naphtha prices have been between 150 €/t and 400 €/t. Table 2 shows the costs for different fuels compared to naphtha.

The naphtha price is lower than benzene, diesel and light fuel. For processing naphtha to plastics precursors, the same amount of energy as the energy content of naphtha is needed again.

Table 2: Production energy as accumulated energy requirements (AEE) compared to procurement costs and disposal costs for plastics and other materials

Material	AEE MJ/kg	Procurement costs		Heating Value MJ/kg
		€/t	€/MWh AEE	
Naphtha	55	332	21,7	43,5
LDPE plastic film	91,8	800	31,4	46
HDPE plastic film	99,8	800	28,9	46
PP die casting	118,8	850	25,7	44
PVC plastic film	66,3	820	44,6	20
PS (high impact)	91,8	860	33,7	46
PET bottle	101,4	1060	37,6	46
PET plastic film	109,2	1020	33,6	46
Steel	35,8	247	24,8	0
Aluminium	193,3	1450	27,0	0
Clear glass	12,7	140	39,6	0
Corrugated card board, Carton	19,8	160	29,1	15
Paper (graphic etc.)	44,8	500	40,2	17
Chipped wood f. hard-boards	17,0	55	11,6	16
Wood trunk, green	14,0	150	38,6	10
Wood trunk, dried	19,0	220	41,7	15

About 20 million t plastics per year are produced in Germany. Assuming an average AEE of 90 MJ/kg, these 20 million tons would equate about 62 Gigawatt thermal output capacity, if not produced. Taking 50 % electrical efficiency as a basis, this equals a base load power plant with an electrical capacity of 30 Gigawatt. The installed capacity of all nuclear power plant in Germany is 21.5 Gigawatt, the total average yearly performance is 80 Gigawatt.

Combustion of all those plastics in a waste-to-energy plant with an electrical efficiency of 24 % would only equal a base load power plant with a thermal output of 29.5 Gigawatt and electrical capacity of 7 Gigawatt.

Consequently, only a quarter of the production energy (AEE) can be recovered from plastic waste as electrical power equivalent.

4 Replacement of renewable resources by plastics

Refining of crude oil yields the fractions naphtha, benzene, diesel/light fuel oil, heavy fuel oil and bitumen in a certain ratio. The sale of the products has to follow this ratio.

In the following example it is shown, how the political system is used to influence the fuel market to ensure demand.

In Germany, there has been a trend for private households and industry to replace oil with natural gas as heating fuel. The decreased demand for heating oil/diesel caused a surplus supply. With a lower tax on diesel the demand increased, until today Germany is one of the countries with the highest percentage of diesel sales.

Since the Fifties mineral oil tax or other fees on plastics have never been raised. This is also true for plastics, used for energy generation in coal fired power plants, cement kilns, for reduction in steelworks or for methanol production in the “Schwarze Pumpe” plant. Mineral oil tax is raised on all other mineral oil products for energy generation.

The material use of renewables, for example cotton, is not supported by the government in any way. Textile sellers like IKEA, OTTO, C&A and H&M have taken the initiative and support cotton farmers in Africa, whose survival on the market is threatened by cheap synthetic textiles, partly produced from PET-recycling material.

The German Renewable Energy Sources Act benefits energy recovery from wood as a renewable energy source. Consequently, the wood price is rising, also for material use of wood, which is not supported in any way. Therefore, plastics have a good chance to replace wood in many applications, for example thick-walled products like garden benches, fences or terrace paving.

Natural fibrous insulating material consumes only one tenth of the production energy of plastics based insulation, but even so, they cannot compete on the market with polyurethane or polystyrene materials. Insulation is state-aided in Germany without regard to the production energy of the insulation material.

Because of the high production energy and the high disposal costs, insulating with plastics should be watched critically, considering the ecological and economical impact. Politics are called to act and compensate this inequity.

5 Disposal of plastic waste

Today, plastic waste is mostly considered as recyclable material even though about 50 % of plastic waste is burned in waste incineration plants and recycling of mixed industrial waste is questionable too. The separate collection of plastic waste from households has also come under public criticism.

5.1 Energy Recovery of Plastic Waste

Pure polyethylene and polypropylene production waste with a low pollution level can be used for energy recovery in coal fired power plants and cement kilns.

In general however, plastics contain several critical pollutants such as chloride, bromide and especially heavy metals like mercury, lead, cadmium and antimony. Besides emission control, the product cement and the residues from the power plant should be taken into consideration.

5.1.1 Cadmium pollution

Cadmium is a waste product from tin smelting and has been used a pigment in plastics in general and especially as stabilizer in PVC. According to our evaluation of pollutant distribution in a coal firing power plant with co-combustion up to 25 % of thermal capacity, the limit value for cadmium is < 0.4 mg/kg fuel. Only then the required quality of the desulphogypsum can be maintained.

Biogenic waste material, not containing plastics, can meet this requirement. The limit value for cadmium of the “Bundesgütegemeinschaft Sekundärbrennstoffe e.V.”, an association of RDF producers, is 4 mg/kg RDF and is aimed at lower co-combustion rates. Waste containing plastics can barely keep this new, low limit.

According to the EU Directive 76/769/EWG, the limit value for plastics is 100 mg/kg. Germany imports more than half of the plastics for internal demand, even though all in all there is an excess of exports. The cadmium content of the imported plastics is nearly impossible to monitor. Some plastics contain up to 200 mg/kg cadmium.

5.1.2 Antimony pollution

The corrosion catalytic properties of antimony during combustion are still unknown and, until now, have also not been investigated. Antimony concentration in plastics is 1’000 to 2’000 times higher than in coal. In natural products antimony concentration is < 0.01 mg/kg. PET contains 300 mg/kg and Polyester 150 mg/kg due to the production process conditions. Flame retardants, also containing antimony, are used in electronic products in cars and in building. In the back cover of a TV set for example, 4’400 mg/kg antimony were measured.

Migration of toxic antimony from PET bottles into the liquid has been verified in 2006. Doctors are warning against wearing PET textiles, which are produced partly from PET recycling material, because of sweat releasing antimony and possibly causing skin irritation and neurodermatitis.

Replacement of antimony by titanium and phosphate in PET-production was tested in Japan. However, due to an unavoidable yellow tinge of the product, the new process could not take hold. Currently there are no alternatives to the use of antimony.

Antimony limit value in waste for combustion in cement kilns in Switzerland, was originally at 5 mg/kg and has since been adjusted to 300 mg/kg for „plastic waste“ and to 800 mg/kg especially for PET-waste. In Germany, the limit value for antimony in RDF has been raised to 50 mg/kg by the „Bundesgütegemeinschaft Sekundärbrennstoffe e.V.“. Until today there has been no long term study on the migration of antimony from concrete containing antimony polluted cement. So far, there exist no binding declarations by the plastics industry concerning a restricted use of antimony. Technically there is no alternative for antimony, neither as a stabilizer in PET and polyester nor as a synergist in bromide containing plastics.

5.1.3 Lead Pollution

Lead is used as stabilizer for the PVC production and as pigment. PVC in today’s waste contains about 2’000 mg/kg lead, the limit value for co-combustion is at 70 mg/kg.

According to a voluntary declaration of PVC producers (Vinyl 2010), the use of lead in PVC production shall be reduced from 2015 on.

5.1.4 Mercury pollution

Hydrochloric acid is used for PVC production. Two thirds of hydrochloric acid is produced with chlorine-alkali-electrolysis and the amalgam process. In this process, contamination of the hydrochloric acid with mercury is unavoidable. In consequence the mercury is also incorporated into the PVC. Around 1973, 58 mg mercury per kg chlorine was used in PVC production. PVC products have a lifetime of 2 to 50 years. The limit value for co-combustion is 0.6 mg/kg.

5.1.5 Chlorine pollution

The chlorine content of waste containing plastics stems to 60 % to 95 % from the plastics. Best known example is crude PVC with a chlorine content of 57 %. The final PVC products contain about 30 % to 80 % of crude PVC; resulting in 12 % to 30 % chlorine content in the PVC based plastics. Separation by automatic sorting is therefore difficult. The reject material is not recyclable as PVC and the operators of waste-to-energy plants do not accept this mixed PVC waste, containing > 10 % of chlorine. Chlorine is further used in many other plastics as flame retardant.

Energy recovery in suitably designed waste-to-energy plants with combined heat and power is possible for nearly all plastic waste. Nonetheless, thermal treatment in waste incineration plants is generally classified as disposal. Discrimination between energy recovery and disposal in waste incinerators is determined in Germany by the German Life-Cycle Resource Management Act (KrW-/AbfG).

Chlorine, together with chloride-forming heavy metals and alkaline, is responsible for high temperature corrosion in the boiler. Many waste-to-energy plants have a permit for burning material with maximum of only 1 % chlorine. Not all flue gas cleaning systems of currently operating waste incineration plants or waste-to-energy plants allow for chlorine content higher than 2.5 %. On top of the costs caused by boiler corrosion, f. ex. higher maintenance costs, less availability and shorter run time, chlorine causes also higher utilities consumption for chlorine binding and higher costs for disposal of residues.

The total extra costs because of the chlorine load are 400 to 700 €/t PVC, basic costs for waste incineration not included. These extra costs are included into price escalation clauses of waste-to-energy plants by the operators. It is evident, that the presence of PVC in a mixed waste, declared for energy recovery, is not any indication for the suitability of PVC for energy recovery.

5.2 Raw material recycling

Raw material recycling of plastics is irrelevant at present, since the coal-oil-plant in Bottrop, Germany, was closed in 1999; the gasification plant for methanol synthesis SVZ shut down in 2005 and the steelworks do not use plastic waste as reduction material since 2005. Antimony content is important for steel production because antimony causes grain boundary segregation and, even more so, surface segregation of steel and iron based alloys. This causes embrittlement and higher corrosion risk of the steel. Commercial steel contains about 10 mg/kg antimony. Due to the increasing use of low quality scrap metal from car recycling, electronics scrap metal and ferrous scrap metal from waste incineration slag, it is likely that the antimony content of steel will increase. We do not expect a “revival” of the use of plastic waste in the steel industry.

5.3 Material recycling

We also investigated material recycling of waste, containing plastics. The term “recycling” of plastics implies that the same product can be produced again from the recyclate granulates. Up to now, this is regrettably not the case.

Even in plastics of the same sort, plasticizers evaporate and are present in different concentrations, depending on the age of the material. Different additives are uses according to the different applications of the material. Post consumer waste is therefore not recyclable even if separated into uni-type fractions and is only usable for down cycling.

The term „bottle-to-bottle“ in PET- bottle recycling does only mean a 15 % addition of recycling PET to the raw material for production of new bottles. The highest recycling quality to date is reached by blending regranulates from production waste with new raw material. This application for high quality products however, is not possible from post consumer waste without an inappropriate sorting effort and by mixing more than 10 % into the product.

Material recycling of plastics usually means production of thick-walled products. These can not be recycled after use and have to be disposed of by thermal treatment. So the incineration of the original plastic material is delayed, but ecologically and economically it is still the better alternative compared to land filling.

However, there is not enough waste incineration capacity in Germany today for disposal of all plastics waste in any case. 15 million tons of plastics have been consumed in Germany in 2007. Standardized to average heating value for waste incineration, this equals a waste incineration capacity of 60 million t/a, if the plastic waste would be treated in waste incineration plants. The waste incineration plant capacity can not be increased at the same rate as the plastics production of the last few years and also take into account the average lifetime of the material.

5.4 Society Landfill

The term “society landfill” is implying the intermediate storage of polluted plastics in society in the form of thick-walled plastic recycling products, such as garden benches, fences or even bicycle stands, prior to their final disposal. The society landfill secures the plastic waste for a subsequent controlled disposal.

5.5 Thermal Disposal by Waste Incineration

The most accepted and best way for the disposal of plastics waste is waste incineration. Plastics are responsible for 50 % to 80 % of incineration costs even though their proportion in the waste is only 15 % to 40 %. Because of their high heating value they account for 50 % to 90 % of the thermal output of the waste incineration plant.

Costs depend mainly on the waste volume, determining logistics, bunker and feeding costs as well as on pollution of the waste and on the thermal output of the plant.

The mass throughput is only a minor factor for the costs of waste incineration. One ton industrial waste with a high plastics content and 16’000 kJ/kg heating value is displacing two tons household waste with 8’000 kJ/kg heating value. Consequently, the plant operator earns only half when processing this industrial waste.

Average costs for waste incineration have been about 150 €/t in Germany during the last 3 years relating to an average heating value of 10’000 kJ/kg. One ton of plastic waste with 40’000 kJ/kg heating value consequently displaces four tons of household waste. The theoretical costs for disposal of plastic waste are therefore about 600 €/t, in case it were possible, to operate a plant only with this plastic waste. With exception of the circulating fluidized bed combustion (CFB), no waste incineration plant in operation today can tolerate heating values of 16’000 kJ/kg in the long run.

5.6 Landfill

Plastic waste from car recycling and plastics in the MBT landfill fraction are still land filled legally in Germany. In other countries, with few exceptions, disposal of plastic waste on landfills is still the main disposal method.

5.7 Export for pseudo recycling

Officially, plastic waste goes mainly into material recycling in foreign countries. In 2008 the “Bundeskriminalamt” (Federal Criminal Police Office) has published a report about „Waste management cross-border crime in connection with the EU enlargement to the East“. Quotation: „On the European waste market there is a large dark field of illegal transport, especially of so-called pseudo recycling. The 2002 ecological report of the German Council of Environmental advisors states, that this is usual practice and calls this development a perversion of waste management. Compulsory use of the public disposal system for recycling was abolished and consequently the national and international waste transport increased…“

In our opinion plastic waste has to be regarded as hazardous waste. The danger to the environment is only perceivable in the long term. The point is not an alleged acute toxic effect but the extremely high persistence of plastics in the environment.

In 2004 it has been discovered, that several million tons of plastic waste are drifting in the Pacific Ocean between California and Hawaii. These plastic are slowly crushed mechanically and raise the plastic content of the plankton. This has been monitored. Degradation and therefore release of the toxic pollutants however, is estimated to take more than 500 years.

Air and water pollution can be remedied in a few years time. For example the air pollution in the “Ruhrgebiet”, an industrialized area in the west of Germany, could be quickly reduced by installation of filter units. In contrast the pollution of the environment by plastics can last over 1’000 years.

The most obvious problem with using oil is carbon dioxide emission. This problem applies to 90 % of the oil application an can – at least in theory – be solved in a time frame of fifty to hundred years by switching to renewable resources. The other 10 % are used for production of plastics. The consequences by irresponsible disposal of plastics are not reversible during the next millennium.

6 Conclusion

Plastic waste is not recyclable. The real system costs of plastics production are principally higher than the use of basic material like glass, paper, wood, natural fibres, stone, metal etc. for the same application.

The system costs of oil based plastic production will increase along with the increasing shortage of crude oil. Less plastics production is consequently leading to fewer possibilities for the material recycling of plastics. The pressure for pseudo recycling can only be reduced if the compulsory use of public disposal systems is re-established for waste containing plastics.

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