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Setting priorities in plastic waste management — lessons learned from material flow analysis in Austria and Poland[**)]

Summary — Due to the increasing amounts of plastic waste, the appropriate waste management strategy is of high importance. Based on the conclusions drawn from material flow analyses (MFA) on plastics in Austria (1994 and 2004) and in Poland (2004), priorities in plastic waste management are presented. They concern three major aspects: early recognition of potentially valuable as well as hazardous plastic waste stocks, priorities for collection and treatment of plastic wastes and design of future plastic materials in the view of multiple recycling and final disposal.
Key words: plastics, material flow analysis, plastics waste treatment, waste management.

OKREŚLENIE PRIORYTETÓW W ZAGOSPODAROWANIU ODPADÓW Z TWORZYW SZTUCZNYCH NA PODSTAWIE ANALIZY METODĄ BILANSU MASY PRZEPŁYWÓW MATERIAŁOWYCH W AUSTRII I POLSCE

Streszczenie — W artykule przedstawione zostały priorytety w tworzeniu systemu gospodarki odpadami tworzyw sztucznych. System ten powinien uwzględniać podstawowe cele gospodarki odpadami: ochronę człowieka i środowiska, ochronę zasobów oraz składowanie odpadów bez niekorzystnych konsekwencji dla przyszłych pokoleń. W Instytucie Jakości Wody, Zarządzania Zasobami i Zagospodarowania Odpadów na Politechnice Wiedeńskiej stosując metodę bilansu masy (ang. *material flow analysis*, MFA) wykonano dwie analizy przepływu tworzyw sztucznych w Austrii w latach 1994 i 2004, oraz w Polsce w roku 2004. Wyniki analiz zaprezentowane na diagramach obrazują wielkości przepływów tworzyw sztucznych z wyszczególnieniem przepływów odpadów poddawanych odpowiednio: recyklingowi, przekształcaniu termicznemu oraz składowaniu (rys. 1—3). Porównano wielkości strumieni odpadów odpowiednio w Austrii w wyżej wymienionych latach (tabela 1) oraz w Austrii i Polsce w roku 2004 (tabela 2). Ze względu na narastanie ilości długoterminowych produktów z tworzyw sztucznych w procesie konsumpcji, wzrasta znaczenie tzw. materiału/zapasu w użyciu (ang. *stock "in use"*). Zaprezentowano dynamikę rozwoju materiału/zapasu w użyciu, który stanowi źródło przyszłych odpadów (rys. 4). Podsumowując wyniki analizy zwrócono uwagę na potrzebę wczesnego rozpoznawania materiału/zapasu w użyciu tworzyw sztucznych w procesie konsumpcji, określenia priorytetów zbiórki i unieszkodliwiania odpadów z tworzyw sztucznych oraz planowania przyszłych produktów z uwzględnieniem późniejszego zagospodarowania odpadów.
Słowa kluczowe: tworzywa sztuczne, bilans przepływu masy, przetwarzanie odpadów z tworzyw sztucznych, gospodarka odpadami.

200 million tonnes of plastic materials were produced worldwide in the year 2004, 25 % of that in Western Europe [1]. Also in Poland polymer production develops dynamically in recent time [2]. Due to significantly increasing consumption, plastics management becomes not only a matter of interest for producers but also for policy makers in the field of waste management [3, 4]. Various concerns regarding appropriate plastics waste treatment exist; it is therefore important to clearly define the priorities for plastics waste management. They should be consistent with the main goals of waste management:

— protection of humans and the environment,

— resources' conservation,

— aftercare-free landfills and waste management (no export of waste problems in time).

The aim of this paper is to present the importance of priority setting in plastic waste management, based on the results that can be drawn from the two studies on plastic flows in Austria and Poland conducted at the Institute for Water Quality, Resources and Waste Ma-

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[**)] Paper presented at 5 th Central European Conference "Plastics Recycling and Recovery. Science — Industry, Wrocław (Poland), 18—20 October 2006.

nagement at the Vienna University of Technology [5, 6]. In particular, the conclusions concern three major aspects:

— early recognition of potentially valuable as well as hazardous plastics waste stocks,

— priorities for collection and treatment of plastics wastes,

— design of future plastic materials in the view of multiple recycling and final disposal.

MATERIAL FLOW ANALYSIS AS THE TOOL TO ANALYZE PLASTIC FLOWS AND STOCKS

To fulfil the goals of waste management, under often strict economic conditions, policy and decision makers must clearly set the priorities of the system. It is important to define the hierarchy of problems to be solved, and to propose the relevant measures which can be used.

Material flow analysis (MFA) is a tool making possible the identification and quantification of flows of goods and substances. Moreover, material stocks and their changes can be observed in time [7]. All this information is indispensable to design an effective plastics waste management system.

The significance of MFA as a tool aiding an early recognition of current waste and basis for future planning of plastics waste treatment system and policy is shown on the example of two studies. The first one, titled "Plastic flows and the possibilities of their management in Austria" [5] was conducted in 1997 by the Austrian Federal Environmental Agency and the Institute for Water Quality, Resources and Waste Management. It was aimed at identifying and quantifying of plastic flows in Austria in the year 1994 using the methodology of MFA. The results obtained in this study are presented in Figure 1. Recently, a project titled "Plastic flows in Austria and Poland. Challenges and opportunities" [6] was conducted at the same institute. In this study flows of polymeric goods were updated for Austria for the year 2004, and plastic flows in Poland were analyzed.

Using MFA, the annual amounts of plastics flows and stocks produced, consumed, collected and finally recycled, thermally treated or disposed at landfills in Austria in 1994 and 2004, as well as in Poland in 2004 were analysed. The analyses were based on data taken from the national [8—12] and international [13] statistics, information from Ministries of Environment, reports of companies producing and converting plastics, and recyclers. Moreover, due to scarcity of the detailed data, the assumptions concerning structure of consumption in time and life spans of plastic goods were made. Therefore, the result shown in Figures 2 and 3, should be treated as approximate and presenting the general situation in

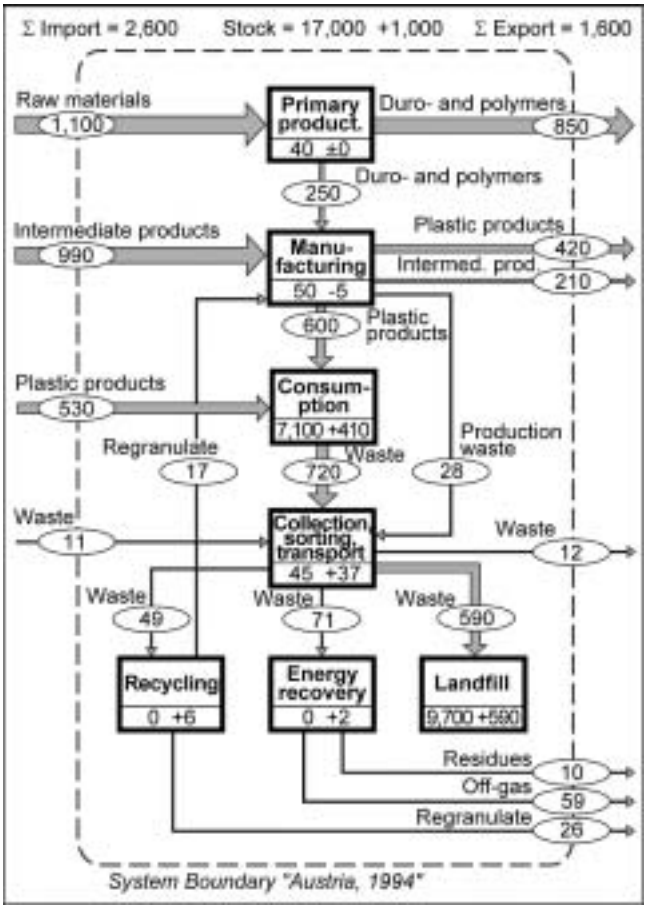

Fig. 1. Plastics flows and stocks in Austria in 1994 (units: flow — 10^3 · t/year, stock — 10^3 · t) [5]

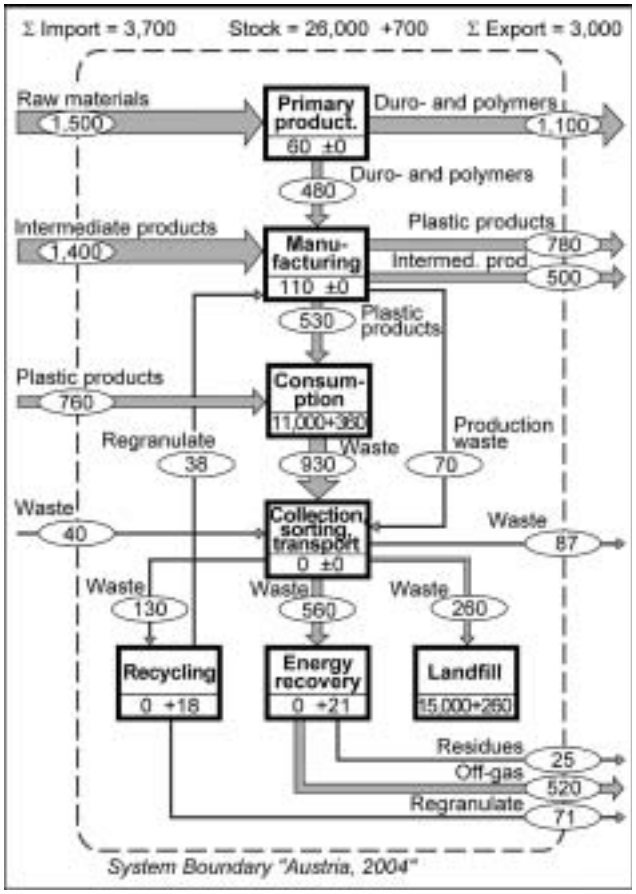

Fig. 2. Plastics flows and stocks in Austria in 2004 (units: flow — 10^3 · t/year, stock — 10^3 · t) [6]

plastic flows management in both countries. However, they are exact sufficient to fulfil the goals of this paper.

In 2004 the average Austrian consumed around 160 kg of total 1.3 million tonnes, while in Poland these numbers were 95 kg and 3.7 million tonnes respectively [6]. In comparison, in 1994 one citizen of Austria consumed around 140 kg of a total 1.1 million tonnes of plastic goods [5], so the consumption within this period increased by 15 %. In Poland this increase since nineties is even higher (see Figure 3).

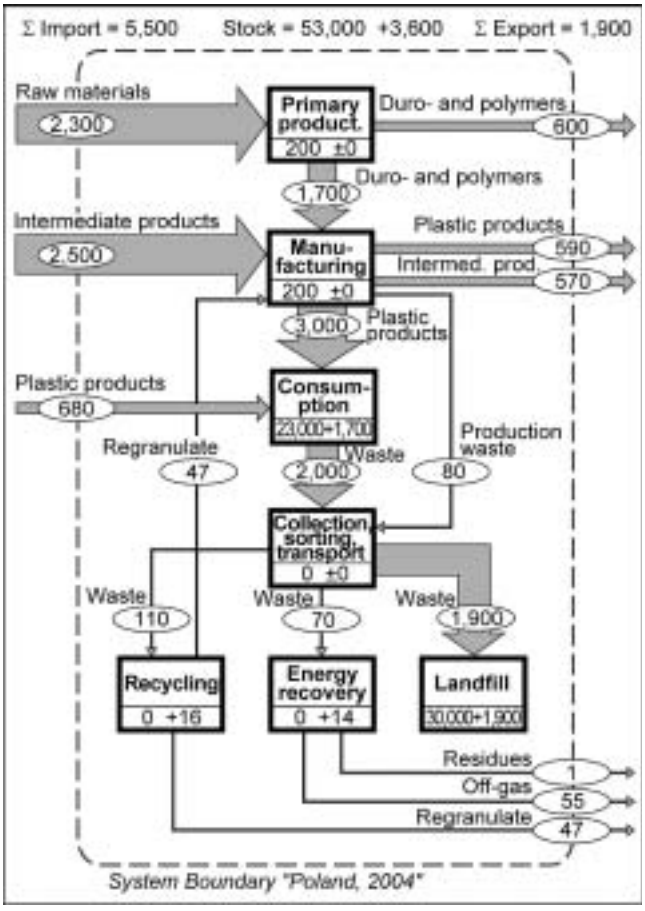

Fig. 3. Plastics flows and stocks in Poland in 2004 (units: flow — 10^3 · t/year, stock — 10^3 · t) [6]

Because of the diversified features of plastics, they are appropriate for short- and long-term applications. The "short-lived" products, consisting mainly of packaging or *e.g.* some medical equipment, become waste in very limited time, while "long-lived" durable goods, like constructional materials or household equipment, accumulate in the anthroposphere creating so called stock "in use".

The results of the above mentioned studies show that this stock in Austria in 1994 was 7.1 million tonnes [5], while ten years later it reached 11 million tonnes. The stock of plastic goods in Poland is estimated to be around 23 million tonnes. This is a significant potential for future waste and resource management. The annual increase of the stock is approximately 9 % in Poland and between 3—4 % in Austria [6]. This shows that the growth of the stock "in use" in Poland is fast; therefore, care should be taken in the future planning of plastics waste management.

NEED FOR EARLY RECOGNITION

The relevant plastics waste treatment system should be consistent with the three main goals of waste management mentioned in the introduction. In order to set the priorities for plastics waste management the following issues should be taken into account:

— Large stocks of plastics build up in comparatively short time. The example of the development of the Austrian plastic stock "in use" within the period 1994—2004 shows that in 10 years this stock increased by nearly 60 % [6]. Dynamics of the stock "in use" development on the example of Austria is shown in Figure 4. Within continued growth of plastics consumption and plastics waste production the stock "in use" is increasing drastically.

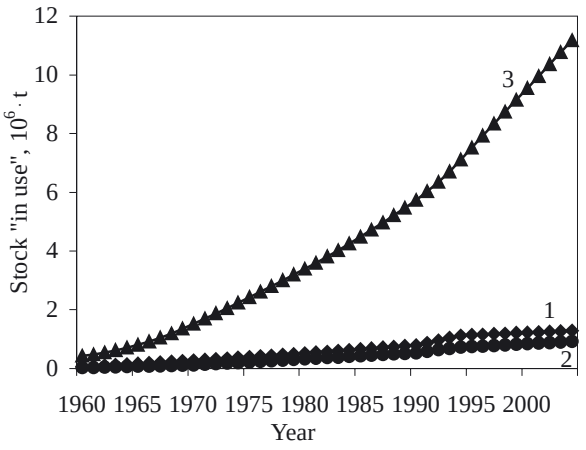

Fig. 4. Stock "in use" as future waste potential [6]: 1 — consumption of plastics, 2 — plastics waste generation, 3 — stock of plastics "in use"

— Plastic goods, especially those of long-term applications, contain additives, used to improve the features of products and enhance their resistance. Some of them contain hazardous substances, *i.e.* heavy metals like zinc or lead, or toxic organics compounds. This influences the quality of the plastics stock and limits the possibilities of future plastics waste treatment.

— For goods with long residence times, many years will pass until they reach the waste management stage. So even if the use of some substances, *e.g.* cadmium, is already banned, it does not mean that it is quickly eliminated from the cycle. Even decades after the goods containing cadmium were produced it will be found in the waste stream, *e.g.* in constructional materials.

LANDFILLS AS SINKS FOR PLASTIC GOODS

Growing consumption of plastics results in increased waste generation, which in 2004 amounted to nearly 120 kg *per capita* in Austria and 55 kg *per capita* in Poland. It means that nearly 1 million tonnes and 2 million tonnes of plastic wastes were produced in 2004 in these two countries, respectively.

The greatest flow of plastics waste in Poland, around 1.9 million tonnes, is disposed directly in landfills. The total amount of plastics waste that has accumulated in Polish landfills until 2004 is around 30 million tonnes. This number increases rapidly, because about 90 % of plastics waste is still landfilled [6]. The current system has some drawbacks with respect to the goals of waste management. Significant amounts of high caloric value plastics waste are simply landfilled, which neither satisfies the needs of environmental protection, nor resources conservation (energy, space, materials). Thousands of tonnes of hazardous additives in plastics are landfilled without the possibility to control long term effects. Thus, diverting of plastics waste from landfills is an important priority in plastics waste management in Poland.

LEGISLATION AND PLASTICS WASTE MANAGEMENT

Plastics waste management in Austria has improved in the last years. In 1994, 83 % of all plastics waste was directly landfilled [5]. During the next 10 years, the quantity of untreated plastics waste landfilled decreased by more than 50 %. However, the amount of plastics wastes accumulated at Austrian landfills totalled nearly 10 million tonnes of plastics until 2004 [6]. The comparison of plastics flows and stocks in Austria in 1994 and 2004 is shown in Table 1.

T a b l e 1. Quantitative comparison of plastics waste management in Austria in 1994 and 2004

	1994		2004	
	in 10^3 t	% of waste	in 10^3 t	% of waste
Plastics waste production	710	100	950	100
Recycling	50	7	130	14
Energy recovery	70	10	560	60
Landfilling	590	83	260	26
Stock Landfill	9700	—	15 500	—

This significant improvement was certainly stimulated by introducing waste management legislation. The Austrian Landfill Ordinance implemented in 2004 prohibits direct landfilling of waste with organic carbon content higher than 5 % [14]. It promoted thermal treatment of waste: at present 60 % of plastics wastes are incinerated and used for energy recovery. In 1994, only about 10 % of plastics wastes were incinerated [5, 6] (see Table 1).

Even before the European Commission introduced the Directive on Packaging and Packaging Waste (94/62/EC) [15] the Austrian ARA (Alstoff Recycling Austria AG) System was created in 1993, and was responsible for the collection and recovery of packaging waste. Due to its development as well as the contributions of a few other smaller companies, the amount of plastics wastes recycled increased from 7 % in 1994 to nearly 14 % in 2005 (see Table 1).

Poland joined the European Union in 2004, and therefore the legal regulations concerning waste management must be adjusted to those of the EU ones. However, the Packaging and Packaging Waste Directive refers only to a limited part of plastics wastes. In Poland at present 90 % of plastics waste is landfilled, while only 4 % is thermally treated and 6 % recycled [6]. Data concerning plastics waste management in these both countries are summarized in Table 2.

T a b l e 2. Quantitative comparison of plastics waste management in Austria and Poland in 2004

	Austria		Poland	
	in kg/capita	% of waste	in kg/capita	% of waste
Plastics waste production	120	100	55	100
Recycling	16	14	3	6
Energy recovery	70	60	2	4
Landfilling	30	26	50	90
Stock Landfill	1900	—	790	—

Further reaching regulations are required to support the process of diverting plastics wastes from Polish landfills. Besides legislation, there is a strong need for appropriate technologies and treatment plants. The example of Austria shows that implementing relevant legal regulations, like the Austrian Landfill Ordinance, is effective in improving waste management systems towards set goals.

CLEANING THE CYCLES

Another objective of plastics waste management is "cleaning the cycles" from undesired hazardous substances. Heavy metals or other toxic substances contained in polymeric materials are of concern related to plastic waste. To prevent risks for humans and the environment these substances must be taken out of the cycle and disposed of in safe sinks. Prevention of their uncontrolled dissipation in the products from recycling may be achieved by collecting and processing only the "clean", mainly short-lived use waste fraction. Mixed and dirty, mainly long-lived plastics waste, containing high

amounts of hazardous substances, should be rather treated thermally in plants equipped with appropriate emission control devices. This can effectively eliminate the hazard of inappropriate disposal of substances like cadmium.

FUTURE DESIGN

As hazardous substances influence the quality of goods and limit the possibilities of reuse of plastic materials, finding of environmentally friendly substitutes for the problematic additives could solve the problem of "cleaning the cycles" in the long term.

Moreover, appropriate design of goods, taking into consideration all life cycle phases including dismantling and waste treatment of the products, could also facilitate future recycling and recovery and enhance such possibilities. Interdisciplinary cooperation of specialists from different disciplines, among them experts from material sciences, process design, construction engineering as well as waste management is therefore necessary.

One of the problems is the lack of an economic link between producers/suppliers and recyclers of "long--livied" goods. It is difficult to establish such a link, due to several reasons such as: the owners of the goods can change, future technologies of waste management are not known yet, transaction costs are known but the costs possible to be saved in the future are unknown.

CONCLUSIONS

For decisions regarding plastics waste policy and management, today's consumption patterns and plastics stock changes must be known in order to assess future waste amounts and compositions. MFA focusing on consumption, stocks and wastes is well suited for this task, serving as a base for early recognition of resource potentials and hazardous wastes, and for priority setting. MFA is relatively fast and allows characterizing the total system (from production to waste management) contrary to direct waste analysis, which is time consuming, limited to chosen samples, and does not make possible to observe the stocks' changes.

It appears to be effective and most consistent with the aims of waste management to collect and recycle clean plastics wastes, mainly from short-term plastics products, and to thermally treat highly stabilized mixed wastes from long-term plastics products from constructions, automotive goods, etc.

For future plastics production and plastics waste management, three actions are crucial:

— design for recycling,

— logistic systems and technologies to establish "clean" plastics waste cycles with safe final sinks for hazardous substances,

— environmentally sound treatment technologies such as energy recovery with sophisticated air pollution control for the large mass of currently existing hazardous plastic additives.

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