

## RECOVERY AND RECYCLING OF POST-CONSUMER WASTE MATERIALS

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## Summary

Recycling of post-consumer waste materials is gaining increased interest due to public awareness, legislative promotion and imposition, economic benefits and appropriate technologies being available. The present paper does not deal with municipal solid waste as such, but only with the recyclable constituents.

The paper does not aim at presenting recycling process details, but focuses on the major recyclables with their reuse potential, recycling technologies used, problems and solutions. These target components include paper, aluminum cans, glass beverage bottles, scrap metal and steel cans, scrap tires, batteries and household hazardous waste.

The assessment of the waste availability, the existing and currently developed recovery and recycling technologies, and the economically rewarding markets while recycling, stress the technical, economic and environmental importance of this waste management sector.

The activities associated with the recovery and recycling of post-consumer wastes require a strong chemical engineering input at all phases of the treatment, from input quality control, to the selection of the most appropriate technology and the delivery of the recyclables as readily re-usable feedstock.

## 1. Introduction

Recycling, curbside, segregated collection, sustainability, materials recovery facilities, landfill bans and tipping fees, municipal solid waste, refuse-derived fuels, waste-to-energy, and other words or descriptions have become part of our daily vocabulary. In the era of growing awareness of sustainable development, it appears no longer viable or acceptable to deal with municipal solid waste MSW as an unfortunate flow of materials to be disposed of by land filling or incineration. MSW contains a multitude of products that can be recycled: a new solid waste management strategy has hence emerged,

environmentally more desirable and part of the sustainability objectives. MSW indeed contains a variety of products, present at varying weight percentages depending on e.g. source, location and public awareness in waste segregation.

An illustration of such average composition, albeit per group of the main constituents only, is given in Figure 1. Clearly, there is potential for feedstock recycling.

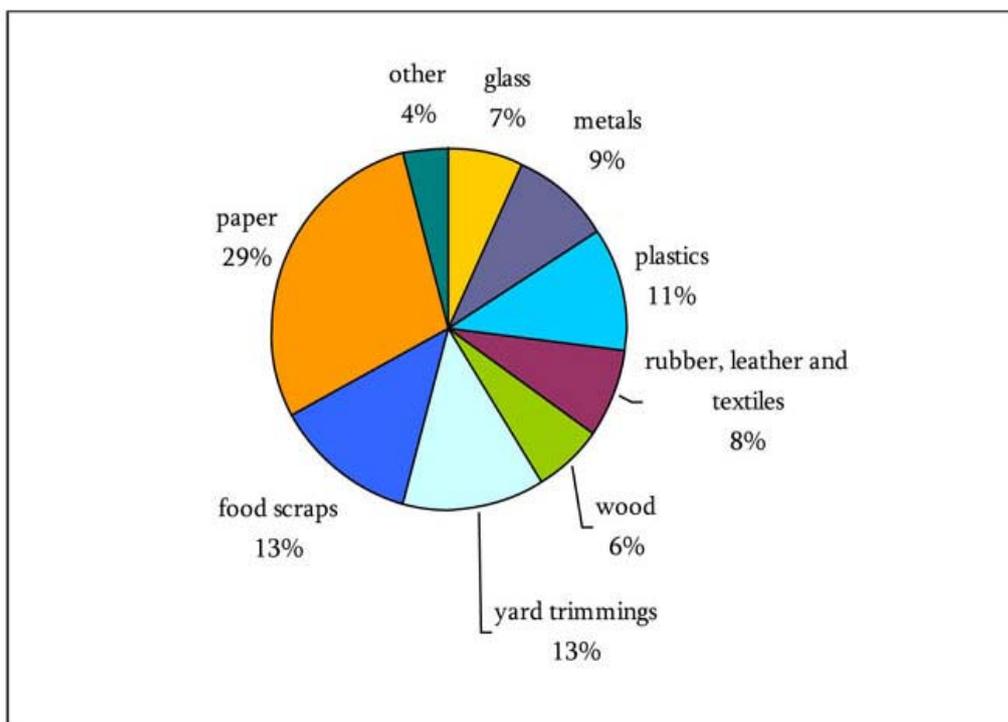


Figure 1. Average composition of municipal solid waste MSW

The present section of the Encyclopedia will not deal with MSW as such. It will concentrate on major recyclables including paper, aluminum cans, glass beverage bottles, plastics, scrap metal and steel cans, end-of-life tires, batteries and household hazardous waste. Minor components such as wood, leather and textiles are not dealt with. Food scraps and clean yard waste are now commonly and successfully recycled through composting or anaerobic digestion. The methodologies and technologies used in the treatment of this “green” waste are not covered by the text, since involving a totally different approach and dedicated plants.

The chapter does not aim at presenting recycling process details, but rather to focus on the major recyclables with their reuse potential, recycling technologies used, problems and solutions. These “case-studies” will be carried out by some general views about the recycling sector, the related legislation, the targets, priorities and markets.

## 2. Recycling: A Growing Field of Sustainable Development

Recycling is the solid waste management strategy which is clearly the environmentally preferred method of solid waste management. The general public’s perception of what recycling is, remains often limited to those visible elements including curbside

programs, recycling centres, segregated waste collection, etc., and a vague understanding that this is good for the environment because these materials do not go to a landfill or incinerator. This view also usually encompasses a demand to recycle a greater variety of materials than is practically or economically feasible at this time and needs a clear understanding about what can and cannot be recycled.

The legislation must promote and impose recycling of those materials in the waste stream that are selectively easy to separate and for which known and relatively stable markets exist. In addition, these definitions ignore previously established industrial recycling efforts based on purely economic needs of avoided cost of disposal and intrinsic value of industrial raw material-derived waste.

Recycling occurs for social, economic and legal reasons. The social aspect relates to protecting the environment and conserving resources. The economic aspect is due to avoiding cost of environmentally acceptable disposal of waste and the commercial value of recyclables. Finally, in response to both public demand and a growing lack of alternative waste disposal methods, governments impose recycling and include a variety of economic and civil penalties and incentives in order to encourage recycling.

While recycling is a must, the market for those materials has often been ignored or misunderstood with barriers encountered through both competition with existing products manufactured from virgin feedstock, and the sensitivity to the relationship between supply and demand for materials. The effect on the economy and a better view on the integration of recyclables within the current product markets must certainly be given additional consideration in the future.

### **3. Legislative Evaluation**

Over the past decade, numerous new legislation concerning solid waste reduction, recycling and recovery has been issued. Within the EU, Global Framework Europe plays an increasingly decisive role in the development of the legislation of European countries. National and regional initiatives have to fit into these European directives. The key European initiatives related to sustainable production and consumption are listed in Table 1.

| Year      | Topic   |
|-----------|---|
| 2000      | Lisbon Strategy of Economic and Social Renewal  |
| 2000-2005 | European Commission's Social Policy Agenda  |
| 2001      | The Community Guidelines on State Aid for Environmental Protection                            |
| 2001      | Commission Interpretative Communication on Environmental Considerations in Public Procurement |
| 2002-2006 | 6 <sup>th</sup> EU Framework Program for Research and Technological Development               |
| 2002      | 6 <sup>th</sup> Community Environmental Action Program  |
| 2002-2006 | Commission Communication on Corporate Social Responsibility                                   |
| 2003      | EU Consumer Policy Strategy   |
| 2004      | Integrated Product Policy IPP   |
| 2004      | Communication on Member State's Use of Market-based Instruments in Environmental Policy       |
| 2005      | EU Environment Technology Action Plan   |
| 2006      | Thematic Strategy on Waste  |
| 2006      | REACH   |
| 2006      | Sustainable Development Strategy  |
| 2006      | Commission Interpretative Communication on Social Considerations in Public Procurement        |
| 2006      | Directive 2006/12/EC on Waste (former Waste Framework Directive 75/442/EC)                    |

Table 1. Key European initiatives for sustainable production and consumption

The thematic strategy "Taking sustainable use of resources forward - A Thematic Strategy on the prevention and recycling of waste" determines the long-term goal for the EU "to become a recycling society that seeks to avoid waste and uses waste as a resource". As resources that are introduced into the market sooner or later totally or partly turn into waste, and all productive activities generate a certain form of waste, measures must be taken in order to reintroduce that waste into the economic cycle. Directive 2006/12/EC of 5 April 2006 on Waste (the former waste Framework Directive 75/442/EC) sets out the course for the European waste legislation, but is currently under review to introduce concepts of by-product and the end-of-waste status.

The new European regulation on chemicals REACH contains provisions concerning chemical substances as such, in preparations and objects. As waste materials are excluded, in principle there is no overlap. The following question however arises: when is waste no longer waste? In other words, when does the waste legislation apply, and when does REACH? The discussion on REACH is therefore directly linked to the conversion point of waste to product.

The principles of the Integrated Product Policy (IPP) are defined in a Communication of the European Commission and the Greenbook on Integrated Product Policy. These principles and instruments will ensure producers to create new product generations that are "greener" than their predecessors. To boost the production and purchase of "green"

products, the European Ecolabel has been introduced in 1992, to encourage both sustainable production and sustainable consumption. Products or services carrying the European Ecolabel have a reduced environmental impact during their life span, but are otherwise of a similar quality to equivalent products. The governments are important actors in the sale of these products. The EU tries to encourage Green Public Procurement among its own institutions and government bodies and among the authorities of the different Member States. In March 2004 the Council and Parliament approved two new directives on ‘public procurement’. These contain provisions regarding the integration of environmental factors into public tenders, as explained in the handbook “Buying Green ! A handbook on environmental public procurement”.

The situation in the USA is more complex, since federal laws and state/district laws are put into place, whereas the Environmental Protection Agency EPA also plays an important role in developing appropriate solid waste management strategies.

One of the EPA’s publications, “The solid waste dilemma: an agenda for action”, addresses the EPA’s goal of managing 25% of the US’s municipal solid waste through source reduction and recycling. While the 25% goal is not a federal law, the EPA provides recommendations to reach that goal and has published numerous reports regarding waste reduction and recycling.

In regulations proposed under the federal Clean Air Act, the EPA proposed that waste-to-energy incinerators be obliged to reduce the amount of garbage they burn by 25% through recycling and composting. The EPA sees this plan as a way to cut toxic substance emissions, reduce the amount of land filled ash, and promote its goal of 25% national waste reduction.

The national waste reduction and recycling legislation is on the move as a result of organized opposition to land disposal of solid waste and general public awareness of the need to reduce the amounts of wastes in general. The basis for the legislation was in many cases the lack of available landfill capacity, the not-in-my-backyard (NIMBY) syndrome, the escalating expense of waste disposal, and the environmental consequences of disposal. Most states have already issued necessary laws, whereas other states have replicated portions of laws from other states that have developed viable solutions. Solutions proposed include recycling, composting, and waste reduction strategies.

The federal government will moreover need to provide the legislation for waste reduction to some rural states that have not yet developed the needed waste reduction legislation.

The detailed treatment of these various legislative initiatives at federal or state level would lead us too far, and readers are referred to some relevant references.

#### **4. Recycling: Targets, Priorities, Quality Control and Marketing**

##### **4.1. Targets and Priorities**

The initial success of the recycling program will depend on how it is integrated in the

existing waste management with land filling or incineration as today’s common final disposal methods. The ultimate success will depend on the public participation, where some citizens will genuinely want to help the environment, whereas most citizens will only participate as a result of legal or economic incentives.

Legislation is certainly a key-factor, with bans on the disposal of e.g. tires, batteries, yard waste, household hazardous waste etc. The recycling venture will therefore need short- and long-term targets to guide its implementation and assess its progress and effectiveness subsequently and continuously.

Short-term targets focus on planning and orientation to encompass all actors (community, processing plant, marketing of recyclables). Long-term targets will then consider program expansion, additional marketing efforts, legislation and effectiveness of the program. Typical short- and long-term targets are presented in Table 2.

| <b>Short-term targets</b>   | <b>Long-term targets</b>   |
|---|--|
| <ul style="list-style-type: none"> <li>• Prepare a complete recovery and recycling plan</li> <li>• Determine priority recyclables to be collected</li> <li>• Assess and secure markets for recyclables</li> <li>• Establish appropriate processing plants and capacity</li> <li>• Promote recovery/recycling targets with the public (education, promotion)</li> <li>• Implement curbside, drop-off, segregated waste collection</li> <li>• Train and motivate recycling staff</li> <li>• Keep clear records of achievements</li> <li>• Live up to mandatory legislation</li> </ul> | <ul style="list-style-type: none"> <li>• Meet targets and implement methods of improvement</li> <li>• Explore recovery of secondary recyclables</li> <li>• Identify additional markets and negotiate long-term contracts</li> <li>• Explore methods to reduce costs, expand plants</li> <li>• Continuously ensure public awareness and discipline</li> <li>• Improve collection systems</li> <li>• Assess program effectiveness</li> <li>• Continuously evaluate achievement records</li> <li>• Stimulate new legislation, if necessary</li> </ul> |

Table 2. Typical short- and long-term targets

Over the past years, some authorities (e.g. Continental Europe) are imposing a strictly segregated collection system and apply weight-based waste disposal fees for residual waste products, while making the collection of segregated recyclables (glass, paper, metal...) free of charge. Under these pay-per-weight systems, citizens can be expected to try reducing the quantities of residual garbage, while at the same time participating in the recycling initiative at little or no charge.

#### 4.2. Quality Control is Essential in Recycling

The success of materials recycling depends upon (i) its ability to consistently turn waste products into high quality and marketable end products; (ii) ensuring a stable market for

the end products; and (iii) produce in a cost-effective manner. Quality control measures are hence essential at all stages of the process from source segregation, professional collection and delivery, to pre- and post-process inspections.

Contaminants should be avoided. The end markets for recycled glass are e.g. sensitive to contamination by ceramics, lead glass, light bulbs, laminated glass, etc. To maintain glass quality, contamination should be avoided and recycling should apply sorting techniques to eliminate these contaminants, yielding a higher price for the high-quality end product. Consumers' education, adequate process design and well-managed operation are the keys to produce high-quality recyclable materials.

Quality control problems arise at all stages of the recycling process:

- Cross-contamination can occur when residents have to separate the recyclables into specific multi-bins, e.g. ceramics should not be disposed off in the glass containers;
- The presence of hazardous wastes within potentially recyclable feedstock, e.g. paints and light bulbs;
- Handlers and transporters face difficulties to monitor the presence of comingled materials in the bin collection programs;
- Central sorting and processing facilities can be controlled with difficulty due to technical inefficiency, leading to 20 to 30% rejects. With large scale curbside collection programs, rejects are normally limited to some 5 to 10% of the total incoming tonnage;
- Health and safety hazards associated with manual pre-sorting and the difficulty to remove smaller rejected objects effectively.

Recyclable products are subject to severe materials specifications: e.g. aluminum should not contain iron and lead in excess of 1 %, recyclables should have a limited moisture content, plastics should not contain excessive percentages of non-conformity materials, etc..

In view of this necessary and strict quality control, analytical procedures (visual inspection, laboratory analyses) are stringent and important, albeit function of the waste material being considered.

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### Biographical Sketches

**Jan Baeyens** (born in 1946, Belgium) studied Nuclear Engineering (Brussels) and Chemical Engineering (Leuven). He obtained his Ph.D. at the Postgraduate School of Powder Technology (Bradford-U.K.). After 16 years of full-time employment in divisions of various Belgian engineering companies, he became a part-time professor at the University of Leuven (B) and worked as a process and project consultant in Europe and overseas. Between 2003 and 2005, he joined the University of Antwerpen (B). Since 2005, he is part-time Visiting Professor at the University of Birmingham (U.K.). In 2009, he joined the School of Engineering of the University of Warwick, again on a part-time basis, with main focus on process design, sustainable development and renewable energy. He will moreover continue to co-ordinate research in the above fields, while also acting as consultant. He has contributed to over 250 publications in international and national journals, is co-author/editor of 14 books and a regular speaker at international congresses.

**Anke Brems** (born in 1985, Belgium) studied Biochemical Engineering (major environmental technologies) at the University of Antwerpen. She thereafter joined the University of Leuven, Campus De Nayer, within the research group of sustainable development, where she performed research regarding the thermal treatment of biomass by fast pyrolysis under the supervision of Professor R. Dewil. Together with Jan Baeyens and Raf Dewil, she is actively involved in the co-ordination of the Flemish Center for Powder Technology, a non-profit center of technology transfer and applied powder research. Her PhD thesis, supervised by both professors, focuses upon the thermal recycling of polymeric substances.

**Raf Dewil** (born in 1979, Belgium) studied Chemical Engineering at the Katholieke Universiteit Leuven and obtained in 2006 a Ph.D. in Bioscience Engineering at the University of Antwerp under supervision of Prof. Jan Baeyens. In November 2007, he joined the Association K.U.Leuven, Faculty of Technology and Bio-sciences as assistant professor, where he lectures on Sustainable Process Engineering and Powder Technology. In March 2009, he became assistant professor at the Chemical Engineering Department of the Katholieke Universiteit Leuven. His main research interests are waste-to-energy processes (anaerobic digestion, thermochemical conversion) and wastewater sludge treatment. Up till now, he has (co-)authored 25 publications in international journals and over 40 presentations on international congresses.