CHE 5102-RECYCLING AND RESOURCE MANAGEMENT
Material and energy flow management and analysis, influences of production and consumption, ecological and economically valuation of substances, assessment of sustainability of material flows, optimisation of material-, energy- and information flows, treatment technologies, design for recycling, upgrading and repair, recycling and reuse, engineering cost estimation, and regulatory/legal aspects of waste management are included, waste minimization, basic unit processes, processing, application and utilization of reclaimed products.

Contents

1 Introduction

Manufacturing, use, and disposal of products of every kind are inevitably connected to generation and movement of resource streams. These streams do not only consist of the resources actually used in the product, namely the used materials and consumables, but also of emissions, residues, and energy flows. These resource streams have reached quantitative and qualitative dimensions that start to affect our global substance balance. The effects stretch from growing waste occurrence from households, trade, and industry to climate change and scarcity of resources [Nickel, 1996].

Figure 1 shows the development of waste occurrence in Germany between the years of 2000 and 2006. Municipal waste has mostly stayed the same while mining waste and construction and demolition waste declined. At the same time production and commercial waste rose.

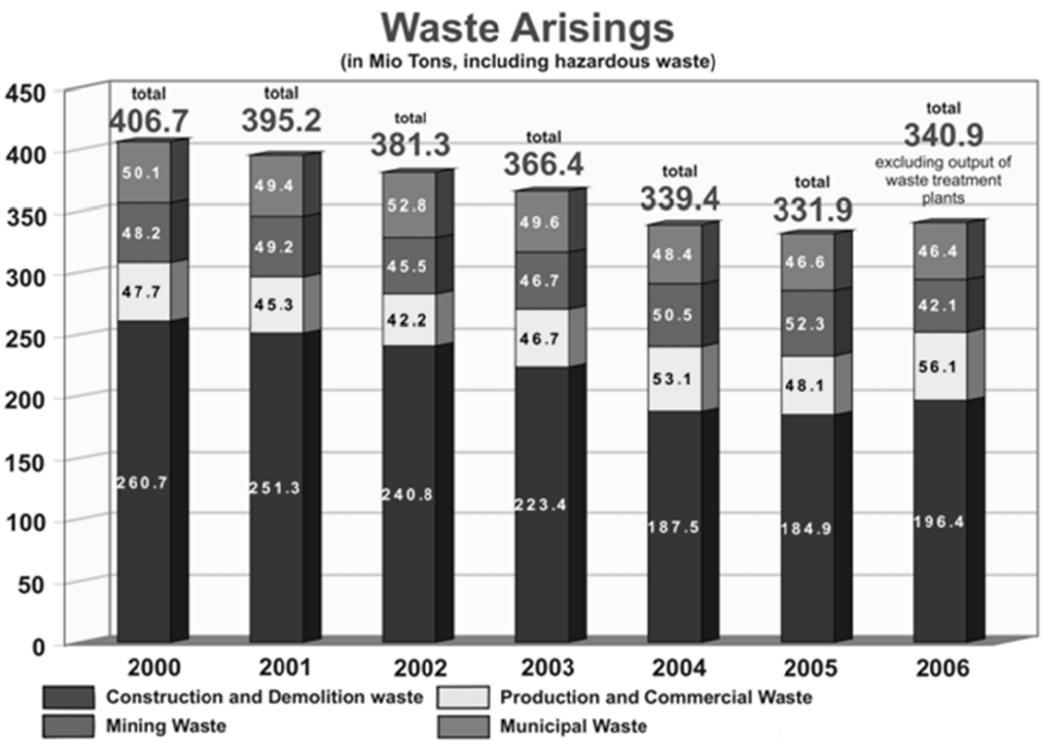

Figure 1: Waste occurrence in Germany 2000-2006 [BMU, 2008b]

A new kind of thinking led to the integration of the product life cycle into waste management. Not just developing a general product idea, manufacturing and transport to the consumer are important, but also resource development, usage, and disposal or recycling. Past experiences show that effective environmental protection has to be done preemptively as aftercare just leads to a displacement of encumbrances [Nickel,1996].

The general idea of recycling is very old. The use of production waste can be dated back to the start of industrial development. Usually the promoting element was cost efficiency. Especially in times of war many countries tried to cope with resource scarcity by intensive collection of waste materials. Today’s recycling primarily aims to reduce waste volumes [Tchobanoglous, 1993].

Recycling is a series of activities that include collecting, sorting, processing, and converting used materials into useful products. It is considered a very important part of waste management, because it reduces volumes brought into landfills and extends active landfill time. At the same time the use of virgin material can be reduced. The Bureau of International Recycling reports that most products would end up in landfills if not recycled and resources would be lost from the product cycle forever. Three different recycling methods are used currently:

- Source separation

  Households and businesses separate their waste right at the point where it occurs. By using small containers or bins per resource type the valuable resources get sorted and can then be distributed by scrap dealers or consolidation sites to different processors.
- Container separation

  Large containers are used to create three fractions: Recyclable, non-recyclable, and organic waste. After collection the recyclables get sorted by type.
- Commingled collection

  All waste is commingled and collected together. Recyclables are sorted and processed by mechanical means. A huge disadvantage of this kind of collection is that the recyclable material is largely contaminated.

Most recycling systems concentrate on public involvement. Recyclable waste is collected regularly as part of the trash collection service to motivate people for the separation process. Special items like Christmas trees, scrap electronics or paint have been collected by drop-off stations as part of a trial. Another strategy is the so-called buy-back program. This is a centralized operation, whereby items such as i.e. aluminum cans or glass bottles can be returned to a recycler for a fixed amount of money [Vaughn, 2009].

A newer strategy is the reduction of the volume of occurring waste. This idea, also known as pollution or waste prevention, starts at the design stage of new products. It aims to design products and packaging in such a way that waste is minimized and almost everything can be recycled. For example, in the German law for waste management the following Figure 2 is a center piece.

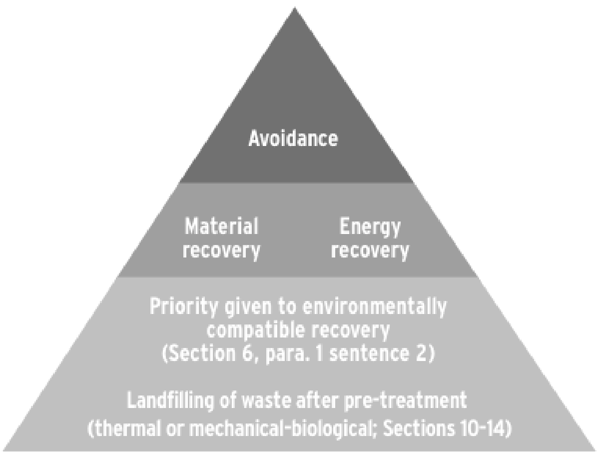

Figure 2: The waste pyramid: The political credo of modern waste policy [BMU, 2008a]

This puts avoidance at the top of the pyramid as the most important aspect. Next material and energy recovery (recycling) are treated as equally important. Then priority is given to the environmentally more compatible method of recovery and finally at the bottom, land filling is placed.

Another important point is the reduction of toxicity in the occurring waste. One of the main goals in waste management is reducing the amount of waste deposited in landfills. Governments worldwide are getting more demanding in their approach to reuse and recover material which would before have been disposed of in landfills [BMU,2008a].

Waste minimization is based upon the principle of cleaner production in a larger geographic area. Cleaner production is considered one of the most efficient tools in waste management practice as it acts in an industrial surrounding and can decrease municipal waste occurrence by clever design strategies [Nickel, 1996].

To achieve the goal of reduced landfill usage, the European Communities Directive has decided that only waste that has been subject to treatment can be accepted on landfills. Possible treatment options are physical, thermal, chemical, and biological means as well as sorting, which is used to reduce the volume of the hazardous nature of waste, facilitate its handling or enhance recovery. Especially biodegradable waste amounts should be reduced significantly to reduce production of GHG methane from the landfill [Stegmann et al., 2006].

2 Strategies and Objectives

2.1 Strategies

Recycling strategies are plans a community or country finds for recycling of waste. Important facts for finding the right recycling strategy are the occurring waste masses, the acceptance of recycling and the will or the capability to spend money for waste recycling. This means recycling is reasonable if it is economically and ecologically preferential. For cost effectiveness a market for secondary resources and products has to exist, because the recycling process is more expensive than disposing of waste in landfills. Secondly the environmental impact of recycling should be considered. Taking into account the savings in primary resources through recycling it has to be less environmentally damaging to be justifiable [Nickel, 1996].

To have a proper market for secondary resources they have to be publicly accepted. If consumers refuse to buy products made from recycled materials, recycling will inevitably fail. Not just acceptance is important, but the participation in waste separation at the place of occurrence. There are two main strategies to make recycling possible or reach higher participating levels with a better output.

First the arising of public awareness by different means:

- Billboard advertisement: Raise public awareness for the topic of recycling by bringing it up in the public sphere.
- Carnival, exhibition, and briefing: The aim is to organize some kind of public feast to attract people and combine amusement with information.
- Printed matters: Posters, pamphlets or bulletins are used to inform people about recycling opportunities.
- Electronic medium: Use of television, radio, and internet means can help raising awareness. Especially in the case of the internet people can independently enhance their knowledge about recycling.

- Transportation: Most people use transportation on a daily basis. Using trams or roadsides for public information is a relatively cheap and effective way to raise awareness.

All those methods can just work if a proper infrastructure for recycling waste is given. Secondly the infrastructure for waste disposal can be enhanced or increased. The best known method of waste collection is the dispense of waste cans all over town, but other means are possible as well, as for example the implementation of collection stations, where people can bring their recyclable garbage [Vaughn, 2009].

2.2 Recycling and environmental protection

Recycling was not in the first place an idea for environmental protection, but for cost reduction. It used to be a way to reduce material costs as leftovers were reused and brought back into the production cycle.

Just in the 1960s an environmental movement formed which demanded to dispose of less waste in landfills. In the 1980 households in the US began to separate their waste into differently colored receptacles. People also started to protest against waste incineration, they wanted a real recycling process. The idea of "reduce, reuse, recycle" was born. Since the 1990 more and more companies jumped onto the "recycling train" as they noticed that a "green" image enhances their position in the market. This development is a good example of how consumers can influence the market and achieve environmental protection by spending their money on more environmentally friendly products [Nickel, 1996].

2.3 Objectives

Recycling transforms materials that would otherwise just become waste into valuable resources. Paper, metal, plastics, and glass etc. can be collected, separated, and be reprocessed into new materials. The following graph shows the fractions of recyclable waste:

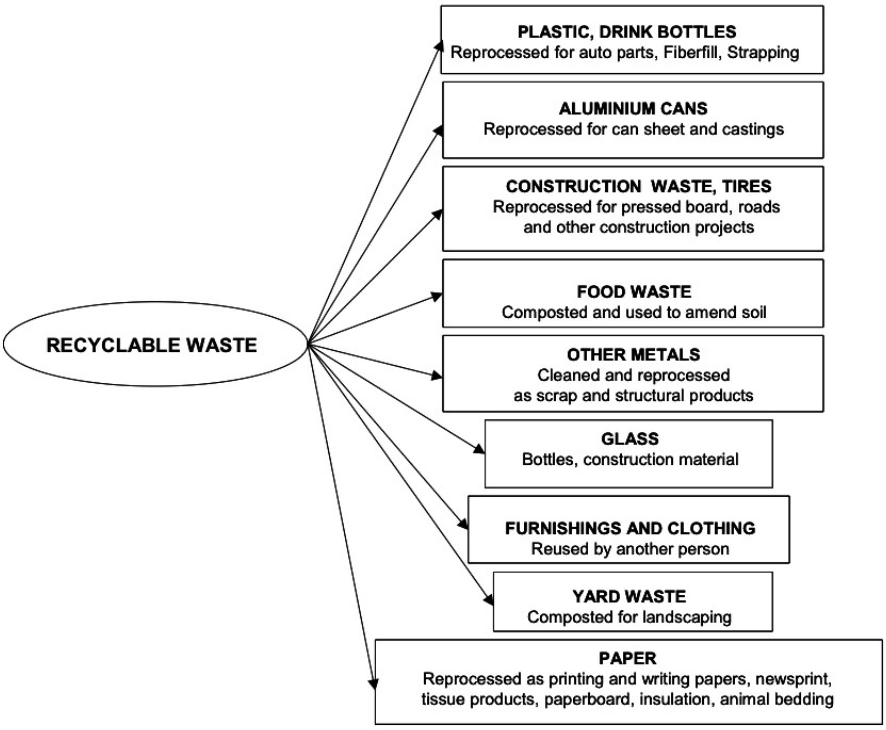

Figure 3: Recyclable materials in the waste stream [Stegmann et al. 2006]

The objective of recycling is to put those valuable resources back into the resource loop. The idea is that almost every waste can be reused or recycled; just some toxic residues and less active ashes have to be disposed of in landfills [Nehlsen, 2008].

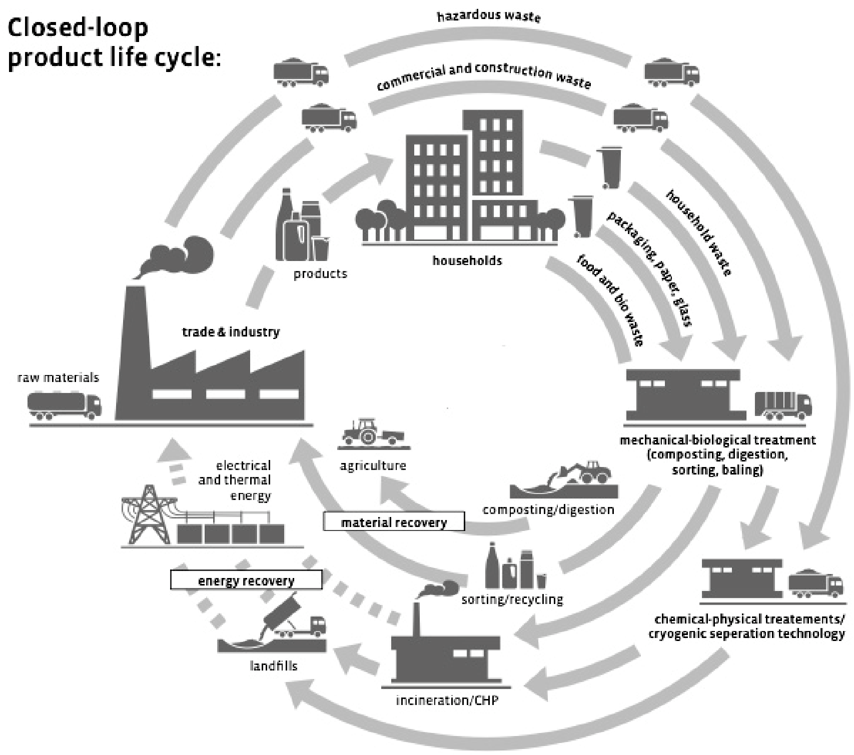

Figure 4: Closed-loop product life cycle [Nehlsen, 2008]

2.4 Requirements and constraints of recycling

Recycling depends on two factors: the availability of recycled material supplies and a market for those goods. Without source separation recycling is hardly feasible, because the value of fractions dramatically decreases as they are dirtied and broken down in a commingled collection. The next important requirement is the existence of producers able and willing to use secondary resources. This depends highly on consumers not only accepting recycled products but favoring them to influence companies' policies [Nickel, 1996].

3 Recyclable materials

Many materials can be recycled. Not just those commonly known, like glass, paper, and plastics are recyclable, but also batteries, organic waste, and scrap automobiles. When it comes to recyclability, the first deciding factor is the ease of separation of a certain fraction, or more precisely: how much does it cost to sort this material out of the mass of municipal solid waste? Secondly, whether there is a demand for that resource, or: how much is this fraction worth? If the revenues from secondary resources cover the costs of sorting, recycling is feasible from a financial point of view. On the other hand, ecology is important. If recycling does not reduce GHG emissions and use of raw materials, it is not ecological and should be discouraged. Waste paper, many kinds of plastic, glass, and scrap metal can be reprocessed with relative ease and the secondary resources are demanded by the market [Stegmann et al, 2006]. The following graph (Figure 5) shows recycling rates in Hong Kong in the fractions electrical scrap, glass, tires, textiles, non-ferrous and ferrous metals as well as wood, plastics and paper.

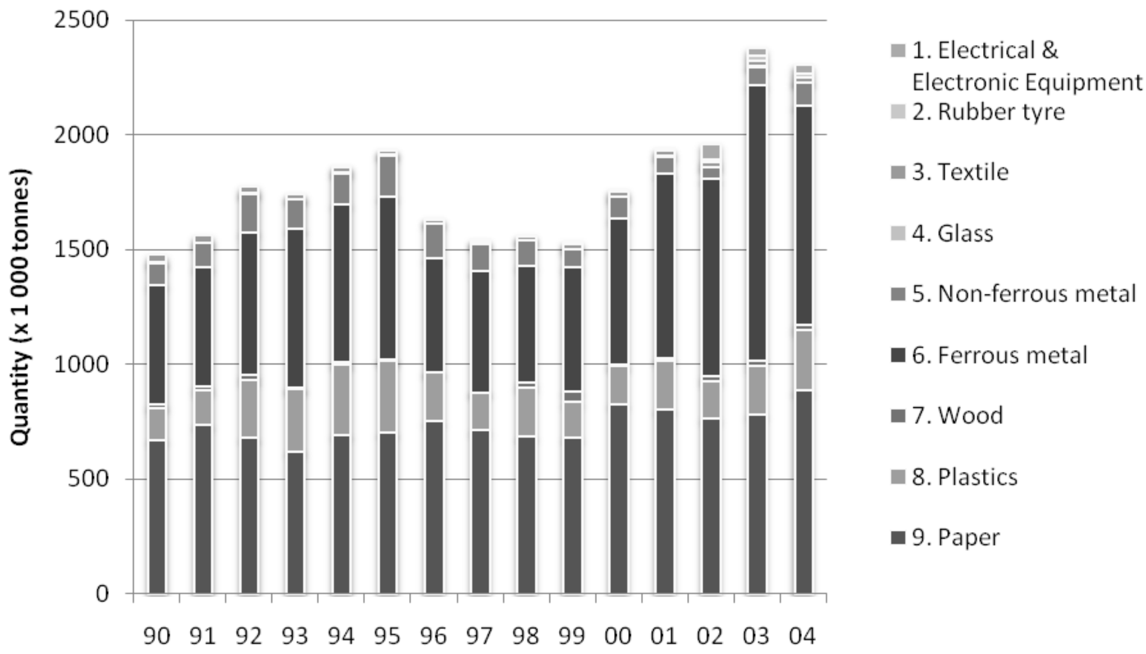

Figure 5: Recycling quantities in Hong Kong 1990-2004 [Environment Hong Kong 2005]

Possibilities for recycling occur where waste materials can be reused in production. Therefore, those have to be separated from other fractions. Only if both conditions are met, recycling really is possible. Today paper, plastics, glass, and metals are most commonly recycled. Still it is possible to recycle many more fractions. Hindrances today are, for example, unfit recycling techniques and primary resource prizes too low to promote recycling, but examples of progressive states show that recycling may be feasible for almost everything in the future [Environment Hong Kong, 2005].

4 Reuse and Recycling opportunities

4.1 Recycling of Glass

"Nowadays glass is much less expensive and is taken for granted as a packaging material in addition to its use in windows and other applications. New glass is made from a mixture of four main ingredients: sand, soda ash, limestone and other additives. These additives include iron for color (brown or green), chromium and cobalt for color (green and blue) respectively, lead to alter the refractive index, alumina for durability and boron to improve the thermal options." [Wasteonline, 2010].

Glasses are classified by variety and applications into four major groups [Britglas, 2010]:

- Commercial glass ("Soda-Lime-Glass")
- Lead glass
- Borosilicate glass
- Glass fiber

Results of a German study (Berlin, 1991/1992) illustrate that packaging glass makes up a large percentage of the household waste. The percentage of glass in the waste stream of urban areas is 25.5 (residential) and 4.7 (commercial) and of rural areas 18.5 (residential) and 4.4% (commercial). Since glass is very easily recycled, the glass packaging can be readily transferred to the glass manufacturing industry to decrease the need of raw materials [Bilitewski, 1994]. Before the reunion, Western Germany reached a glass recycling rate of 38 kg/p*y in the year 1991. In contrast a glass recycling rate of 43 kg/p*y has been found for the year 2005 in Germany [Destatis, 2010]. The ascertainable amount of the recycling rate depends on the attitude of participants towards sorting waste. To improve the quality and quantity of the recycling potential a correctly sorted collection is needed. For separating colorless, green, and amber glass a differentiated collection-structure is needed. The sorting accuracy and its quality are very important for the efficiency and economics of glass factories. Recycling of glass requires five fundamental processing techniques [BVSE, 2010]:

- raw- and color-resorting to optimize sorting accuracy
- crushing to optimize the following processes
- magnetic separation to sort out ferrous materials
- air classifying to remove light-weight and plane materials
- optical sorting to remove contaminants (e.g. ceramics in the furnace)

Because the manufacture of glass has a high quality requirement, a high quality standard of the recycled product is a prerequisite. If the specifications are being kept, the quality will increase. In Germany the following quality requirements are in effect:

- min. 97 weight-% sorting accuracy
- max. 1 weight-% free contaminants
- max. 2 weight-% of glass below quality specification
- The percentage of wrong-colored glass varies between the several glass types (max. 8% for amber, max. 15% for green, max. 3% for white) [BVSE, 2010]

For the glass production process energy is used in the extraction, transportation, and processing of raw material. Especially processing takes large amounts of energy, because materials have to be heated to a very high temperature. Large amount of fossil fuels are used to provide this energy supply and they are inevitably combusted to carbon dioxide. An efficient furnace needs 4 GJ of energy for a ton of melted glass, but still many old furnaces are on duty. In 2002 the British glass industry consumed an amount of 8,611,000,000 kWh of energy (including electricity) and was responsible for 1.8 mill. tons of carbon dioxide emissions [Wasteonline, 2010].

The good news is that glass can be recycled indefinitely, since its structure keeps the same properties. Therefore recycling of glass is easily feasible and secondary products don't have trouble being marketed. 80% of reclaimed scrap glass called "cullet" can be used for production of bottles and jars. Cullet from commercial sources has a known composition and is therefore a high value resource, while bottle banks deliver a mixed glass, which composition is unknown most of the times [Wasteonline, 2010].

Energy demand for glass made from scrap glass is highly reduced. After taking transport and processing into account, 315 kg of carbon dioxide can be saved for every ton of melted glass. Recycling also reduces the demand for raw materials. For every ton of glass recycled another 1.2 tons of raw materials are conserved [Wasteonline, 2010].

Waste glass recycled doesn't need to be disposed of in landfills and reduces the volume of waste landfilled. Glass is inert, so it is not one of the problematic fractions in landfills, but it will also never be degraded [Wasteonline, 2010].

The UK currently has a recycling rate of 34% for container glass, which is bad compared to countries like Switzerland, Finland, and Germany who each recycle over 90% of their glass. 50% and over are standard in Europe [Wasteonline, 2010].

The development of the glass recycling rate in Germany from 1974 to 2002 is shown in Figure 6.

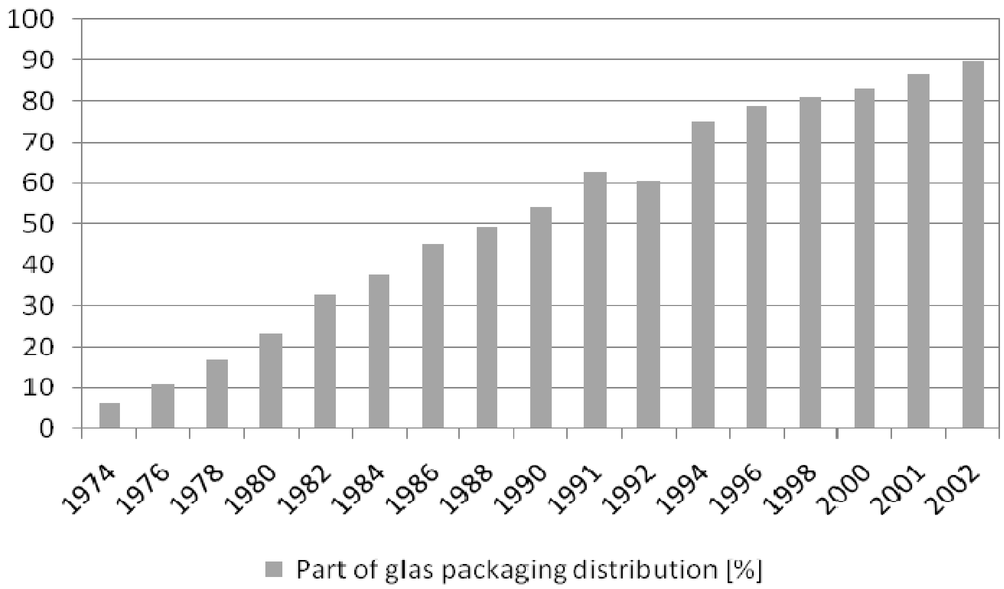

Figure 6: Development of glass recycling rate in Germany from 1974 to 2002 [BVSE, 2010]

The main barrier to glass recycling in the UK is the little amount of clear cullet collected. In the UK primarily clear and amber glass are produced. A lot of clear glass ends up as spirit bottles, which are then exported and don't return to the glass container collection. On the other side consumers are not putting packaging glass into the so called "bottle banks", which leads to an overall little clear cullet collection. Glass imported is mostly green glass (from wine bottles) and amounts to twice as much green glass as produced in the country. That fact has led to a surplus of green cullet. In the last years the glass industry has been working hard to increase the amount of green glass recycled and today green glass bottles produced in the UK contain over 85% of recycled green glass [Wasteonline, 2010]. This is illustrated in Figure 7.

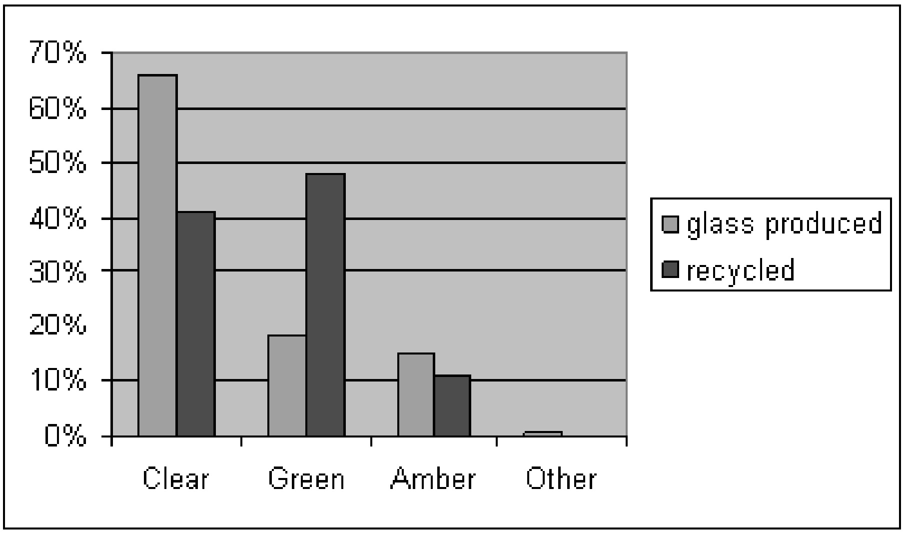

Figure 7: Comparison between produced and recycled glass in the UK [Wasteonline, 2010]

In addition to recycling it is possible to reuse glass. Bottles can be returned to the retailer and customers receive the deposit in return, which used to be common practice. Nonetheless environmental and financial advantages of the return-bottle systems decreased as small producers closed and transport costs to larger facilities became higher. Milk bottles are one of few types of bottles still refilled. They are used 12 times in average. Reusable bottles have to withstand more wear and tear than single-use bottles, which makes them heavier. Also the cost of cleaning has to be taken into account. Still returning bottles are the best alternative if recovered and refilled in close vicinity [Wastonline, 2010].

Environmental benefits of using scrap material as opposed to usage of raw material according to [Vellini, 2008]:

- lowered energy consumption in glass manufacturing (endothermic heat for glass reaction, sensible heat for glass heating and batch gases)
- no harmful emissions from transformation of raw materials in vitrifying mixture
- consumption of less raw material, resulting in lower energy consumption and thereby lower environmental impact

4.2 Recycling of Paper and Paperboard

In terms of weight, paper and paperboard are the largest contingent in municipal solid waste, representing 25 to 40 %. Recycling is done by paper mills, which introduce the wastepaper and paperboard into the pulp used to form new paper products. Paper mills have to use raw material of certain qualities to mix the pulp as desired for the product. A special regard is therefore put on the quality of the wastepaper, which should be as homogenous as possible. Classification of wastepaper and therefore the prize this wastepaper achieves is based on the quality of the paper (long fibers vs. short fibers) as well as on the printing and color. The association of German paper mills has defined five groups of paper qualities:

1) lower grades including original mixed waste paper from residential collections etc.
2) middle grades consisting of original newspaper, wood pulp, files from file shredding etc.
3) better grades like continuous forms, punchcards, multi-print wood free paper etc.

4) **Kraft grades** which includes all kraft papers as well as paperbags
5) **Special grades** an unspecified paper from multi-component collection

Post-consumer paper, a mixture of newspaper, cardboard, magazines, and household paper, achieves a very low quality standard without preprocessing of any kind and has a limited use. Table 1 shows an approximate distribution of different paper kinds in household wastepaper collection. Therefore paper has to be sorted according to quality standards to achieve a certain price at the paper mill to make recycling economically feasible [Tchobanoglous et al., 1993].

Table 1: fraction's distribution in household wastepaper collection [Bilitewski, 2004]

Fraction	Minimum [%]	Maximum [%]
Packaging paper	13.8	39.7
Graphical and other papers	57.0	83.1
Wallpapers	0.4	4.8
Impurities	1.6	3.6

To efficiently reuse paper it has to be recovered from consumers first. The following Figure 8 shows graphic paper consumption as well as recovered wastepaper in tons and recovery rates in Germany in the years 1994 to 2006.

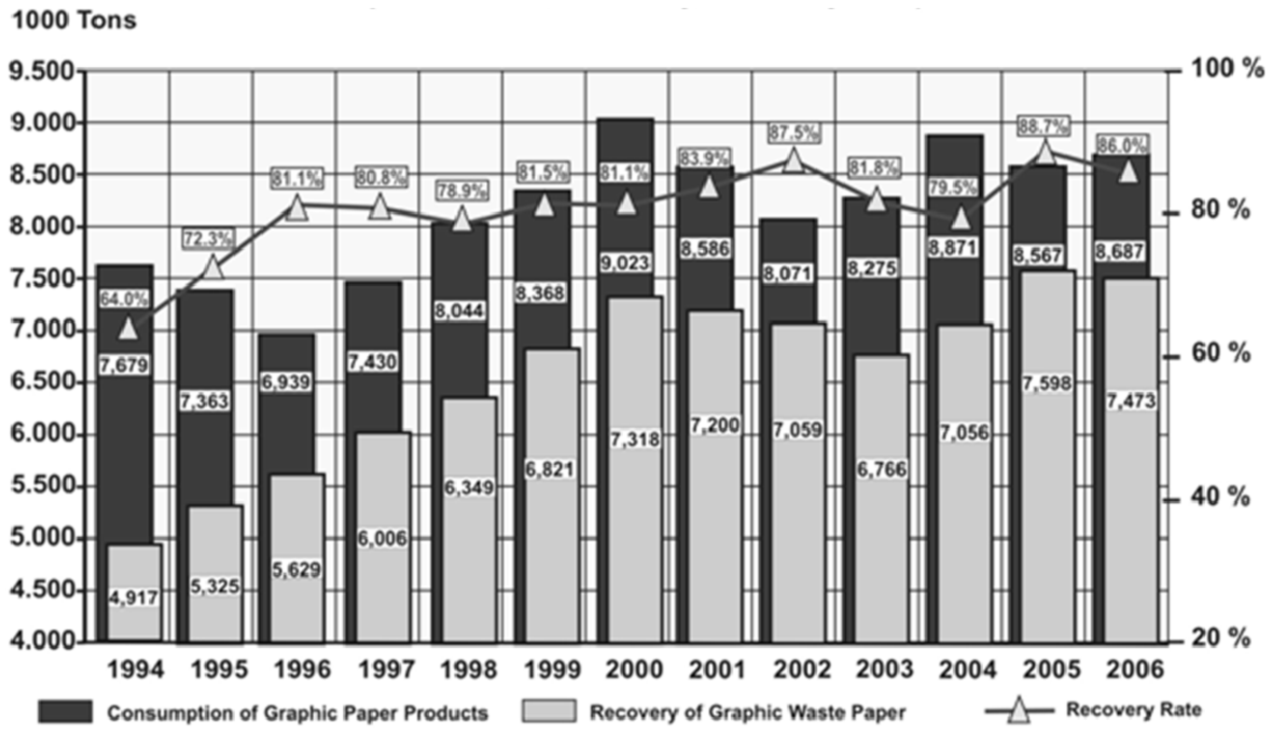

Figure 8: Consumption, recovery, and recovery rates of graphic papers in Germany 1994-2006 [BMU, 2008b]

To introduce wastepaper into a pulp for producing new paper or other paper products it needs to go through the steps of **solution**, **cleansing**, **screening**, and **deinking**.

In the first step the paper mill mixes different kinds of wastepaper to produce an optimal pulp. Those papers are dissolved in water to let the individual fibers run free. These fibers than have to be cleansed from other particles such as paperclips, staples, or foil. Afterwards fibers are filtered to sort out too short fibers. Finally ink needs to be removed by chemically bleaching the pulp. The process takes place in large basins in which the solution is mixed with sodium hydroxide solution, hydrogen peroxide, water glass, surfactants, chelating agents and a number of other chemicals depending on the desired product. There are two different de-inking methods: the flotation and the washing [Fricker et al., 2007].

In the flotation method the deinking pulp is constantly stirred and ventilated, so that foam with ink residues appears on the upper surface. The froth is than skimmed from the surface and concentrated for disposal. A loss of 7-10% of fiber can be expected for this method. Figure 9 shows the basic deinking schematic.

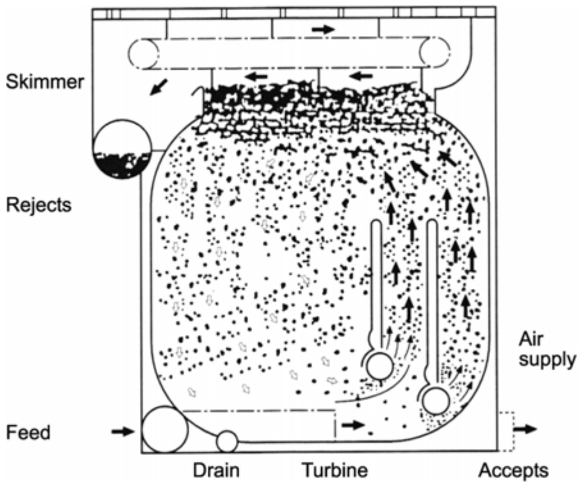

Figure 9: Schematic of deinking after the flotation method [Fricker et al.,2007]

The washing method uses large amounts of water to clean the fibers from ink. A loss of 10-20 % fiber can occur [Umweltlexikon, 2010]. It is therefore less applied were water prices are high and jurisdiction on Water purification is strict. In some European countries the washing method is prohibited [Fricker et al.,2007].

The relevance of paper recycling is big as Table 2 shows. In the packaging paper and paperboard group 93.2 % are made from recovered paper. This had developed very early, as comparisons with 1992 show, since color is not very important for packaging material. Methods of deinking have been optimized, so recovered paper can be utilized to a higher grade. It is used for 43.3 % of graphical paper production, for 75.5% of hygiene papers and for 45.0 % of technical papers. Overall 64.5% of the paper production in Germany use recovered paper [Bilitewski, 2004].

Table 2: Utilization of waste paper in new paper products in Germany [Bilitewski, 2004]

Main product groups	Recovered paper utilization [Mg/a]		Total production [Mg/a]		Rate of recovered paper utilization in paper production [%]	
	1992	2003	1992	2003	1992	2003
Packaging paper/ board	4,353,000	6,969,000	4,166,000	7,481,000	92.3	93.2

Graphical papers	1,300,000	4,092,000	5,784,000	9,450,000	18.1	43.3
Hygiene papers	575,000	795,000	828,000	1,053,000	54.9	75.5
Technical papers	515,000	593,000	1,095,000	1,318,000	38.6	45.0
Total	6,743,000	12,449,000	111,873,000	19,302,000	48.6	64.5

4.3 Recycling of Biowaste

Bio-waste is a term used for organic waste from different origins. The commonality is that all bio-waste is putrescible (biodegradable). It may consist of food waste like vegetable peelings, half-eaten fruit, or leftover food, paper towels, and yard waste consisting mainly of leaves, grass cutting and small branches. The general two methods to process bio-waste are composting and anaerobic digestion. These two processes would occur in nature over time as well [Stegmann et al., 2006].

Aerobic composting is the most commonly used method for the conversion of organic matter. It is very cost-effective and can be applied for yard waste, separated municipal solid waste (MSW), commingled MSW, and co-composting with wastewater sludge. Aerobic digestion takes place in 3 general steps:

1) preprocessing
2) aerobic decomposition of the organic matter
3) product preparation

It is very important for an aerobic process to ensure the availability of oxygen for the degradation process. Three methods are known to reach composting [Tchobanoglous et al., 1993]:

- windrow with periodic turning
  The material to be composted is placed in rows and turned regularly to ensure a good saturation with oxygen. This method is favorable for yard waste with a low smelling activity.
- aerated static pile
  Piles are formed and stay steady but are aerated from below to avoid anaerobic zones. The rows are covered in less active material to avoid direct contact with outside air.
- in-vessel plug flow
  Composting takes place in an enclosed vessel. Air is injected and removed from the vessel. New composting material is pressed into the vessel by a hydraulic press and leaves on the other side as composted material.

Several design considerations should be made beforehand for an optimal composting process:

Table 3: Design considerations for optimal composting process [Tchobanoglous et al., 1993]

Parameter	Limits of variation
Particle size	should be between 25 and 75mm
Carbon-to Nitrogen (C/N) ratio	ratio between 25 and 50 to avoid ammonium production
Blending and seeding	mixtures of different kind of wastes can reduce composting time
Moisture content	50-60 %, optimum appears to be at about 55%
Mixing/turning	drying, caking and air channeling should be avoided
Temperature	for best results a temperature of 50-55°C in the first days is favorable, after that 55-60°C; over 66°C activity is reduced
Control of pathogens	pathogens, seeds, and weeds can be destroyed by maintaining a temperature between 60-70°C for 24 hours
Air requirements	air requirement for composting can be calculated according to the estimated activity
pH-control	to remain at 7.0-7.5, should not rise over 8.5 to prevent massive ammonium gas-out
Degree of decomposition	can be estimated by measuring a final drop in temperature, the amount of decomposable and resistant organic matter in the composted material, rise in redox potential, oxygen uptake, and the starch-iodine test
Land requirement	plant for 50 ton/d will be about 1.5-2.0 acres, less for larger plants

For odor control anaerobic pieces in a composting facility should be avoided. Therefore preprocessing with sorting out slow rotting matter or plastics is important.

After a finished composting process the material is less reactive and can be sold as compost if free of unpleasant odors, toxins, and impurities like glass and plastics. This brings an enormous economic advantage compared to not selling the product. Figure 10 visualizes the rising treatment capacity in Germany between 1980 and 2006. Biggest recipient is agriculture, where farmers mix the compost with their soils, but households as landscaping companies use compost from bio-waste as well [BMU, 2008b].

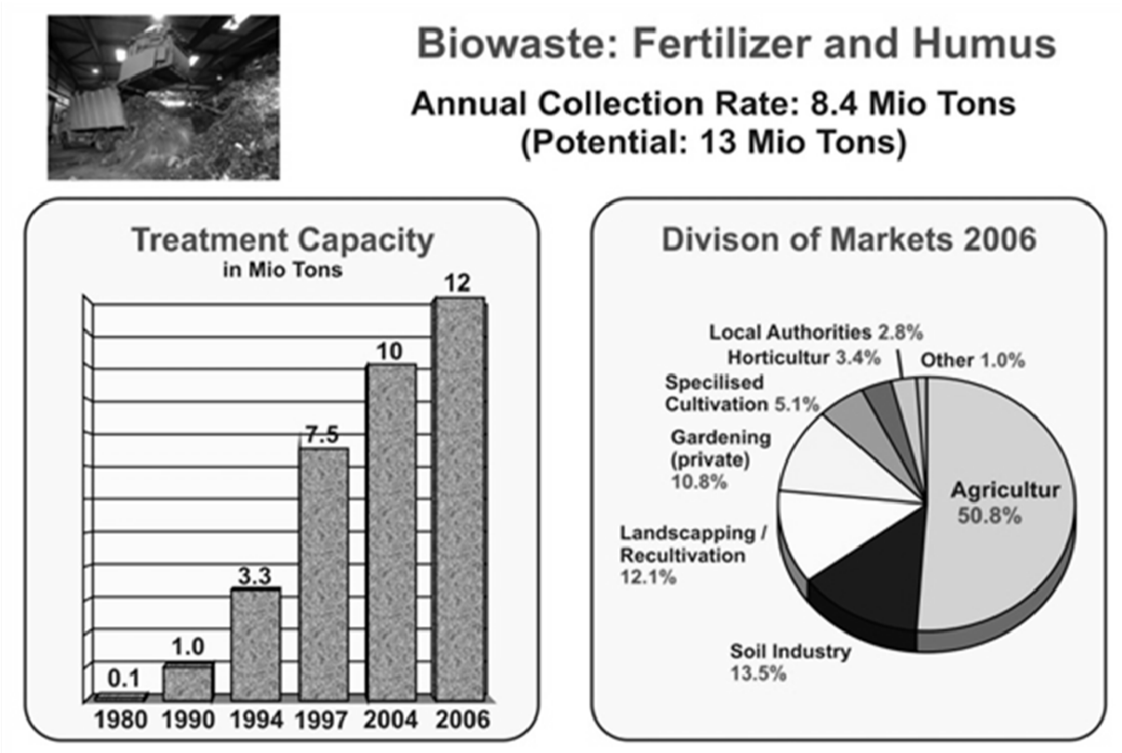

Figure 10: Treatment capacity in Germany from 1980-2006, usage of compost [BMU, 2008b]

Anaerobic digestion occurs under oxygen-free conditions. The first step of decomposition is hydrolysis. Big molecules are cut down by extracellular bacterial enzymes. In the second step those are broken up into lower-molecular-mass compounds and finally these molecules are digested by bacteria to produce methane and carbon dioxide as the two main products.

To achieve proper gas yields anaerobic bacteria need a high moisture level and temperature, pH and C/N ratio need to be adjusted differently from the aerobic composting. Up to 80% of easily degradable material can be transformed into biogas. The gas yield and composition depends strongly on the process conditions and the substrate. It varies from 0.1-0.4 m^3/kg dry substance and 50-60 Vol.-% methane in the biogas [Stegmann et al., 2006]. Table 4 shows gas yields for different kinds of waste.

Table 4: Biogas production for different organic wastes [Stegmann et al. 2006]

Substrate	Dry substance [%]	Organic dry substance TS [%]	Degradation rate of organics [%]	Biogas-yield from degraded organic substance [Nm^3/kg oTS]
Biowaste	25 - 35	65 - 78	50 - 60	1 - 1.2
Market waste	9 - 11	75 - 89	50 - 60	0.98 - 1.02
Liquid manure	3 - 12	65 - 85	20 - 50	0.9 - 1.11
Green waste	16 - 24	78 - 88	40 - 55	0.86
Household waste	45 - 55	40 - 60	40 - 60	0.9 - 0.98
Catering waste	9 - 25	79 - 93	50 - 70	1.1 - 1.3

Anaerobic digestion systems can differ in size from 10,000 to 1,500,000 Mg annual throughput. Small plants typically use one type of substrate, known as mono-fermentation, whereas some big plants co-ferment organic household or commercial wastes with manure or organic production residues [Stegmann et al., 2006].

According to their dry-substance content all anaerobic digestion systems can be classified into wet and dry fermentation. Further differentiation is possible by the number of process stages (one/two/multi-stage) and the process temperature. In Europe approximately 90% of all full-scale anaerobic digestions plants for municipal solid waste and organic household waste are one-stage, mesophilic systems [Stegmann et al., 2006].

In the following design considerations for wet and dry fermentation of bio-waste are mentioned:

Table 5: Design Considerations for wet and dry fermentation [Tchobanoglous et al.,1993]

	Wet fermentation	Dry fermentation
Particle size	shredded to a size that does not interfere with pumping and mixing	shredded to a size not interfering with efficient feeding and discharging
Mixing equipment	avoidance of scum building, mechanical mixing recommended	depends on the reactor type
Percentage of solid waste mixed with sludge	50-90% have been used, optimum seems to be at 60%	depends on sludge characteristics
Hydraulic and mean cell-residence time	washout time of 3-4 d, use 10-20 d residence time for design or pilot plant studies	residence time 20-30d or pilot plant studies
Loading rate	0.6-1.6 kg/m³*d; not well defined, higher rates have been reported	6-7 kg/m³*d; not well defined, higher rates have been reported
Solids concentration	typically 4-8 (10)%	typically 22-28 (35)%
Temperature	30-38°C for mesophilic, 55-60°C for thermophilic	30-38°C for mesophilic, 55-60°C for thermophilic
Destruction of volatile solid waste	60-80%, depending on amount of inert material	90-98+%, depending on mass retention time and the BVS loading rate
Total solids destroyed	40-60%, depending on amount of inert material	varies with the lignin content of the feedstock
Gas production	0.5-0.75 m³/kg of volatile solids destroyed, 55% methane, 45% carbon dioxide	0.625-1.0 m³/kg of volatile solids destroyed, 50% methane, 50% carbon dioxide

Digestion residues from anaerobic treatment consist of water, inorganics and undergraded organic compounds and can be used as fertilizer in agriculture without further treatment. However, in most cases a liquid-solid separation is in place. The solid fraction is composted and can then be used similar to original compost.

Residues from solid waste and food waste, which could have pathogens, have to undergo a hygienisation process. Caution should be exercised regarding heavy metal concentrations [Stegmann et al. 2006].

The following Table 6 gives an overview for comparison of aerobic and anaerobic digestion [Tchobanoglous et al.,1993]:

Table 6: Characteristics of the aerobic and anaerobic processes in overview [Tchobanoglous et al.,1993]

Characteristic	Aerobic process	Anaerobic process
Energy use	net energy consumer	net energy producer
End products	humus, Co2, H2O	sludge, CO2, CH4
Volume reduction	up to 50%	up to 50%
Processing time	20-30 d	20-40 d
Primal goal	volume reduction	energy production
secondary goal	compost production	volume reduction, waste stabilization

4.4 Recycling of plastics

Plastic use has grown rapidly in the last 30 years. Plastics have replaced metals and glass in packaging because they have several advantages. The light weight of plastic packaging reduces shipping costs. Containers are durable and provide a safe packaging, while being flexible and easily formable in a variety of shapes. Furthermore plastics are good insulators and are well suited for wet food and microwave oven usage. Although plastics compromise one 7 percent of MSW by weight they compromise a larger percentage on the volume basis. Recycling is made easier if producers mark their products with either registration numbers or abbreviations for the type of plastic used. Common plastics are Polyethylene terephtalate (PETE), high-density polyethylene (HDPE), low-density polyethylene (LDPE), vinyl/polyvinyl chloride (PVC), Polypropylene (PP), and polystyrene (PS). Mixtures of plastics for example as multi-layered material occur [Tchobanoglous et al., 1993].

Table 7: Classifications of plastics and common uses [Tchobanoglous et al.,1993]

Material	Original uses	Percent of total used for packaging
Polyethylene terephtalate	carbonated soft drink bottles, food containers	7
High-density polyethylene	milk bottles, detergent bottles, film products such as produce bags, etc.	31
Vinyl/polyvinyl chloride	household and food product containers, pipe	5
Low-density polyethylene	thin-film packaging and wraps, other film material	33
Polypropylene	Crates, cases, closures, labels	10
Polystyrene	foamed cups and plates, injection molded items	10
All other resins and multi-layered materials	commingled plastics	4

1) Polyethylene terephtalate (PETE)

   PETE is recycled to polyester fibers most of the time. Those are used to produce sleeping bags, pillows, quilts, and cold-weather clothing. Post-consumer PETE is also reused for carpet backing and fibers, molded products, polyisocyanurate insulation board, films strapping, food and non-food containers and engineering grade plastics for the automotive industry.

   Also chemical depolymerisation can be used to produce ethylene glycol and terephthalic acid, which then are repolymerised to virgin-quality resins for new soft-drink bottles.

2) High-density Polyethylene

   The properties of HDPE can vary broadly depending on the product use. Milk jugs are made from resin with a low melt index which can be blow-molded, whereas form molded resins have a high melt index. Common items manufactured from postconsumer HDPE are detergent bottles and motor oil containers. These bottles are built in three layers with the middle layer consisting of recycled HDPE. Inner and outer layer are made out of virgin HDPE. Recycled HDPE can also be used for protective wrap, grocery sacks, pipe, and molded products as toys and pails.

3) Polyvinyl chloride (PVC)

   PVC is used for food packaging, electrical wire and cable insulation, as well as plastic pipe. Classic recycling products are shower curtains, truck bed liners, laboratory mats, floor tiles, garden hose, flower pots, toys and nonfood containers. It can also be used to produce drainage pipes, moldings, sheet, and injection-molded parts.

4) Low-density Polyethylene (LDPE)

   A large quantity of LDPE films is not recovered but ends up in landfills. Problems in recycling occur because most LDPE is printed. Granulized LDPE has an inconsistently colored texture which can be compensated by overprinting or general coloration of the plastic foil (mostly brown or black). Other possible uses are plastic protectors for cargo and mixed plastic products.

5) Polypropylene (PP)

   Polypropylene is often found in automotive battery casings, caps, bottle and jug labels, and food containers. Labels and caps are usually granulated with HDPE and can be left in bottle-grade HDPE regrind. A larger part of PP finds itself in the mixed flake and can just be used for low-specification products as outdoor furniture, pilings, posts, and fencing.

6) Polystyrene (PS)

   Polystyrene has a very bad reputation as it is said to account for large amounts of waste. In fact it is used for fast-food containers, plates, meat trays, cups and as rigid packaging material, as well as food utensils, clear drinking glasses and yogurt containers. According to the plastic industry it just accounts for 0.26 weight-% and 1 vol.-% of municipal waste in the US. Recycled PS is used for production of foam foundation insulation board, office accessories, food service trays, trash receptacles, insulation, toys, and injection-molded products.

7) Mixed and multi-layer plastics

   Mixed and multi-layered plastics have a limit use since they are of a mostly unknown specification. They can be sold to manufacturers whose products don't have strict resin specifications as for outdoor benches, tables, car stops, fence posts, pallets, and stakes. PETE should be kept out of the mixture because it has a higher melting point than the other plastics. Another possibility is the usage as a reductive additive in the steel industry.

Processing of plastics works a multi-step process. First presorted bales are broken up and put on a conveyer for final sorting where undesired plastics are removed. Plastics are then cut into small flakes by a granulator and washed to remove all labels and adhesives. After that they are separated by flotation or hydro cyclones and dried subsequently. An air classifier can be used in-between to separate small pieces of PP from the HDPE rest. Electrostatic separation can be used to remove aluminum from caps. In a mixture of flow friction and supplemental heating an extruder then melts the flakes and removes remaining impurities with a fine screen. Finally the pellet machine cuts of little pieces of melt with a rotating knife, which are cooled and again dried and then packed for shipping [Tchobanoglous, 1993].

4.5 Recycling of Municipal Solid Waste (MSW) and production of Refuse Derived Fuel (RDF)

With the increase of global primary energy demands and the exhaustion of natural resources, energy prices underwent a successive rise. This resulted in an increased cost pressure especially for energy intensive industries. RDF substitutes conventional resources and reduces carbon emissions which results in cost effectiveness as well as in ecologic advantages.

Fuel Surrogates are fractions of refuse with a heating value of between 12 and 18 MJ/kg. Sources are bio-mechanical treatment and commercial waste sorting plants [Flamme, 2008].

RDFs are fractions with a heating value exceeding 18 MJ/kg. Sources: production specific wastes, specially prepared fuels after extensive conditioning [Eckardt, 2010].

Figure 11: Example for RDF from bulky waste after treatment [Academic, 2010]

RDF application areas [Eckardt, 2010]:

- Mono-combustion: waste incinerators, RDF power plants
- Co-combustion: power plants (partly substitution of conventional fuels), cement, brick, and lime works.

Conditions for RDF usage:

For stable combustion processes quality requirements for RDF catched on that are documented in the German law of waste [KrW/AbfG, 2007 (§6, Abs.2)].

1. the heating value of a single, unmixed waste is at least 11 MJ/kg
2. a combustion efficiency of at least 75% is achieved

Furthermore heat from the combustion process should be used by the incinerating facility or be distributed through district heating to consumers. Wastes resulting from the combustion should be disposed in an appropriate environmentally way.

"The combustible fraction recovered from mixed MSW has been given the name "refuse-derived-fuel" (RDF). The specific surface dimension and water content as well as the thermal conductivities determine the burn rate of one material. Because the feedstock composition changes in size and burn duration, the MSW is inhomogeneous comparing to conventionally fuels. In addition, the MSW is not optimal fuel, because" [Wittmaier et al. 2009]:

- "High ash and moisture content generate the low heating value
- The energy content varies annually, also in long-term periods based on changes in lifestyle
- Heavy metal and halogenated compounds is comprised in MSW as well as in paper, paperboard and plastics
- Table 8)

Table 8: Hazardous substances in household and other predominant wastes [mg/kg] [Wittmaier et al. 2009]

Hazardous Substances	Household Waste	Waste Paper (8% Moisture Content)	Plastic (6% Moisture Content)
Cd	2.9	0.5	43.1
Cr	76.0	22.0	28.2
Cu	31.0	65.0	78.0
Ni	13.0	10.7	18.8
Pb	294	65.7	171.1
Zn	310	108	402.3
Cl	4760	1789	55012
F	71	104.0	14

Due to rising fuel prices in recent years, the use of RDFs has become more interesting for energy intensive industrial operations and has only been made possible through pre-treatment processes [Wittmaier et al. 2009].

"Typically, systems that recover a combustible fraction from mixed household waste utilise size reduction, screening, and magnetic separation. Some facilities have used screening, followed by size reduction (pre-trommel screening), as the fundamental foundation of the system design. A number of considerations enter into the determination and the selection of the optimum order of screening and size reduction for a given application. Other unit operations may also be included in the system design, including manual sorting, air classification, and pelletization, as the need dictates for recovery of other materials and for achieving the desired specification of the solid fuel product" [CalRecovery, 2005].

It is a common practice nowadays to treat raw municipal solid waste with the mechanical biological treatment (MBT). The MBT concept is illustrated in Figure 12.

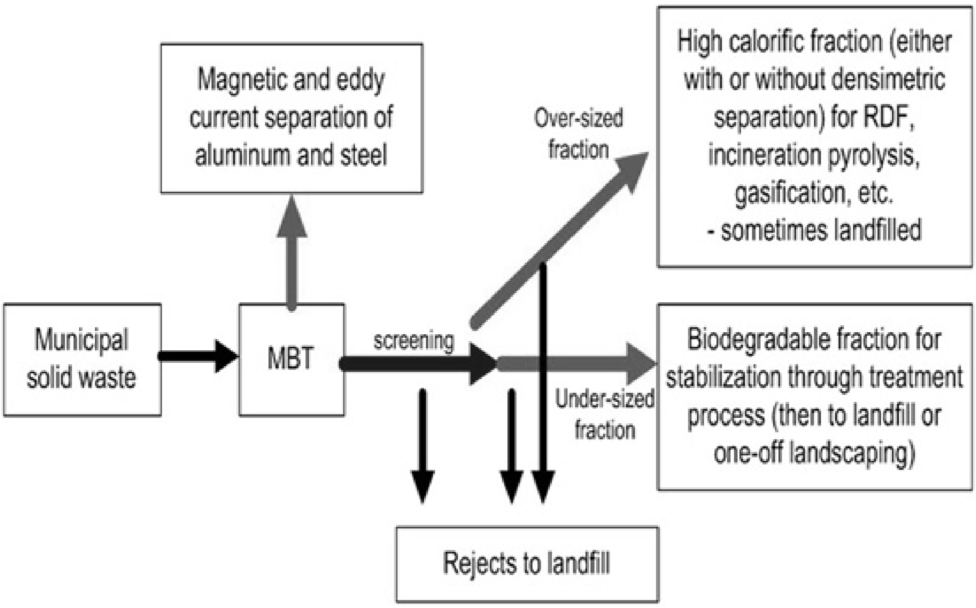

Figure 12: System design for RDF production by the MBT-concept [Alf-Cemind, 2010]

"In terms of application, RDF has been used in industrialised countries as a fuel supplement for coal-fired utility boilers and as the sole fuel for firing in dedicated boilers that use RDF exclusively. When fired as a supplemental fuel in coal-fired boilers (co-fired), experience has shown that RDF with heating values in the range of 12,000 to 16,000 J/g (wet wt basis) can successfully contribute up to about 30% of the input energy" [CalRecovery, 2005]. [Wittmaier et al. 2009] declares the energy content of RDF as 11.6 MJ (moisture content: 28.2%) and the minimum for household waste as 7.9 MJ (moisture content: 31.3%). Table 9 shows the important fuel properties of RDF.

Table 9: Important fuel properties and characteristics [CalRecovery, 2005]

Type of fuel	Heating Value As Received [J/g]	Moistre Content [%]	Ash Content [%]
RDF	12,000 to 16,000	15 to 25	10 to 22
Coal	21,000 to 32,000	3 to 10	5 to 10
MSW	11,000 to 12,000	30 to 40	25 to 35

Quality requirements:

In order for RDFs to be used in industrial processes high quality standards must be met. The following attributes influence the quality according to [Flamme, 2008] to a high degree:

- heavy metal content
- grain size and mean density
- contaminants
- heating value
- chlorine content

4.6 Recycling of Batteries

Old batteries can be divided into household batteries and lead-acid batteries, which are used for automotive and machinery purposes. In the US more than 2.5 billion batteries are purchased annually, which is approximately 10 for each person. There most batteries are not collected separately but are discarded in household waste. Batteries contain mercury, cadmium, lead and other heavy metals, which become toxic contaminants in incinerators or landfills. Return opportunities for household batteries exist in most electronic stores, but are still very thin in the whole of the US [Tchobanoglous et al., 1993].

Differently the story goes for lead-acid batteries (LAB). About 90% currently get recycled by cooperating battery manufacturers and secondary lead reclaimers. Annually approximately 1.4 million tons of lead are produced in the US from which 80% are used to make LABs. The average battery contains 18 pounds of recoverable lead. Typical recycling starts with crushing of batteries and then separates lead, plastic and sulfuric acid. All lead components are put in a reverberatory furnace where oxides and sulfates are reduced to metallic lead. The molten lead is drained of and leaves a sludge with still ~29 % lead, which is treated in additional blast furnace under addition of silica, iron, and lime as fluxing and scavenging agents. If the remaining sludge still contains more than 5 ppm it has to be disposed of in a hazardous landfill [Tchobanoglous et al., 1993].

Newer technologies use a vibrating screen for separation of the crushed battery. Reusable sodium hydroxide and sulfuric acid are recovered from the solution via electrodialysis, acid/lead-paste slurry is neutralized, and lead oxides are separated. Lead oxides are then reduced by electrolysis and combined with metallic components before being melted and cast into ingots. Polypropylene and battery-grade sulfuric acid are recovery additionally to lead. This method is called Engitec Impianti method [Nickel, 1996].

The European Union has an EU directive (91/157/EWG) which regulates that consist of more than 25 mg mercury, 0.025 mg cadmium, and 0.4 mg lead are toxic waste and have to be collected separately. Battery producers therefore committed to a voluntary agreement to take all batteries and rechargeables back [Nickel, 1996].

4.7 Recycling of Construction and Demolition waste

Processing of construction and demolition (C&D) waste methods have successfully been used by the mining industry for a long time. In a first step material needs to be reduced in size. This happens with impact, jaw, and roll crushers. Then classification takes places. Matter is sorted by particle size with bar grates, rods, or heavy duty screens. Primary screening is generally used to remove fill and mid-sized materials. In a third step separation takes place. Non-product specific components get removed by hand as well as magnetic separation. The product can also go through flotation to remove wood, light construction materials, paper, wrapping and so on. Wastewaster from these steps is often highly contaminated and has to be treated according to applicable standards. Additional costs for wastewater treatment, sludge disposal and the high water demand are a disadvantage of wet washing procedures [Bilitewski,1994]..

Processing aggregates are known as mobile, semi-mobile, or stationary with federates between 50 and 400 t/h. Mobile C&D waste processors have the advantage of minor site preparation, low transportation costs for the waste when processed directly at the construction site, and a potential of directly reuse as clean fill or for road construction. Disadvantages are the relatively high operational costs, a limited range of end products, difficulty of limiting noise and dust generation and also to control delivered waste and feed efficiencies. Figure 13 shows the recovery rate of C&D waste for Germany in 2006. Recycling of C&D waste is largely done by producers from the building industry themselves with little state control [Bilitewski,1994].

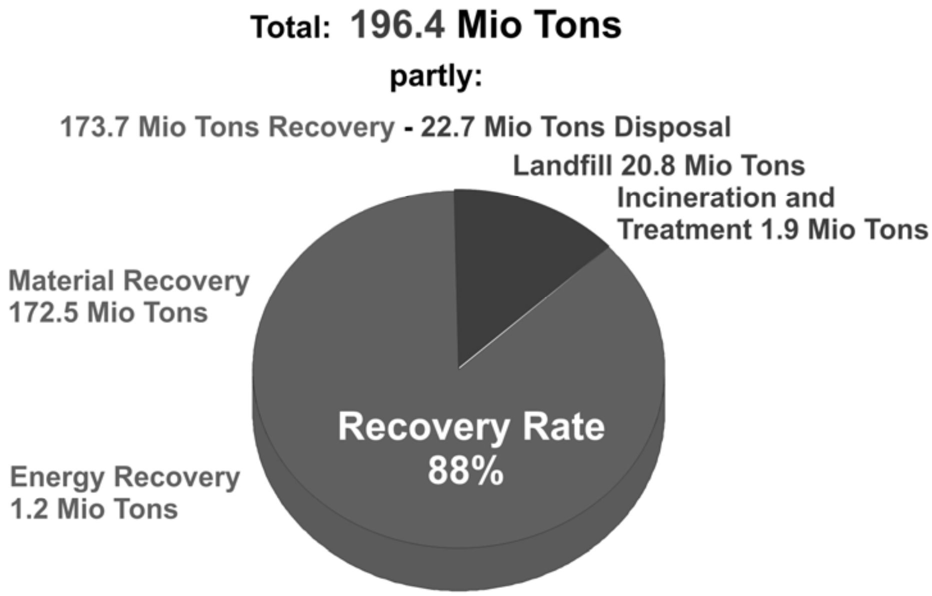

Figure 13 Construction and demolition waste recovery rates in Germany 2006 [BMU, 2008a]

4.8 Recycling of Wood

Wood wastes are a big component of yard waste as well as C&D waste, which accounts for about 25%. It has common characteristics according to its source. Harvested wood wastes origin from land-clearing and forest management activities, while mill residue is a leftover of pulp and lumber mills or secondary manufacturers as cabinet shops and furniture fabricators. Pellet and container waste and other wood wastes (mixture of yard, orchard, nursery, and agricultural waste) also exist. Wood reuse has increased highly in the last decades. Primary uses are landscaping and boiler fuel, few landfill material, pulp and paper mill feedstock, and wastewater treatment sludge composting. Fine material is used for composting and soil amendment, whereas clean, fine chips can be used as animal bedding. Successful wood recycling needs a steady market and reliable raw material supplies [Tchobanoglous et al., 1993].

Wood wastes have to be checked for contaminations in a first step, which in this context are pressure-treated wood, painted wood etc. and foreign materials as rocks, dirt or trash.

The center piece of wood recycling is a wood grinder, shredding all material to a defined size. Afterwards sorting trammels classify the shredded material. Ferrous metals can be removed magnetically, while light fractions can be blown off with compressed air. The degree of allowable containment depends on the demands of the market. Soil amendments have to be free of plastics, paper and other foreign matter

[Tchobanoglous et al., 1993].

4.9 Recycling of electronic scrap

Especially in regard to electronic scrap the hierarchy of the waste pyramid in the first chapter (Figure 2) should be taken into account to reach a high recycling rate:

- Avoidance of unnecessary and
- Re-usage of electric and electronic devices
- Material and other forms of recycling
- Reduction of the insertion of hazardous materials into landfills
- Reduction of the mass to be disposed of

Manufacturers of electric and electronic devices are responsible for their handling, reclamation, recycling and disposal. Furthermore different categories should be defined to maximize value creation. In Germany the following categories were chosen [ElektroG, 2007]:

- Large household appliances
- Small household appliances
- IT devices
- Consumer electronics
- Luminary devices
- Electric and electronic tools
- Toys and sports/ leisure devices
- Medical equipment
- Surveillance and control devices
- Vending machines

The collection of scrap electronics is done in communal collection points. The approximate amount can be estimated at about 4 kg/p*y. The general process of the treatment of electronic scrap is presented in Figure 14 [Flamme, 2008].

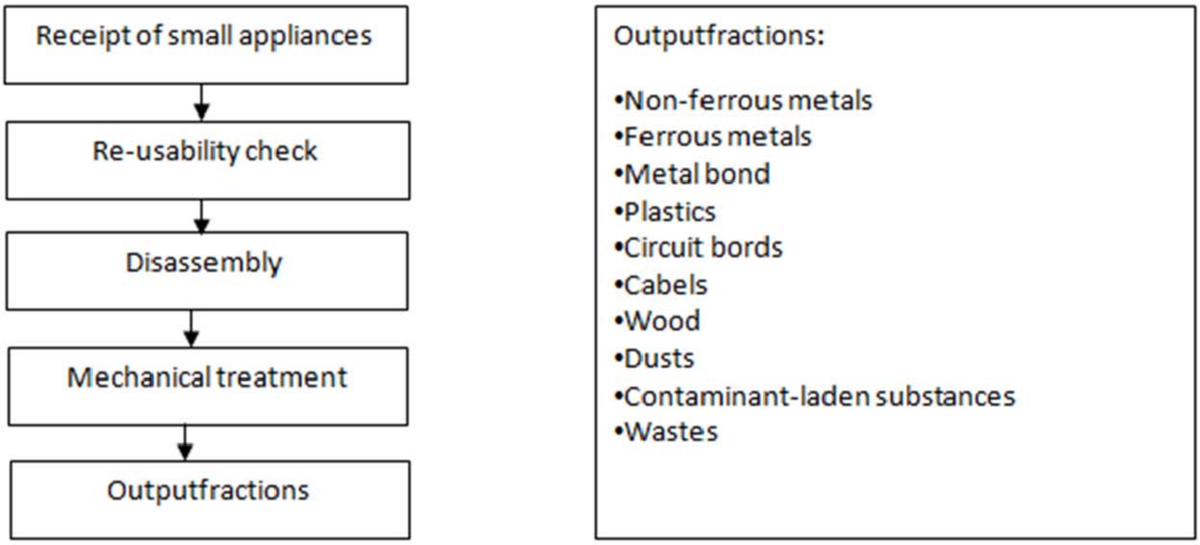

Figure 14: General processing schematic for the treatment of small electronic appliances [Flamme, 2008]

The central process of disassembly is depicted graphically as follows:

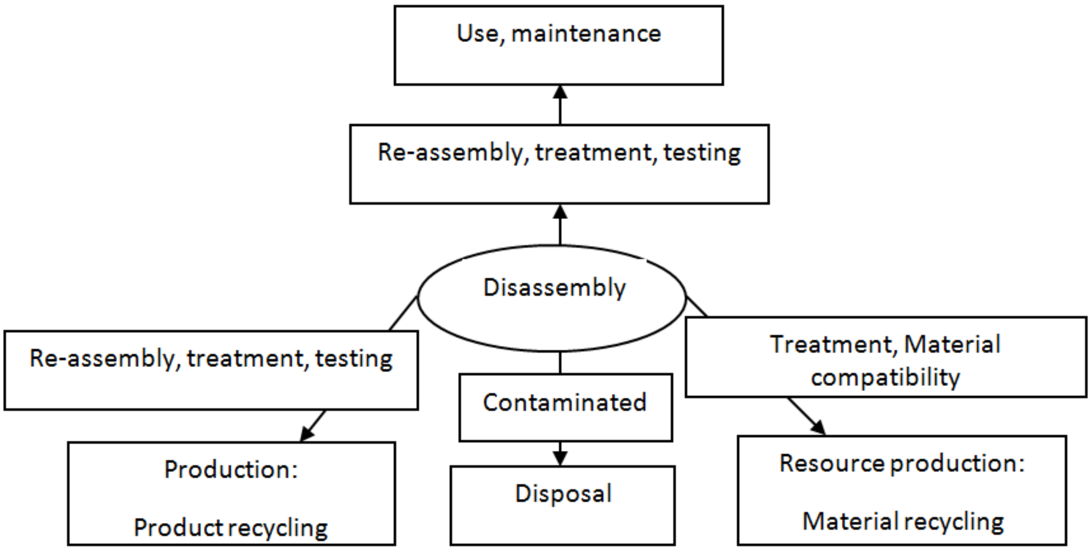

Figure 15: Central process of disassembly [Nickel, 1996]

Material components of small electrical appliances are shown in the following figure.

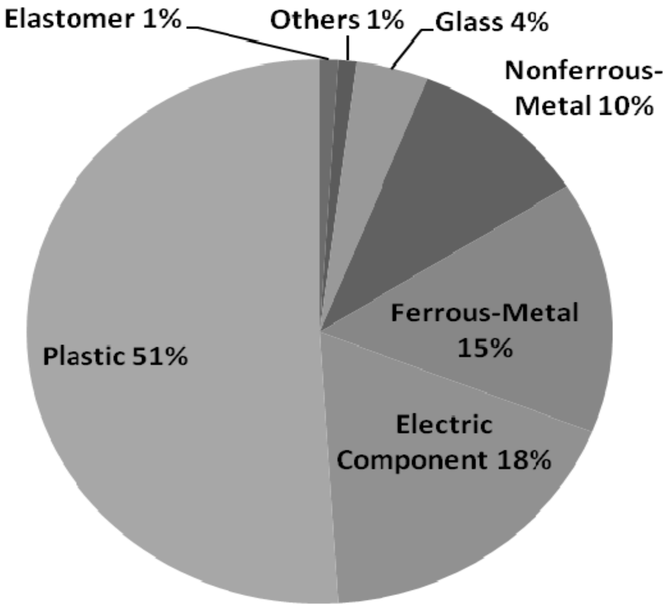

Figure 16: Components of small-sized electronic scrap [Flamme, 2008]

4.10 Recycling of Cooling and Refrigeration Units

According to [ElektroG, 2007] Cooling and Refrigeration Units belong to Category 1 of large household appliances (German law). The required recycling and treatment quota when it comes to re-usage and material recycling is at 75%, at 5% for energy recovery and 20% may be discarded. A typical material composition of Cooling and Refrigeration Units is shown in Figure 17.

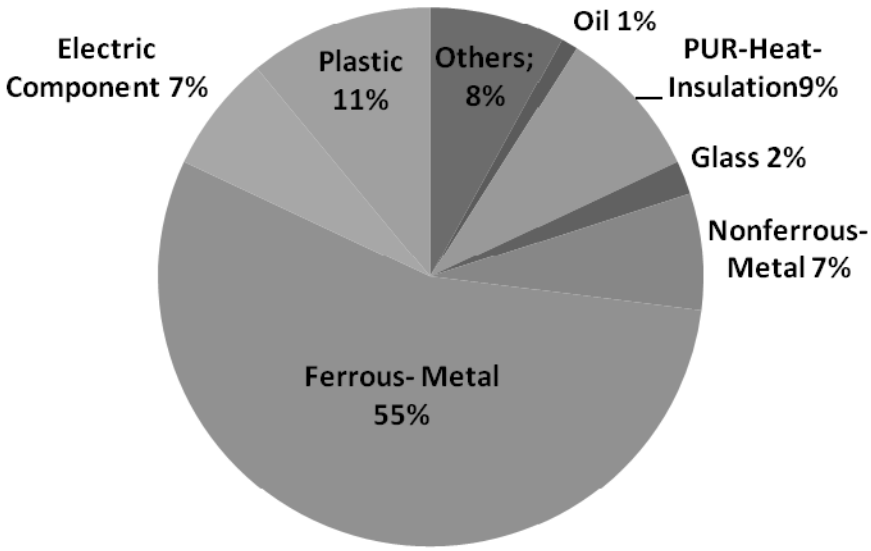

Figure 17: Material composition of Cooling and Refrigeration Units [Flamme, 2008]

The Problem of recycling Cooling and Refrigeration Units

Chlorofluorocarbons (CFCs) and Halon are stable chemical compounds that reach the upper spheres of Earth's atmosphere. CFCs destroy the ozone layer which protects Earth from ultra violet radiation. The degradation of the ozone layer leads to an increase in UV exposure for humans and the environment. Increased UV exposure can lead to multiple health deficits in humans, especially concerning the skin. In 1986 the "Montreal Protocol" was initiated, attempting to greatly reduce and finally abolish the release of CFCs into the atmosphere globally by substituting them with HCFCs (Hydrochlorofluorocarbons), which do not deplete the ozone layer. Later though it was found that some of those HCFCs are much more potent greenhouse gasses then the CFCs they replaced. Since 1995 a drastic decrease in the usage of CFCs and halon in the production of diverse products can be noticed. In Germany this includes amongst others [Bilitewski, 1994]:

- Packaging Material
- Foam application
- Refrigerants
- Compressed gas cylinders
- Any material containing foam

Nowadays glycol is generally added to water to reduce its freezing point.

To completely recycle Cooling and Refrigeration Units the following processing steps are used [Bilitewski, 1994]:

1. Recover combined refrigerant coils with special nippers
2. Degas the oil to less than 0.2% CFCs
3. Disassemble refrigerator and recover recyclables
4. Collect and degas the polyurethane foam

4.11 Recycling of Scrap automobiles

Recycling of scrap automobiles describes the process of recycling raw materials from automobiles to be discarded. In Germany around 3.5 mill. automobiles are disused every year, 95% of which are also disposed of [Nickel, 1996]. The material composition of German automobiles and its development over the years is depicted in Table 10 [Bilitewski, 1994].

Table 10: Average composition and development of German automobiles [Bilitewski, 1996]

Material	Year built % by weight			
	1965	1985	1995	2000
Steel, ferrous	76.0	68.0	63.0	61.0
Aluminum	2.0	4.5	6.5	7.5
Other nonferrous metals (copper, lead, zinc)	4.0	3.0	3.0	4.0

Plastics	2.0	10.0	13.0	14.0
Other (glass, rubber)	16.0	14.5	14.5	13.5

The recycling of automobiles is most frequently done using shredders, like the ones shown in Figure 18 and Figure 19. Contrary to this process, before shredding the automobile a selective disassembly for material recycling can take place (e.g. engine, gearbox and electric generator). Shredding takes place similarly to that done in a hammer mill aggregate. Prior to shredding, remaining fuel and oil remnants are removed. Directly after shredding, the material is treated with a magnetic separator and an air classifier. All that remains now is comprised of non-ferrous metals [Nickel, 1996].

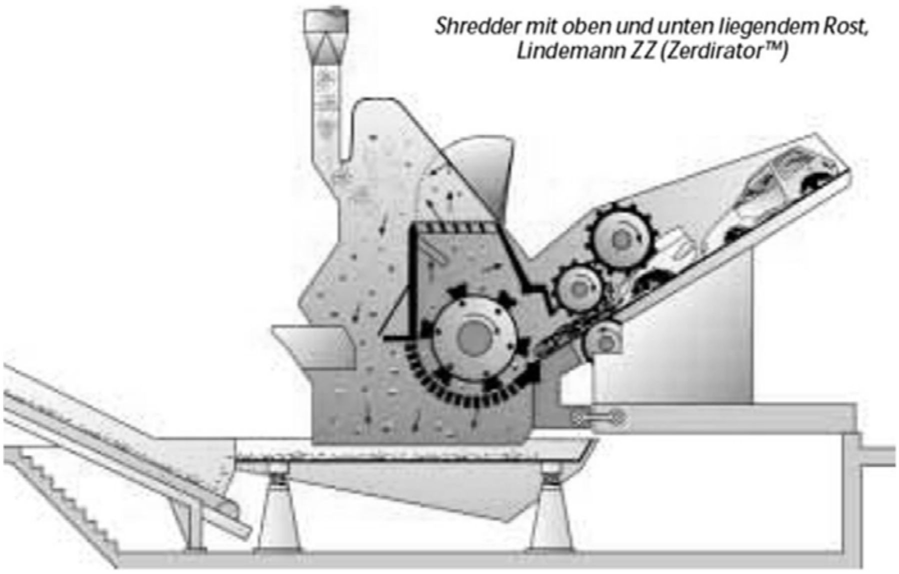

Figure 18: Schematic of a Lindemann Automobil Shredder [Metso, 2010]

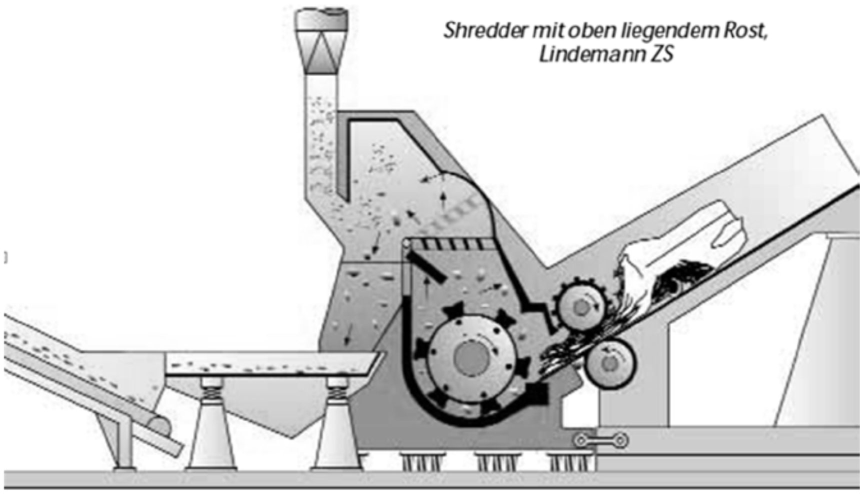

Figure 19: Schematic of a Lindemann Automobil Shredder [Metso, 2010]

The content of ferrous metals in automobiles can be recycled to 100% in this way. Furthermore the shredder delivers additional 25% light weight fractions comprised of aluminum, plastics and other materials.

4.12 Recycling of Scrap Tires

Scrap tires are used tires which are not allowed in traffic anymore due to their wear and tear. The wear does mostly consist of brittleness and reduction of profile depth to below 1.6 mm (in Germany). Because disposing of tires in landfills is forbidden in the whole European Union, they are recycled in different ways materially or energetically (RDF). Automotive tires consist of steel, nylon canvas, natural rubber and different chemicals. The material composition is shown in Table 11 and Table 12.

Table 11: Material Components and part of heavy-metals [BLU, 2008]

Material	average in weight-%
Hydro carbon polymers	47.0
Soot (a part as silicon oxide)	21.5
Steel	16.5
Canvas	5.5
Zinc oxide	1.0
Sulfur	1.0

Table 12: Part of heavy-metals [BLU, 2008]

Heavy Metals	[mg/kg]
Copper compounds	200
Chromium	90
Nickel	80
Lead	50
Cadmium	10

The heating value of scrap tires amounts to approx. 30 MJ/kg which leads to them being preferred as RDF in cement works. Because scrap tires consist of 25% natural carbon, using them as RDF positively effects the CO_2 balance [BLU, 2008].

In 2007, the recycling quota in Germany was 100% with a combined mass of 572,000 tons and 87% in the EU (approx. 500,000 tires).

Using material recycling, there are diverse application areas, like [BLU, 2008]:

- Weighing down cover sheets in agriculture
- Building landfills
- Impact protection for water vehicles and wharf buildings
- Playgrounds and swings

- Shoe soles and sandals (emerging nations and developing countries)

Furthermore scrap tires can be materially recycled through producing granulates and buffing dust as needed for the production of rubber materials i.e. [BLU, 2008]:

- Sports facilities (playing fields, running tracks, tennis courts, equitation sites etc.)
- Insulating material
- Composition elastomers
- Additive for bitumen in road construction
- New-production of automotive tires

4.13 Recycling of Waste Oil

Based on the different compositions and contaminations of waste oil, it is reasonable to categorize them according to their applications to achieve a high success in recycling it. In Germany the following oils are distinguished [AltölV, 2007, §1a Abs.3]:

- motor oils
- gear oils
- hydraulic fluids
- turbine oils
- electro-insulating oils
- compressor oils
- machine oils
- other industrial oils, not used for lubrication
- process oils
- metal machining oils
- lubricating grease

If the oils exceed a rate of 20 mg PCB/kg or 2g total halogen/kg they may not be treated. They have to be removed from the resource stream and should be disposed of. The AltölV also defines a methodology for sampling. Figure 20 shows material and energetic recycling rates.

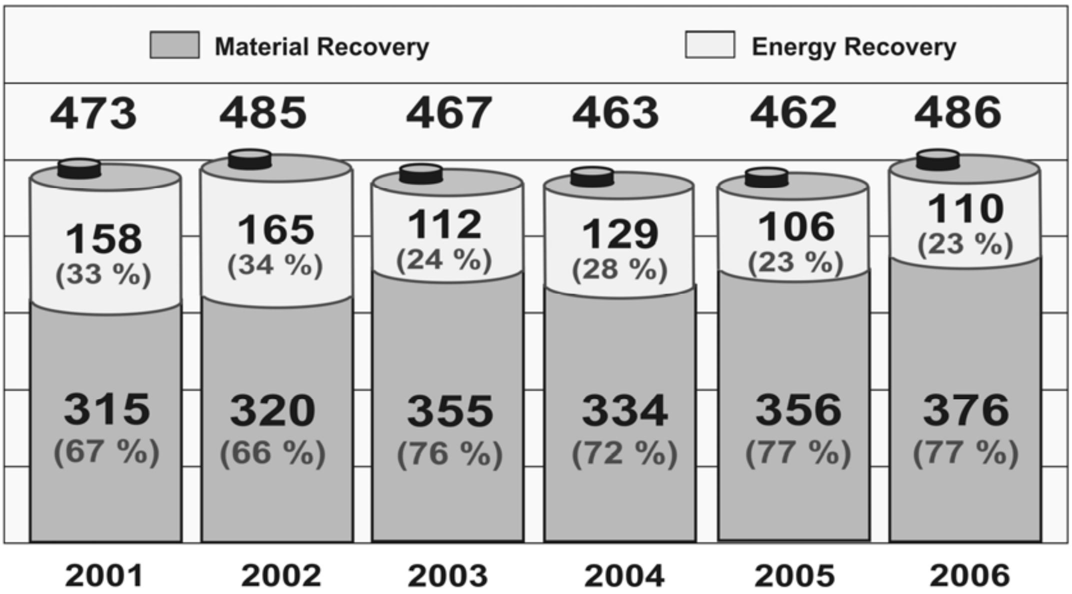

Figure 20: Development of Regeneration of Waste Oil to Base Oil in 1,000 Tons in Germany [BMU, 2006]

Conditioning of waste oil [Patent, 1999]:

- gradual reduction of chlorine content to gain motor oil and diesel-like fuel
- treatment by filtration, centrifugation, dessication (150-300°C), distillation, and adding alkaline compounds

this leads to: separation of water, rough and fine contaminants, reduction of chlorine content

4.14 Recycling of Metals

„Scrap metal is divided into two types: ferrous and nonferrous. Ferrous scrap is scrap iron and steel. This includes scrap from old cars, household appliances, steel beams, railroad tracks, ships, and food packaging and other containers" [Wasteonline, 2010].

Gathering of ferrous metals happens in magnetic separators from MSW or slag from waste incinerators. An amount of about 8-12 kg/p*y of scrap metal is captured [Flamme, 2008].

"Nonferrous scrap metal is scrap metal other than iron and steel. Examples of nonferrous scrap include aluminum - including foil and cans, copper, lead, zinc, nickel, titanium, cobalt, chromium, and other precious metals. Although there is less nonferrous scrap than ferrous scrap, it is often worth more financially. Millions of tones of nonferrous scrap metal are recovered by processors and consumed by secondary smelter, refiners, ingot makers, fabricators, foundries, and other industries." [Wastonline, 2010]

Furthermore old and new scrap metals are distinguished. Waste metal products constitute old scrap while new scrap marks leftovers from metal production i.e. cut-offs [Flamme, 2008].

Recycling of metals is an important foundation for production processes in the U.S., as

Table 13 shows.

Table 13: Substitution of raw materials with several scrap materials [Maker, 1996]

Scrap material	% of total production
Steel Scrap	56
Lead Scrap	66
Aluminum Scrap	37
Copper Scrap	44

The successive increase of recycling quota is shown in the next Figure 21 on the example of aluminum cans. The recycling of aluminum has formed the terms of primary and secondary aluminum. Primary aluminum is fabricated from aluminum ore bauxite, which is then melted by fused-salt electrolysis from clay. Secondary aluminum is not made from ore but from old and scrap metals, which are re-melted. Just 5% of the original energy demand is needed in that process.

Table 14 shows the statistical development of different metal recycling quota between the years of 1987-1993 [Ayres, 1997].

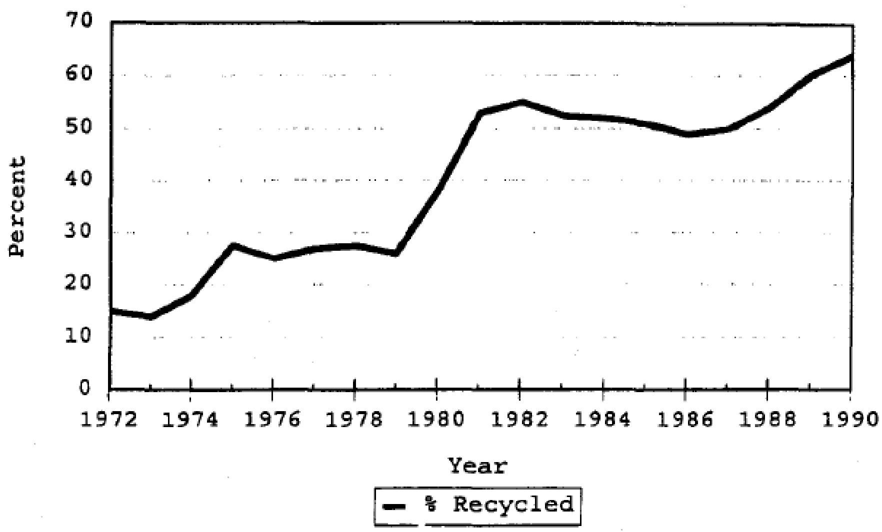

Figure 21: Development of the Aluminum Can recycling from 1972 to 1990 [Makar, 1996]

Table 14: U.S development of recycling statistics for selected metals 1987-1993 [Ayres, 1997]

Year	Quantity [kMt]				Recycle % of apparent consumption
	Recycled metal			Apparent consumption	
	New scrap	Old scrap	Total		
Aluminum					
1987	1134	852	1986	6603	30%
1988	1077	1045	2122	6450	33%
1989	1043	1011	2054	6000	34%
1990	1034	1359	2393	6298	38%
1991	979	1522	2501	6012	42%
1992	1144	1612	2756	6869	40%
1993	1312	1632	2944	7852	37%
Copper					
1987	716	497	1213	2913	42%
1988	788	518	1306	3002	44%
1989	761	537	1298	2945	44%
1990	774	548	1322	2924	45%
1991	682	518	1200	2731	44%
1992	723	555	1278	3028	42%
1993	731	555	1286	3256	39%
Lead					
1987	52,535	657,532	710,067	1259,029	56%
1988	45,274	691,127	736,401	1274,477	58%
1989	49,612	841,729	891,341	1384,725	64%
1990	48,104	874,093	922,197	1345,381	69%
1991	54,970	829,654	884,624	1283,474	69%
1992	55,424	860,917	916,341	1325,408	69%
1993	60,298	843,262	903,560	1390,464	65%
Nickel					
1987			32,331	155,781	21%
1988			41,039	159,019	26%

Year	Quantity [kMt]				Recycle % of apparent consumption
	Recycled metal			Apparent consumption	
	New scrap	Old scrap	Total		
1989			52,131	157,103	33%
1990			57,367	170,042	34%
1991			53,521	156,663	34%
1992			55,871	159,373	35%
1993			54,702	159,313	34%
Tin					
1987	4604	11,462	16,066	59,458	27%
1988	3925	11,350	15,275	60,955	25%
1989	2795	11,545	14,340	47,285	30%
1990	4035	13,200	17,235	53,430	32%
1991	5114	7982	13,096	39,606	33%
1992	4894	8853	13,747	37,321	37%
1993	4453	7219	11,672	42,906	27%
Zinc					
1987	270	82	352	1324	27%
1988	240	97	337	1340	25%
1989	230	117	347	1311	26%
1990	232	109	341	1240	28%
1991	233	120	353	1165	30%
1992	234	132	366	1276	29%
1993	246	109	355	1367	26%

Tinplate is made from cold-rolled steel, which is then coated with zinc in order to prevent corrosion. Wall strengths of 0.5-0.1 mm are average today and a zinc coating of 0.3 µm is sufficient for corrosion protection. Tinplate is a 100% recyclable and can be reused without quality deterioration. Hence recycling quotas in Germany always exceed the required 70% by about 20%. According to [Grüner Punkt, 2010] through recycling about of 800.000 Mg/y of iron ore and 360.000 Mg/y of coal are economized.

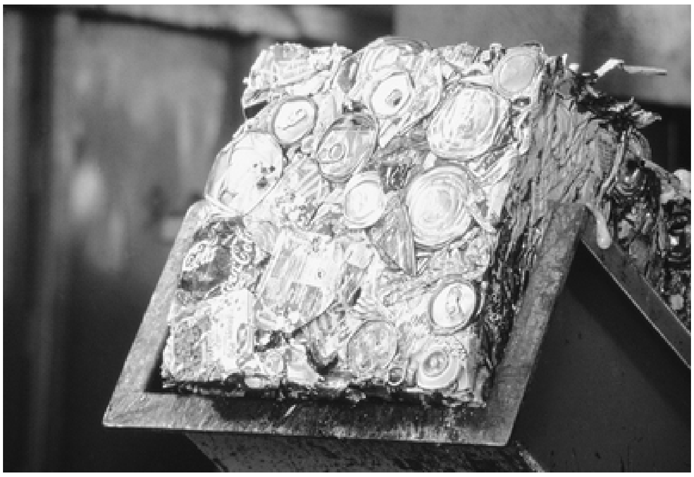

Figure 22: Compressed tinplate [Grüner-Punkt, 2010]

5 Resource Management

5.1 Conditions of recycling

Recycling can only function and be successfully established in the market, if the production of new products can be achieved more economical and ecological with it. Therefore energetic recycling needs to substitute primary energy sources. At the same time material recycling should replace primary resources with secondary resources.

The quantity and quality of secondary resources as well as of secondary products is influenced by the selection system, the return logistics and the processing by recycling companies. Next to quantity and quality the different systems also affect cost effectiveness and environmental impact. At the same time acceptance of the usage of secondary resources plays an important role for the sales market of recycled materials. The production industry demands a high quality standard for secondary resources that is influenced by consumers. To minimize problems in acceptance and limit constraints for usage of secondary resources, a maintained and guaranteed quality of recycled material is essential.

To attain a positive balance of the usage of recycling material in matters of cost effectiveness and environmental impact, the following aspects should be taken into account [Nickel, 1996]:

- Adequate systems for acquisition, collection and transport
- High or ample sorting accuracy of the waste (recyclability of wastes)
- Satisfactory demand of secondary resources and products
- Recyclability of the used product (construction favoring recycling)
- Security of disposal of the wastes occurring in the recycling process
- Availability of fitting recycling technology

5.2 Limits of Recycling

Feasibility of recycling is limited by economic, ecologic and technical constraints. When comparing cost effectiveness of recycling and disposal the following criteria have a high significance:

- Recycling is reasonable, as long as revenues from secondary resources minus the costs for recycling and disposal of residues are higher or at least equal to the cost of total disposal of the waste
- The Break-even point is reached when proceeds equal the difference in costs for recycling versus disposal
- At the break-even point the utilization threshold is reached

[Nickel, 1996] describes this coherence with the following formula:

$E_{SR} + K_B \geq K_R$ from this follows that

$E_{SR} \geq K_R + K_B$

E= revenues
K=costs
SR=secondary resources
B=disposal
R=recycling

In the consideration of environmental impacts through recycling and disposal the following criteria are central:

- Recycling is only ecologically acceptable if the environmental impact of the ecologically weighed mass of secondary material is higher than the difference between the occurring environmental impact and disposal
- Environmental impacts are the sum of all resources spent and otherwise occurring emissions as well as wastes
- Environmental impacts are measured by a life-cycle assessment
- The break-even point is reached at the ecological utilization threshold

The calculation of environmental impacts according to [Nickel, 1996] is carried out with the following formula:

$$\sum_{t_e}^{t_\infty} \sum_{i} (M_{PR} + M_{AE})t, i = UB_{B,R}$$

t_∞= theoretical end of utilization
t_e= theoretical end of disposal
UB= Environmental Burden

Indices:
PR= primary resources
AE= waste and emission
B,R= Disposal / Recycling

That way the environmental impacts for recycling are certain, if considering secondary resources as a substitute for primary resources. With the next formula an evaluation of environmental relief and burden can be achieved. If left and right side of the formula have an equivalent result the break-even point is reached.

$$M = m * b$$
$$M_{SR} \geq UB_R + UB_B$$

M= ecologically weighed masse
UB=environmental impact
SR=secondary resource
B=disposal
R=recycling
b=ecological weighing (effective potential)

Technical barriers show, as the quality of secondary resources does not equal the demand in the application industry. Reasons can be improper return logistics as well as an unsuitable recycling technique. The value of fraction can partially be decreased through the breakdown process in pretreatment.

5.3 Recycling magnitude and proportion

Recycling magnitude and proportion provide key data for the potential of a waste management. High recycling quotas suggest a high potential to substitute primary resources with secondary resources and at the same time reduced waste management costs. In this chapter recycling quota and magnitudes are described.

Comparing the recycling behavior of different European cities very different recycling quota and magnitudes can be seen. While in Copenhagen and Munich almost all waste is recycled, the recycling potential in Budapest, Berlin and Paris can be expanded. Figure 23 shows this very clearly.

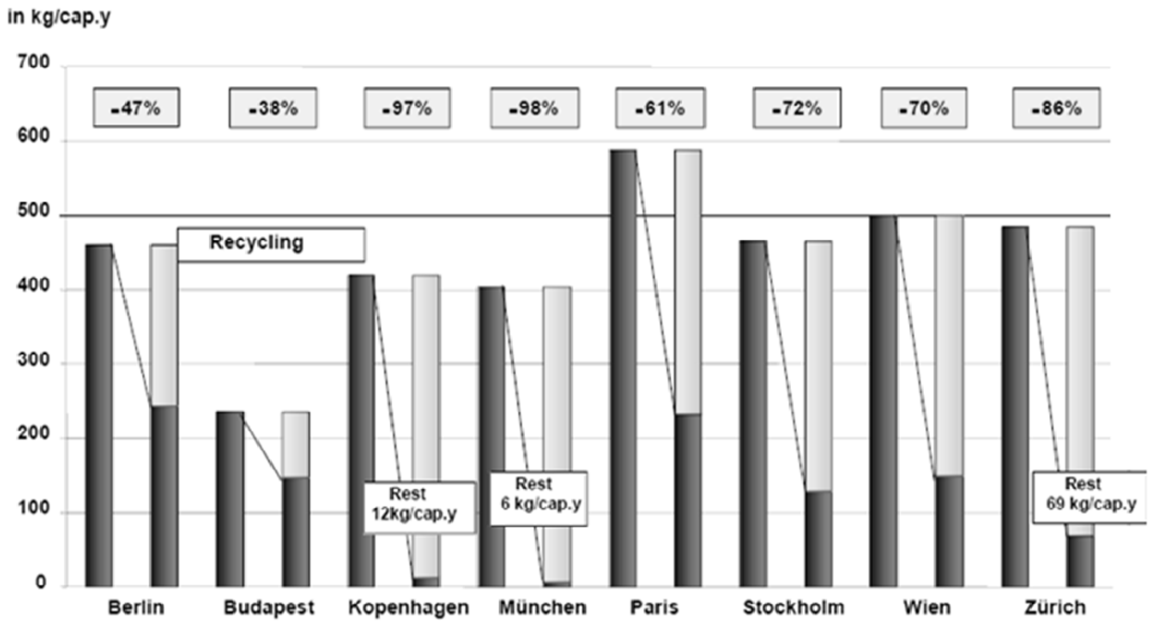

Figure 23: Waste reduction through material recycling, waste-to-energy and slag treatment [Bilitewski, 2008]

Of the construction and demolition waste occurring in Germany in 2006 88% could be recycled, while just 12% had to be disposed of in landfills. Overall an amount of 196.5 mill. tons of waste occurred of which 173.7 mill. tons got recycled (172.5 mill. tons material recovery und 1.2 mill. tons energy recovery). This is a good example of how recycling by the industry itself can lead to high recycling rates. The building and demolition industry in Germany was threatened with legal recycling standards in the 1980s and therefore self-commited to recycling, which shows good effects today. Figure 13 shows this.

When looking at recycling quota of packaging consisting of glass, tinplate, aluminum, plastics and paper a sukcessive increase can be seen. The period of time mentioned here is 1990 to 2003. [Bilitewski, 2006] has put together the recycling quota an magnitudes, which are shown inTable 15.

Table 15: Recycling quota and magnitudes of packaging in Germany [Bilitewski, 2006]

	Unit	1991	2000	2002	2003
amount of waste glass	[1000 Mg]	2049.7	2709.2	2466.4	2320.2
recycling rate glass	[%]	53.7	81.7	85.2	86.4
amount of waste tinplate	[1000 Mg]	250.6	515.3	521.2	436.9
recycling rate tinplate	[%]	33.8	79.8	82.0	88.1
amount of waste aluminum	[1000 Mg]	4.3	60.3	58.5	55.8
recycling rate aluminum	[%]	5.1	76.0	71.5	72.6
amount of waste plastics	[1000 Mg]	30.0	651.1	755.1	784.3
recycling rate plastics	[%]	3.1	58.1	54.7	57.9
amount of waste paper	[1000 Mg]	514.0	1541.9	1659.6	1640.9
recycling rate paper	[%]	28.0	77.4	81.0	78.9

amount of waste Total	[1000 Mg]	2848.7	5612.6	5604.9	5397.2
recycling rate Total	[%]	37.3	76.1	77.1	77.8

At the example of the waste paper recycling quota a historic development can be seen which is shown for the years of 1950 to 2003 in Figure 24 of [Bilitewski, 2006]. Until 1989 the data refers to Western Germany. From 1995 on recycling quotas of re-united Germany are provided. The quota results of waste paper recycling divided by paper usage and multiplied with 100.

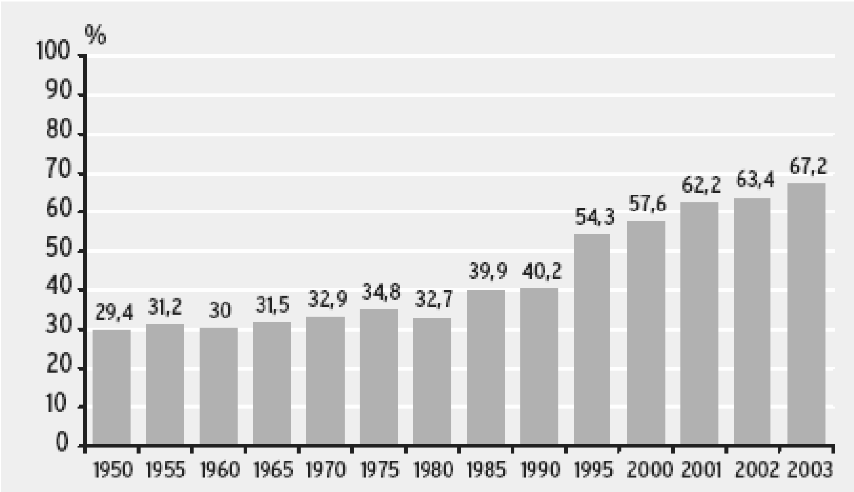

Figure 24: Wastepaper recycling quota, development 1950 - 2003 [Bilitewski, 2006]

Scrap tires get 53% energetically recycled, 28% materially recycled and just 4% are disposed of according to [Rotter, 2005]. At a waste occurrence of 587.000 t/a of scrap tires, about 235.000 t get materially and 310.000 t energetically recycled as depicted in Figure 25.

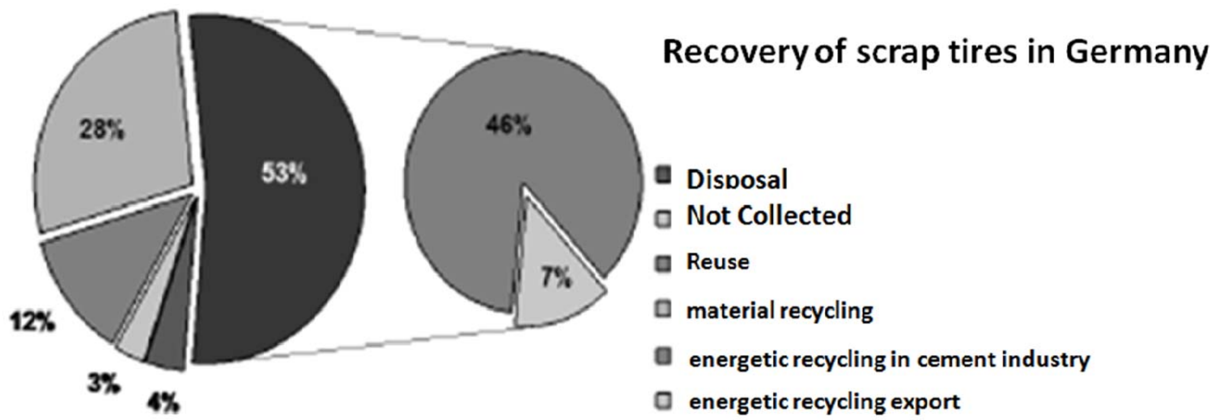

Figure 25: Recycling rates of scrap tires in Germany [Rotter, 2005]

5.4 Logistic of waste collection and recovery

Costs of recycling and its revenues are fundamentally influenced by the logistic concept of the disposal routes. To use and produce secondary resources economically, incentives have to be created on multiple levels. Only thusly, the recycling process can be optimized and enhanced:

- With appropriate waste separation, the costs of waste disposal can be reduced, whereas with inappropriate separation the costs rise and will be passed on to the waste producers
- Waste management companies have to facilitate and abet systems for waste separation in order to increase quantity and quality of value creation
- Processing at the treatment plants needs to be matched and optimized to the composition of the expected waste
- The amount and quality of the secondary resources directly influences the extend of the substitution of primary resources the consumer of the recycled material achieves

The logistic of waste collection and recovery is comprised of the components depicted in Figure 26:

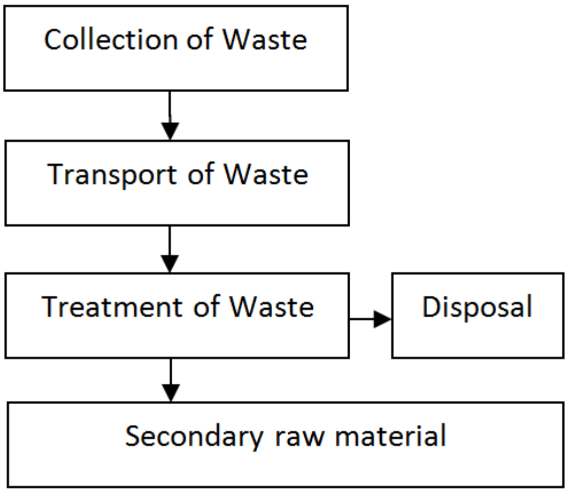

Figure 26: Components of the recycling concept

Costs for collection and transport are influenced by the following factors [Flamme, 2008]:

- Container sizes
- Container costs
- Container density on the collection route
- The frequency of the collection interval
- Transport distance
- Size of the collection team
- Service (full or partial service)
- Duration of the collection time
- Available working time if the collection team
- Performance/capacity of the collection vehicles
- Vehicle costs (maintenance, service and repair, fuel consumption)
- Fuel costs

The value creation of recycling rises with increasing sorting accuracy of the collected waste, so the recycling potential can be more fully realized by presorting the waste directly at the producer. To sensibilize participating citizens for the topics of recycling and waste separation, political awareness training is needed. The technology of processing plants can only compensate for absent separation to a certain amount. The technology and the individual steps of the treatment are illustrated in the Modul „Mechanical, Biological and Thermal Waste Treatment".

Costs for the treatment in processing and sorting plants are influenced by the following factors:

- Investment and operational costs
- Throughput rate (daily, monthly, yearly) and performance of the processing plant
- Amount of the waste input (daily, monthly, yearly)
- Energy efficiency of the aggregates and power costs
- Service and maintenance of machines and vehicles

5.5 Examination of cost effectiveness, costs of product recycling

The complete cost pools are comprised by logistics, clearing and recovery. The cost quota of each pool is weighted at one third, according to [Nickel, 1996]. The three cost pools contain the following subcomponents:

For recycling, the polluter pays principle is applied: the user or last owner of the waste has to pay for the disposal thereof. This is paid through a municipal charge, which depends on the size of the household. In parts, this fee is passed down to the consumers indirectly, when manufacturers e.g. pay a waste tax, which in turn raises the product price.

Costs for disposal and recovery are split between fixed and variable costs, which must be covered by the communal fee structure. Fixed costs are made up by investment costs (and redemption of amortizations respectively) and the expenditure for collection landfills and separately collected waste materials. Examples for fixed costs are [Bilitewski, 2007]:

Table 16: Cost pools of product recycling [Nickel, 1996]

Logistics	Clearing	Recovery	Revenue
Products	Identification	Investment	Source materials
Collection		Disassembly	
Transport		Sorting	
Storage	Classification	Treatment	Energy from combustion
Sorting		Provision	
Distribution			
		Manufacturing	
Material streams			
Proofing		Landfill	
Registration		Combustion with Energy use	
Controlling			

- Fee assessment
- Transportation to the location
- Emptying of the waste containers
- Provision of vehicles
- Acquisition and delivery of waste containers
- Personnel, maintenance, rent, calculatory interests, amortization and other costs

Variable costs are dependent on the increasing number of waste producers and the amount of produced waste. Those are the cost fraction, which occurs with every additional recycled waste unit. Its increase is therefore linear.

Examples for variable costs are:

- Salaries (temporary work, task work)
- Energy cost per ton of recycled waste
- Fuel costs for transportation
- Electricity costs

Flat rate denotes the basic fee the waste producer has to pay. The actual costs are very hard to calculate though. With the flat rate in the middle, the variable costs encircle the actual costs. The profit and loss margins of the recycling industry therefore largely depend on the flat rate, the variable costs and the amount of waste.

The composition of the cost structure is visualized in Figure 27 [Bilitewski, 2007].

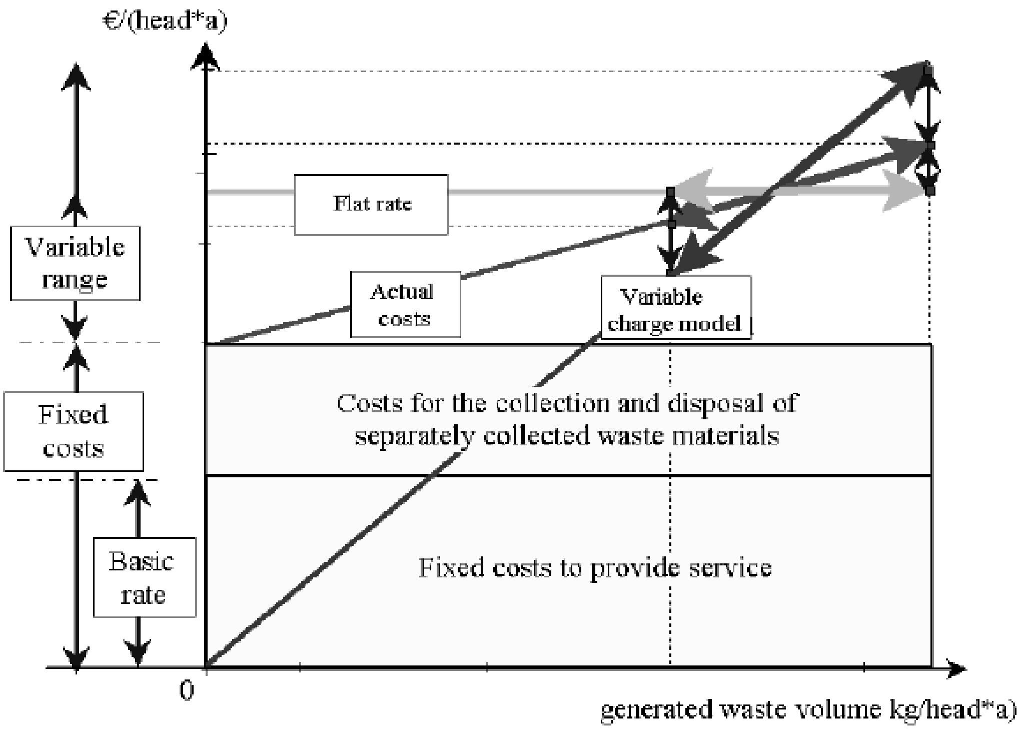

Figure 27: Composition of cost structure [Bilitewski, 2007]

Figure 28 compares the costs for recycling with costs for primary resources and those for disposal, so cost saving from recycling can be localized and an optimum be found. The y-axis shows the cost, while the x-axis shows the quota of recycled material in the waste fraction.

Example:

If no recycling takes place (0%), 100% of the waste amount has to be treated, while with a 100% recycling rate, no waste (0%) remains to be treated.

The recycling costs (dash-dotted line 2) show an exponential slope with the increase of treatment percentage of the waste. This exponential increase is in context with up and down grading. With the increase of the recycling fraction, the resource density drops so the effort to recycle the remainder exponentially exceeds the benefits. Costs for a recycling rate of 100% therefore go towards infinity.

The primary resource costs (line 1) decrease diametrically to the recycling costs because the acquisition of secondary resources substitutes the costs for primary resources. With a hypothetical recycling rate of 100%, the costs for primary resources would drop to 0, as all primary resources would be totally substituted. The y-axis only shows costs, to show revenues as well would complicate the chart.

Adding costs for recycling and primary materials results in Graph “B”. B therefore depicts the margin, in which recycling is cost effective and usage of primary resources can be decreased. Optimum 1 (Opt.1) points to the optimum ratio of recycling costs to primary resources costs. If more then 70% of the waste are recycled, the costs for recycling exceed the revenues of secondary resources respectively the costs for primary resources.

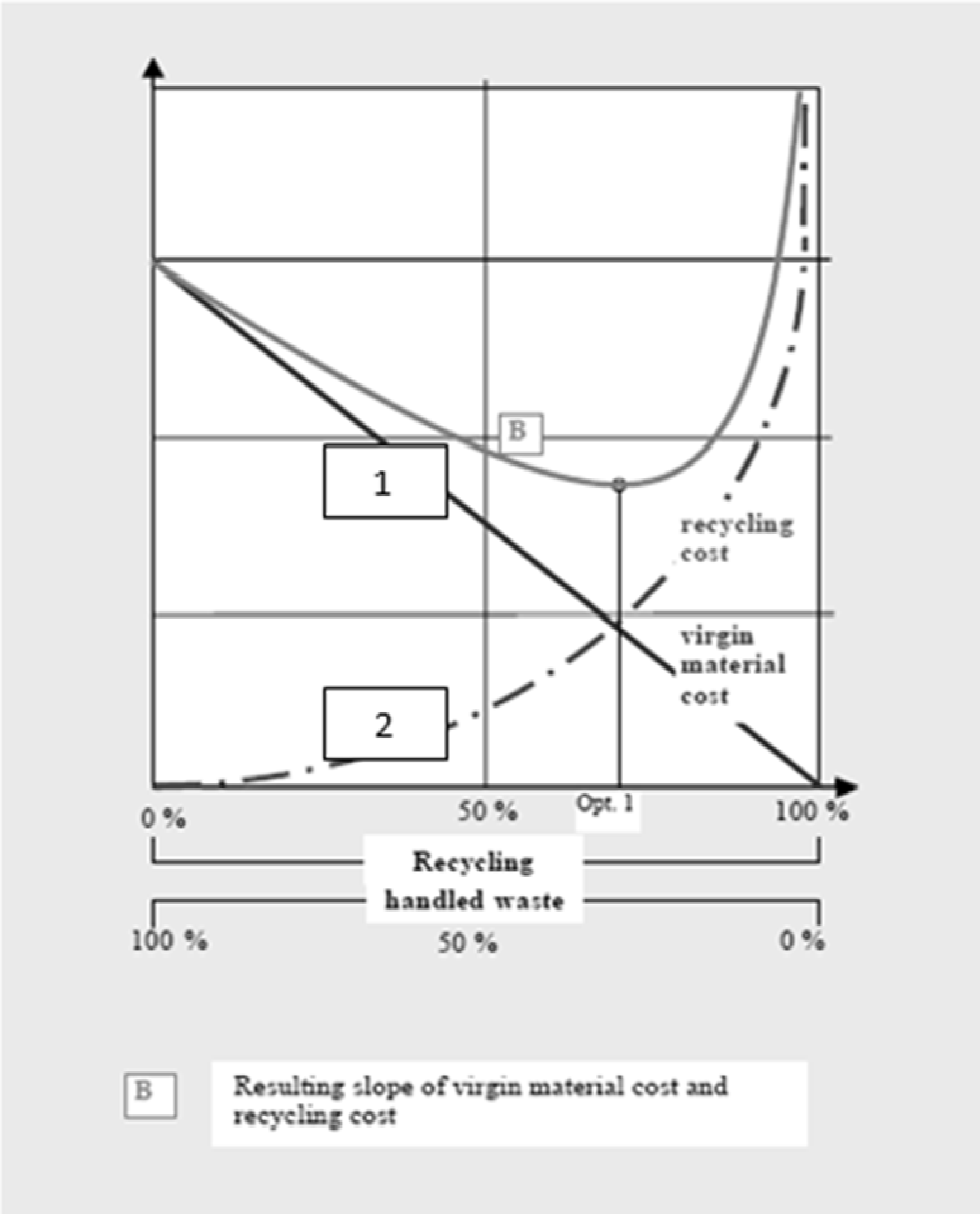

Figure 28: Break-even-Diagram for recycling and virgin material costs according to [Bilitewski, 2009]

This however only presents a simplified assumption, as the costs for disposing of the waste fraction need also to be taken into account. This is shown in Figure 29. The line 3 depicts the costs for disposing of the unrecoverable waste fraction; these costs also decrease with an increasing recycle quota. If no recycling takes place at all, the disposition costs are highest.

Graph “A“ results from the addition of:

- Recycling costs
- Costs of primary resources/revenues from secondary
- Disposition costs.

It therefore expends area B with the disposition costs. Combined, the waste management costs and the virgin material costs result in the “total cost without recycling cost” graph (line 4). Due to the higher negative inclination rate of the linear function, Optimum 2 lies farther to the right. It is only reached at a recycling rate of 80%.

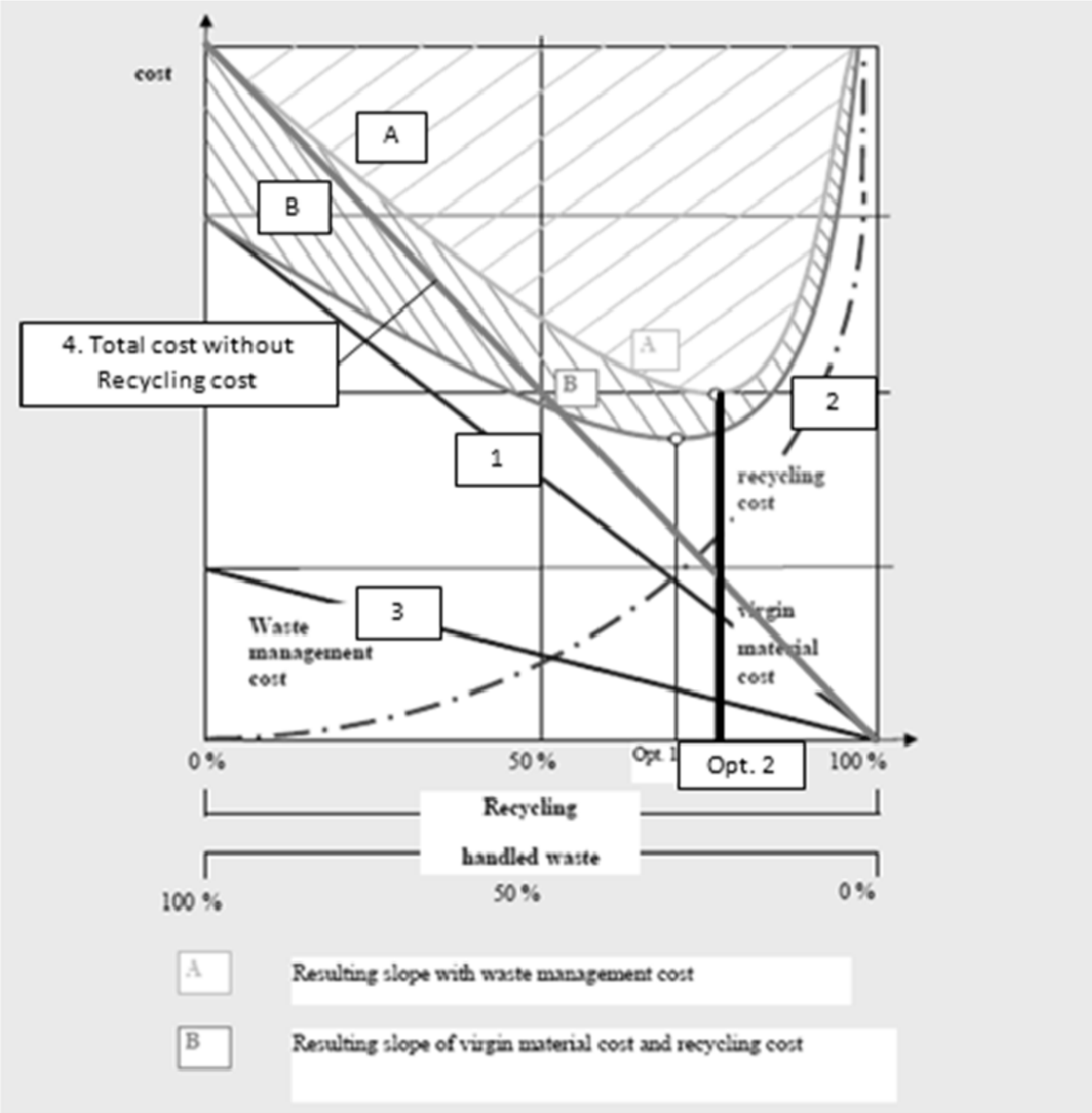

Figure 29: Break-even-Diagram including waste management cost according to [Bilitewski, 2009]

5.6 Influences on marketing of recycling products

Marketing of secondary resources is the sub-process with the biggest optimizing opportunities according to [Bilitewski, 1994]. This sub-process is influenced by different outer factors as shown in Figure 30.

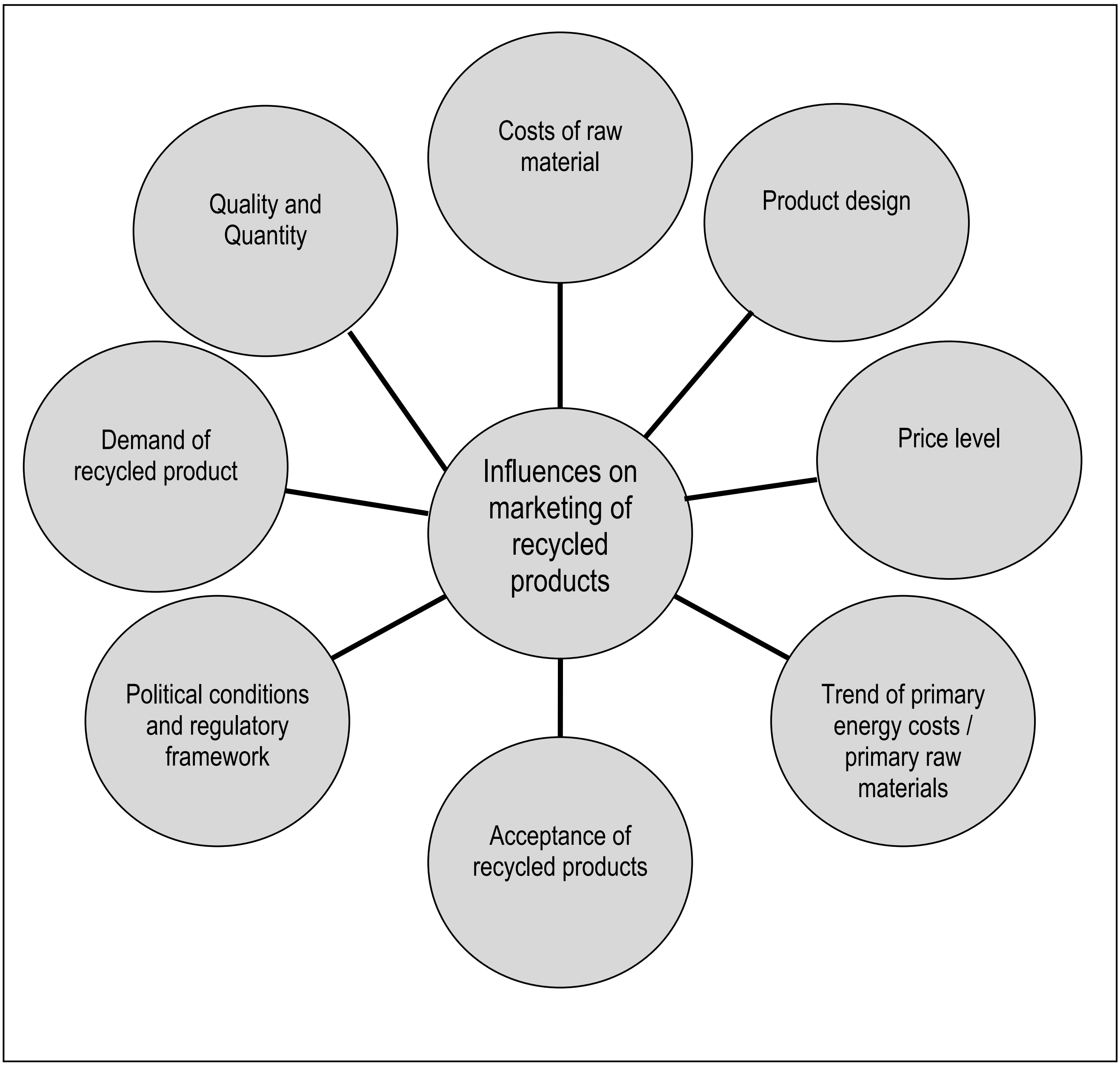

Figure 30: Influences on marketing of recycled products

Trend of primary energy costs / primary raw materials:

With a growing world population, economic growth and globalization of the last years a successive increase of demand for resources and primary energy sources can be seen. Figure 31 clarifies this correlation. With increasing demand and the rising prices for primary resources usage of secondary resources became more interesting for many industrial processes. In the last years Asia and especially China had the largest economic growth which increased resource usage and with this resource prizes.

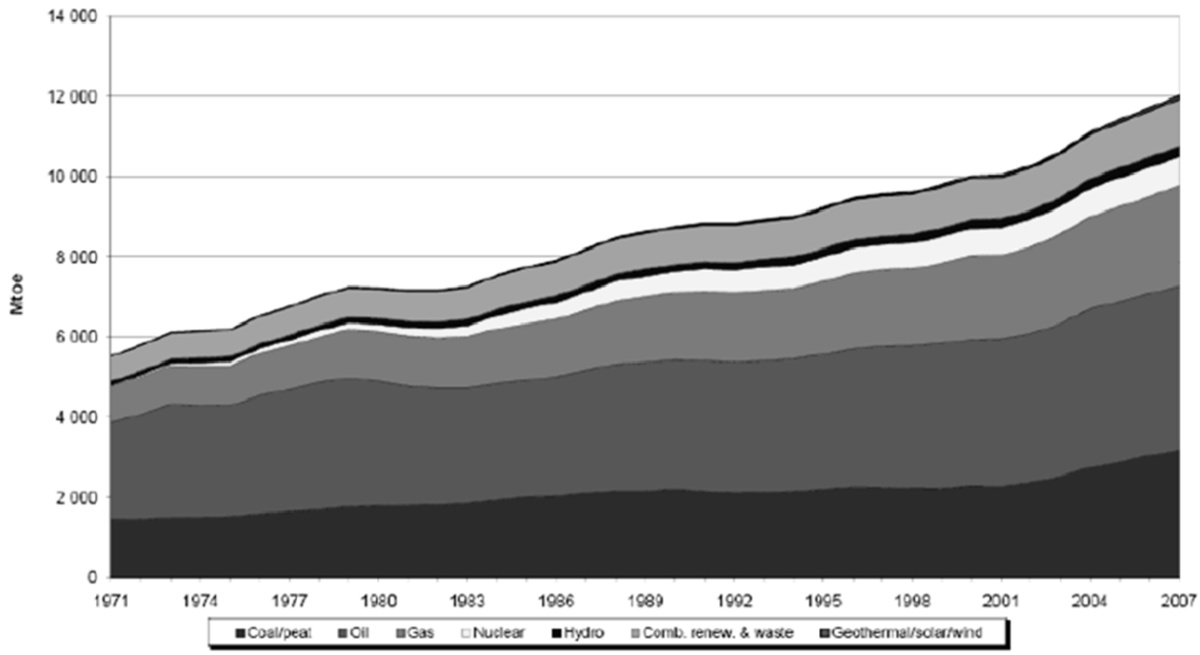

Figure 31: Trend of worldwide primary energy consumption [IEA, 2010]

Political circumstances and general legal conditions/ promotions:

Recycling and its marketing can just function with the help of politics and embedment into legal conditions. The promotion of resource efficiency and the intensified usage of secondary resources can limit the dependency on primary materials and imports, and improves the environmental balance assessment [EuComission, 2010]. Tools for the promotion of waste management are for example [EurActiv, 2010]:

- landfill taxes
- producer's responsibility
- tradable certificates as in the UK
- appeal systems i.e. "pay as you throw"-systems
- Broadening of the IPPC (Integrated Pollution Prevention) guideline
- quality standards for recycling
- research and development
- promotion of demand for recycled goods

Further aspects and reasons having influence on the marketing of secondary resources:

Buyers of recycling products expect a secured amount and a standardized quality of secondary products. These specifications are sometimes only met through intensive efforts. With a very low sorting accuracy secondary products can't be used by buyers, which generates higher costs for the seller (owner of a treatment facility) because loads have to be disposed of or be fed to further treatment. For cost-saving delivery and supply of waste and recycled material the location of the treatment facility and its connection to local infrastructure are important.

In many cases locations are chosen that do allow for delivery via train, ship and truck to the individual acceptor. The marketing of secondary resources is closely linked to the economic situation. In times of low resource and energy prizes there is a high tendency to go back to using primary resources. This situation leads to secondary products just having access to the markets through low prizes. There is a strong correlation between the inhomogeneous quality of secondary resources and the limited usability. The demand takes a large role in the marketing and sale of recycling products. Supply and demand are modulated by an electronic stock exchange to allow suppliers with small products amounts efficient trade as well. Next to aspects of the market the acceptance of products from secondary materials and product design are important. In some cases producers are being accused of having a low self-conciousness concerning the use of recycled material. At the same time economic and ecologic advances could be marketed offensively [BVSE, 2010]. Instead usage of recycling material is often concealed bashfully.

5.7 Revenues and savings through resource management

Recycling can have an extensive share in climate and resource protection. The dimension of contribution is largely affected by revenues from secondary resources. Prizes for recycling products are dependent on the following factors:

- type and amount of fraction
- quality and respectively sorting accuracy
- product demand on the market
- costs of primary resources
- utilization rate of secondary material in production of new products
- prizes of competitors
- recycling capacity

Prizes and revenues do therefore change annually, monthly, even daily. With increasing local recycling capacities higher recycling quota can be achieved, while nationwide growth in capacity (sum of all recycling and treatment facilities) can lead to a decreasing prize for secondary material.

Retailer's prizes for waste paper in Germany are given by [Euwid, 2010] from 23. July 2010 with the values mentioned in Table 17.

Table 17: Retailer's prizes for waste paper [Euwid, 2010]

Material	27.07.2009 [€/Mg]	23.04.2010 [€/Mg]	23.07.2010 [€/Mg]
mixed bales	10 - 20	80 - 90	70 - 75
old newspapers	50 - 55	110 - 115	110 - 115
colored files	65 - 75	115 - 125	170 - 190
white cover chippings	300 - 340	320 - 360	365 - 405

Steal prizes differ for type and sources of the steal. Sorts E1 and E3 belong to the group of „scrap metal“, while E2 consists of „new scrap“, and E4 describes „shredded scrap“. The different sorts have different physical and chemical characteristics. Differences are seen in bulk density, contamination rate, portion of coated material and wall thickness.

[BVSE, 2010] provides actual mean steal prizes of June 2010 for the sorts of E1, E2, E3, and E4 and compares it to the prizes of the previous month (Table 18).

Table 18: steal prizes for May and June 2010 in Germany [BVSE, 2010]

Material	Category	prizes May 2010 [€/Mg]	prizes June 2010 [€/Mg]
Steal E1	old scrap metal	231.6	181.3
Steal E3	old scrap metal	262.9	223.2
Steal E2	new scrap	299.5	280.4
Steal E4	shredded scrap	260.0	212.0

When looking at the prizes for plastics a comparison of costs for primary and secondary plastics is established. Compared are standard plastics in the form of ground stock. Data is provided by [BVSE, 2010] for May 2010.

Table 19: Comparison of prizes for primary and secondary plastics [BVSE, 2010]

Material	primary plastics [€/Mg]	Material	secondary plastics [€/Mg]	Difference [€/Mg]
PE-LD foil	1300 - 1350	PE-LD	450	850 - 1200
PE-HD blow-fitted	1190 - 1210	PE-HD	480	710 - 730
PP- Copolymer	1360 - 1400	PP	470	890 - 930
PVC Foil/cabel	1100 - 1140	PVC-H	340	760 - 800

Treatment of plastics into granulates leaded to the following revenues in May 2010:

Table 20: Revenues for standard plastic granulates in May 2010 [Plasticker, 2010]

Material	secondary plastic revenues in [€/Mg]
PE-LD	810
PE-HD	750
PS	830
PP	960

Revenues for high-value aluminum, copper, zinc, and lead are shown in Table 21 Proceeds relate to a 15 month period and were provided by [Euwid, 2010].

Table 21: Revenues for aluminum, copper, zinc, and lead [EUWID, 2010]

Material	Revenues [US $/Mg]
Aluminum	2115 - 2220
Copper	7005 - 7015
Lead	1985 - 1990
Zinc	1983 - 1988

In [Makar, 1996] the primary energy saved through usage of secondary resource is calculated. Values for aluminum, copper, iron/steal and lead are provided. Energy savings lie between 60% for lead and 96% for aluminum. The energy savings are given in Btu as well (1Btu = 1005,056 J).

Table 22: Energy Savings Related to Recycling (1965-1990) by [Makar, 1996]

Material	Energy required to produce 1 ton of metal from primary ore [kWh/ton]	Energy required to produce 1 ton of metal from scrap [kWh/ton]	Energy savings [%]	Total energy savings [10^{15} Btu]
Aluminum	51.379	2.000	96	6.3 - 10.4
Copper	13.532	1.726	87	1.2 - 2.9
Iron/Steal	6.481	1.784	74	0.09 - 0.29
Lead	7.910	3.176	60	4.1 - 17.3

Furthermore the use of secondary resources as RDF has a positive influence on climate protection and balanced GHG emissions. Through the utilization of RDF in co- or mono-combustion expensive CO_2 certificates can be saved. Whether co-combustion of RDF in a lignite-fired power plant is profitable can be seen in Figure 32 by [Eckardt, 2010]. RDF costs, costs for CO_2 certificates and lignite influence the overall cost savings.

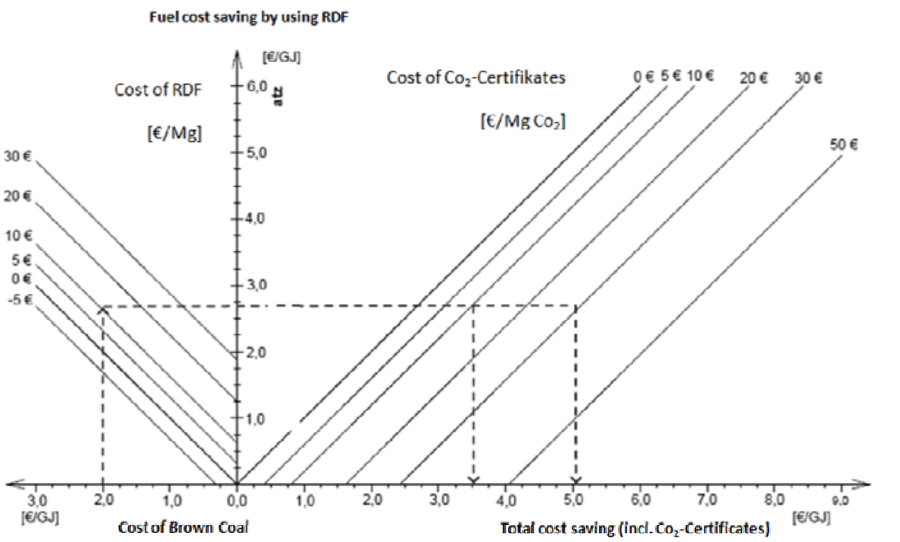

Figure 32: Realized cost savings through utilization of RDF in a lignite-fired power plant [Eckardt, 2010]

5.8 Example of a financial statement of a treatment facility

Looking at the results of a German packaging sorting facility of the Nehlsen company high amounts for the individual fractions occurred. The highest amounts have been measured for mixed plastics, tetra paks and tinplate, while high-quality aluminum and polystyrene showed very little amounts. Data is provided for sorting results for June 2010 with an overall input of 1432 Mg. Figure 33 shows the sorted fractions and their weight.

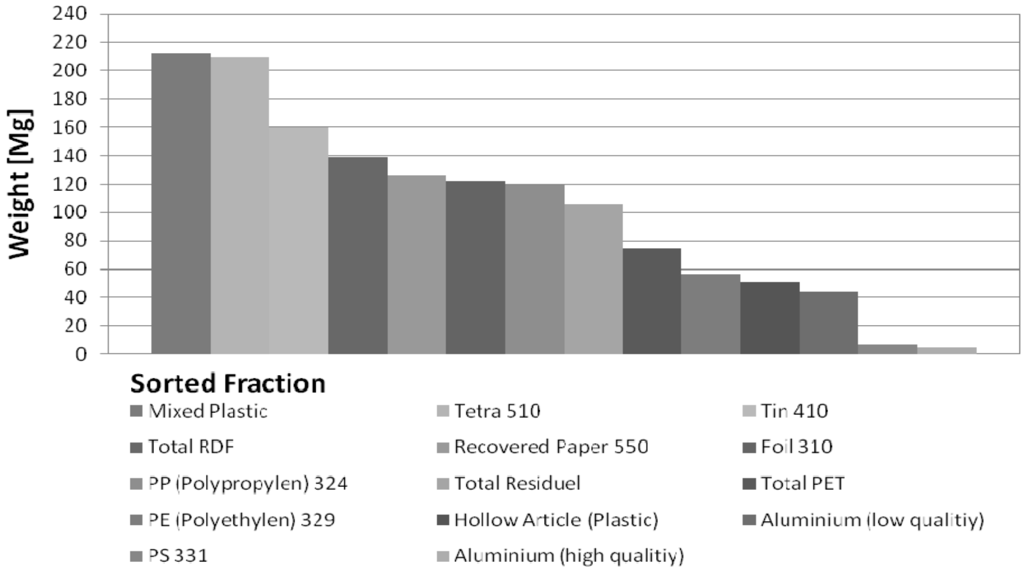

Figure 33: Output fraction (June) of a German treatment plant [Nehlsen, 2010]

For the month of July 2010 in the same treatment facility the results are shown in Figure 34 Input amounted to 1678 Mg. In July the configuration was changed to promoting especially tinplate sorting. This is result of the current tinplate prizes and previous settled supply agreements.

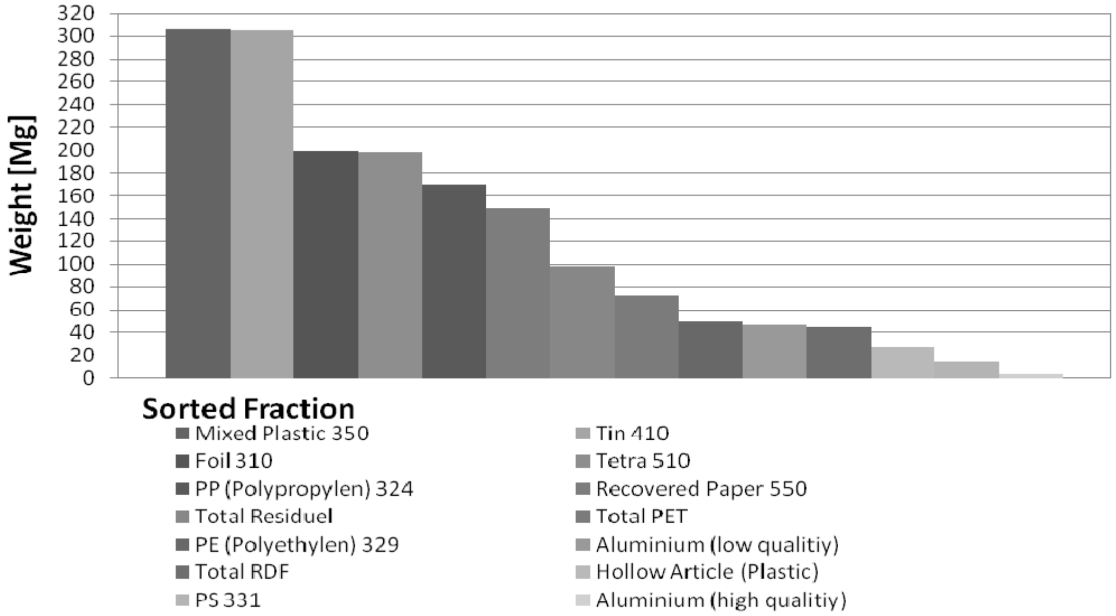

Figure 34: Output fraction (July) of a German treatment plant [Nehlsen, 2010]

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