SIXTH FRAMEWORK PROGRAMME
PRIORITY [policy-oriented research priority SSP 5A]

SPECIFIC TARGETED RESEARCH OR INNOVATION PROJECT

FORWAST

Overall mapping of physical flows and stocks of resources to forecast waste quantities in Europe and identify life-cycle environmental stakes of waste prevention and recycling

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Title: Report chapter with description of three what-if scenarios of waste treatment policies and their interplay with the macro-economic scenarios

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1. INTRODUCTION

This deliverable is part of FORWAST work package five "Scenario and waste technology definitions". The objectives of FORWAST are:

- to provide an inventory of the historically cumulated physical stock of materials in the EU-27 and to forecast the expected amounts of generated waste, per resource category, in the next 25 years.

- to assess the life-cycle wide environmental impacts that result from different scenarios of waste prevention, recycling and waste treatment.

The forecasting component is done by defining two sets of scenarios: a first set of macroeconomic scenarios and a second set describing different waste management policies. These scenarios are crossed, giving a total of 9 scenarios.

The macroeconomic scenarios were presented in the deliverable 5-2. This deliverable is about the waste treatment scenarios and is organised into five chapters:

- The first chapter deals with waste prevention. In a first step the waste streams with the highest potential in waste prevention were identified. A literature review of different strategies for waste prevention in European countries was carried out. These strategies can be classified into: reduction of waste that result from ecodesign and technological innovation, reduction of waste due to a better planning and organisatorial changes, reduction of waste due to changes in attitude and reduction of waste due to substitution. In the last section, the development of the scenario is described.

- The second chapter is about waste recycling. In the first part, the paper recycling process is described in detail. Here recycling was studied from the point of view of technological development: The development in the last 30 years as well as the future trends were identified. It was found that technological development is related to many factors of the recycling process and that technical development does not always go hand in hand with environmental protection; it might be environmentally neutral, or even cause new problems. An example of this is the development of water soluble ink by the printing industry as a response to environmental concerns, which caused problems in the recycling processes.

  Then the recycling of metals, using copper as an example, was looked at in more detail. The main objective was to get an idea about the whole cycle affected by the recycling activities and also to understand the relationships between primary and secondary production. A general review of the recycling of plastic, construction and demolition waste and biological waste was also carried out. The next step was to identify different strategies which are expected to increase recycling. Finally the recycling scenario is developed and described.

- The third chapter deals with the waste treatment scenario. In a first step the legislative framework was identified. Then, a review about the waste treatment activities included in the scenario was done. The waste treatment activities included in this scenario were mechanical-biological treatment, incineration and landfilling, since all other treatment activities are considered in the other two scenarios. The scenario is described in the last part.

- The fourth chapter presents some scenarios related to waste management that were identified in the course of the development of the scenarios. The scenarios were used, on one hand, to see how other groups developed their scenarios, (e.g. what assumptions were done, what was the available information, how are the scenarios presented). On the other hand, these scenarios also constituted a good example of how the FORWAST scenarios could look like.

- The last chapter deals with the interrelations between the macroeconomic scenarios and the waste treatment scenarios. First, a review of the relationships of environmental protection and environment is presented and then the specific interrelations identified for the FORWAST project are presented.

2. WASTE PREVENTION SCENARIO

The term "waste prevention" covers all actions that avoid the production of waste. In a narrow sense, it only includes actions that impede the production of waste. In a wider sense, it also comprises actions where the waste is reused and recycled in the same facility where it is produced, thus reducing the amount of waste leaving the facility. In this document "waste prevention" is limited to actions that do avoid the production of waste at the source; actions that are taken once the waste is produced (e.g. reuse and recycling) are considered in the waste recycling scenario.

Waste prevention can be seen from a quantitative or a qualitative point of view. Waste can be quantitatively prevented if the amount of produced waste is reduced. Qualitative prevention takes place when the toxicity or risk of the waste is reduced (Bilitewski *et al.*, 2000). However, the problems of waste generation are not only related to the risks and threats it poses to human health and the environment, but also to the inefficient use of resources. This is why a reduction in the amount of scarce resources in the waste (if it is not recycled, but disposed) is also interpreted as a qualitative reduction of waste.

Hence, when considering quantitative waste prevention, the actions should focus on larger waste streams. When taking qualitative waste prevention into account, the focus should lie on materials that have a negative environmental impact as well as on materials and products that contain scarce resources.

It is recognized that the most eco-efficient and effective way to foster waste prevention is by taking measures at local, regional or national level and not at an EU-wide level. This, because waste prevention depends on many factors, that can vary from country to country and also because waste prevention may have complex impacts on the environment. For example, it is possible to prevent large amounts of waste and nevertheless cause an increase of its environmental impact. Waste prevention strategies and policies should take into account national production and consumption patterns, their projected trends and their relation to economic growth.

Salhofer *et al.* (2008) describe waste prevention strategies and measures implemented by some European countries. They affirm that, in general, these regional and local efforts have not shown any perceptible effect on waste generation. They attribute this to inconsistent definitions, problems in measuring waste prevention, the absence of a comprehensive strategy and/or conflicts of interests. Other factors limiting the potential for waste prevention are mentioned by (Reisinger and Krammer, 2007):

- The share of imported products is increasing, which reduces the possibility for affecting the eco-efficiency of the products that are traded in the EU.

- The development of eco-efficient products takes more time than the development of standard products.
- Waste prevention measures affect often only a few waste streams. This means that many measures are needed to have a larger effect.
- Because some resources stay for a long period of time in the stocks, there are often long time periods required until the effect of waste prevention measures becomes apparent.
- Technologies that produce less waste are often coupled to higher economic costs.

For the development of the scenarios it is important to know the type of waste as well as its origin. The reason for this is that for preventing, for example, waste paper arising from a household, it is probable that another approach would be used than if waste paper generation is to be prevented from an industry.

The approach followed for defining the prevention scenarios consisted of four steps. The first was to identify the most relevant waste flows; in a further step the activities generating the largest flows were identified. Then relevant information about the potential and prevention strategies of different waste streams and activities was compiled and used as basis for the development of the scenarios.

1.1 POTENTIAL FOR PREVENTING DIFFERENT WASTE STREAMS

Based on Austrian statistics (BAWPL, 2006) the most important waste streams were identified as:
- Construction and demolition waste
- Soil and excavation material
- Wood waste

Thus, the following paragraphs focus on these flows and on the MWS fraction which has been studied in detail by many authors and is also the fraction on which many waste prevention activities focus.

1.1.1 Construction and demolition waste

A large amount of waste is generated during construction and renovation processes. A study by Osmani *et al.* (2006) revealed that around one third of the construction waste arises due to a deficient planning and organization. At least 10 % of all materials delivered to construction sites in the UK end up as waste due to damage, loss and over-ordering. The most important factors responsible for waste generation that were mentioned were: “last minute changes due to client’s requirements” and “design changes”. Architects feel that contractors are responsible for the waste production. Constructors, on the other hand, believe that architects do not take waste issues during the planning into account and that the design is often inadequate, forcing them to make changes. In this area a better planning and communication process among clients, constructors and architects could be able to reduce the waste generation.

Waste during construction can be minimised by spreading successful concepts and ideas. This can be done via pilot projects or by training (BAWPL, 2006). By requiring site waste management plans for construction projects over a certain value, it is expected that a waste reduction is observed due to better planning (DEFRA, 2007). Also it was found that some off-site construction methods can reduce specific waste streams up to 90 % (WRAP, 2007).

Construction and demolition waste can also be reduced by a more efficient and longer use of buildings. A study carried out in Austria found that the prolongation of the use-life of buildings is the action that has the highest potential to reduce the amount of waste (Daxbeck *et al.*, 2002). It was calculated that a doubling of the use-life of public buildings (from 50 to 100 years) can reduce the amount of construction material and construction waste up to 14%. It is recommended to use the available buildings as long as possible and to refurbish them when they do not satisfy current necessities in order to avoid the construction of new buildings. The life time of a building can also be increased if it is designed in a way that allows changing its functionality easily, for instance by having mobile separation walls (Schreibengraf and Reisinger, 2005).

An option for implementing the above mentioned measure in practice could be to develop some standards for increasing the use-life of public buildings and to include them in the biddings (BAWPL, 2006).

Graubner and Hüske (2002) point out that a large amount of construction waste could be avoided if buildings were designed having a "dismantling-friendly" concept in mind. Intact buildings are often demolished because they do not fulfil raising functional expectations (e.g. windows and exteriors are renewed due to insulation problems) or because they just look "old-fashioned" (e.g. floor, wall and ceiling pannelling). It is therefore necessary to distinguish the very long living structures from the short living and installation structures and to design the buildings considering these structures as different layers with different functions and service-lifes. The different layers are joined by connectors that can be detached. This has the advantage that the structure that is being dismantled is not destroyed and could be potentially reused. The labour costs one incurs when dismantling a building are currently higher than the costs of construction waste recycling and sorting (with a large amount of waste landfilled coupled to this option). One way of facilitating deconstruction is to implement a building pass, where the characteristics and materials of the buildings are specified (BAWPL, 2006).

Optimization of the use of the available space. Space, for example in offices, can be used more intensively by increasing the number of workers in the rooms, thus creating free space that could be used for other purposes or rented (Daxbeck *et al.* 2002).

1.1.2 Soil and excavation material

With respect to waste soil and excavation material, it is necessary to note that it is directly related to construction activities. The reduction of city sprawling, by constructing more compacted cities, is expected to reduce excavation waste. Historical trends since the mid 1950s show that European cities have expanded on average by 78 %, whereas the population has grown only by 33 %. A major consequence of this trend is that European cities have become much less compact (EEA, 2006). In some regions in Austria, half of the dwellings currently being build are detached one-family houses. Policies promoting more compact cities could reduce the amount of build area, and thus reduce excavation waste. However, there are no detailed studies available that estimate the amount of waste that could be avoided.

1.1.3 Wood waste

Wood waste is mostly composed of bark and of residues from primary wood processing activities (e.g. sawing) (BAWPL, 2006). This indicates that it is untreated wood waste, which can be used as fuel. No reduction in wood waste is expected, since biomass is promoted as a renewable material with positive (neutral) climatic effects.

1.1.4 Municipal solid waste

There are many studies that investigate the potential for municipal solid waste prevention. Salhofer *et al.* (2008) estimate the potential for different waste streams in Austrian households as:

<u>Paper waste:</u> The prevention potential adds up to around 5.7 kg/cap/y of paper based on two measures. The first aims at limiting the amount of paper used for advertising by implementing an “advertising on request” measure. This is equivalent to a prohibition on unsolicited advertising, since advertising is only delivered to households that wish to receive advertising and formally confirm this. The second measure consists of a campaign about “information about advertising”, which aims at improving the knowledge of households about the existing possibilities for cancelling the delivery of unsolicited advertising (e.g. stickers on the door or mailbox) (Salhofer *et al.*, 2008).

<u>Beverage packaging</u>: The waste prevention potential in Austria was calculated by assuming fixing refill quotas for beverage containers. Salhofer et al. (2008) calculated that it is possible to reduce the waste by 7 kg/cap/y (plastics, metal, glass, composite papers) if a refilling quota of 60% is reached and by 16.7 kg/cap/year with a refill quota of 82 %. To raise the share of reusable packages in the beverage industry it is recommended to increase the amount of information supplied to consumers, to motivate the industry to sell more beverages in reusable packages and to make the presentation of reusable packages more attractive

(BAWPL, 2006). Salhofer *et al*. (2008), mention following additional measures that could stabilize or increase the share for refillable packages: the provision of permits for one-way packages and the setting of mandatory quotas for refillable packaging for each retail enterprise. They also mention that the reorganization of production processes from one-way to refillable packages involves high costs and considerable difficulties.

Wasted food: it is estimated that the largest fraction of waste food is discarded in its original condition (for example, unopened yogurts or loafs of breads), and that its mass approaches almost 40 kg/cap/y (Salhofer *et al*., 2008). In the UK it was estimated that there is a production of 111 kg/cap/y of food waste in the households, and that most of it could have been consumed. They set the target of reducing food waste by 1,6 kg/cap/y until 2008.

The amounts of products that are disposed in Vienna, but could still be used are estimated to be (Schneider and Wassermann, 2004):

46 t/y of essential food items
69 t/y of tinned food and food in jars
15 t/y of non-essential food items (coffee, chocolate)
17 % of the products produced in the bakeries
More than 100 t/y of frozen food items
12 t/y of products per food retailing store

In the textiles product group there already exists a developed second hand market, so that the potential is regarded as being not important. Schneider and Wassermann (2004) estimate however, that 5000-6000 pairs of shoes/y could be still reused in Austria.

Furniture and sporting goods are mostly branded goods and cannot be given away due to contract agreements that compel the retailers to destroy the products that are not sold.

1.2 WASTE FROM SERVICES AND PRODUCTION SECTOR

The amount of waste generated in the manufacturing and service sectors was compared. While industry generates more waste per unit of gross value added (or per employee), it is necessary to note that from an overall quantitative point of view, the waste produced in the service sector is as important as industrial waste. For example, in England, the services sector produced slightly more waste than the manufacturing industry in 2002/2003 (DEFRA, 2007). Since the industry has already reduced its waste generation in the past, there is no available information about the amount of waste that can be further reduced. For the services industry, there are currently only general recommendations for reducing the amount of waste and some specific case studies, which do not allow a general estimation of the waste prevention potential that can be achieved.

A Norwegian report presents some estimates of the amount and type of waste produced by the services sector (Skullerud and Stave, 2002). This waste amounted to 282 kg per capita in 1999. The composition of the waste was: 43 % mixed waste, 37 % paper, 10 % biodegradables, 4 % wood, 3 % glass; the remaining 3 % corresponded to metals, WEEEs (waste electric and electronic equipment), plastics and mineral waste.

The service industries that produce the highest amount of waste per employee are the retail trade, except motor vehicles, and the repair of personal and household goods. The service industries that produce the lowest amount of waste per employee are the public administration and defence, compulsory social security, education, health and social work. The composition of the waste in the different industries is also variable. When comparing the tons of waste produced in 1999 it is seen that the sector of public administration and defence, social security and education are the largest producers of paper waste and WEEEs. The transport services industries are the largest producers of glass waste; the retail trade and reparation of personal and household goods are the largest producers of mixed waste, biodegradables and mineral waste; the wholesale trade is the largest producer of plastics, metals and wood, while most hazardous waste is produced by the services of sale, maintenance and repair of motor vehicles and the retail sale of automobile fuel.

The generation of food waste in the production phase and also in retail activities was studied. It was estimated that between 30-40 % of the gross material inputs of vegetables and salads is wasted in production (Salhofer *et al.*, 2008). In food retail stores it is estimated that around 0.8 % of the products offered by supermarkets are wasted. Products are often discarded if their quality is considered unsatisfactory with regard to some attribute, meaning that they have some flaws, but no impairment to hygiene or nutritional quality. These products are discarded, because of market barriers. Products just prior the “best before” date, are almost not sellable and thus discarded. Other reasons for discarding food products include: overproduction, a surplus in storage, seasonal goods, incorrect labelling, damages during transport, among others. It is expected that other branches have similar concerns. Thus, it is anticipated that there exists a potential for decreasing the waste production, for example, by optimising planning activities. It must however be considered, that some factors are rather unpredictable and that for retail stores selling a large number of different products, it might not be easy (or even possible) to keep an overview of all stocks, its characteristics and its changes. Some stores might not give away their products, or sell them at a reduced price, because this might decrease their income, since this second grade products might replace partly their “first grade” products.

Drugstore retail stores in Austria are estimated to discard 9 t of products each year. Most of these products could have been used (Schneider and Wassermann, 2004).

1.3 STRATEGIES FOR WASTE PREVENTION

1.3.1 Ecodesign and technological innovation

The design of products, determines the characteristics of the waste they become once they are discarded. Well designed products can fulfil their function with less material. Studies about ecodesign are product specific and generally focus on many other goals besides the reduction of waste (minimize energy consumption during manufacture and during the use phase, make dismantling friendly products, use non hazardous materials, use of renewable materials). Thus, it was not possible to obtain general quantitative estimations about its potential for reducing waste generation. Some examples about the contribution of ecodesign and innovation to waste prevention are:

- The reduction of weight of packages. For example the PET bottles have reduced their weight between 10 and 40 %. The mass of 1 litre glass bottles sank from 570 g in 1972 to 350 g in 1992, and the mass of soda cans was reduced between 1950 and 1992 from 80 g to 33g (Beyer and Kopytziok, 2005).

- By producing more concentrated products (e.g. soaps, detergents), it is possible to reduce the size of packages (Ministry of the Environment-Japan, 2007).

- By designing multifunctional office machines (copy-printer-scanner), it is possible to reduce the number of machines needed.

- The amount of waste can also be reduced by avoiding packing that is not necessary, which is also coupled to product design.

The experience of the Xerox Company, described by Beyer and Kopytziok (2005) is a good example of how product design can affect waste production. Xerox produces copiers and printers and collects since 1987 all disposed articles in one place where they are partly dismantled. First it is evaluated if the machine can be repaired. If that is not possible then the intact parts are used for the building of new machines. It is very interesting to note here that components of a printer can be reused in copiers. Behind this there is a large amount in product design, product standardisation and coding of the different components, so that they can be easily reused. Only when that is also not possible, is the machine totally disassembled and recycled. Xerox reuses over 80 % of the disposed parts, thus saving a significant amount of resources and reducing the amount of waste by 70%.

There is still a potential to reduce the mass of the products, however it must be noted, that these reductions may be coupled with an increased mixture of different materials, which make recycling more difficult. One example of this are very thin glass bottles, which might be covered by a thin polymer layer.

Additionally it must be noted, that the production of products is oriented towards the fulfilment of the wishes of the clients. Since consumers are not necessarily interested primarily in waste prevention, the trends in production do not follow necessarily this path. For example, it has been estimated that ELV waste could be reduced by a minimization of the weight of the cars and by increasing the share of smaller vehicles. The current trend, however, is to increase the weight and safety of cars, rather than to produce lighter cars (Reisinger and Krammer, 2006).

1.3.2 Changes in organisation and planning

Three examples illustrating changes in planning and organisations, show how waste might be prevented.

The strategy of **providing a service instead of a product**, incentivates the exchange of services instead of products. Usually producers want to sell as much goods as possible. When focusing instead on the service that customers expect from the purchased product, producers have an incentive to produce products that have a long life and that can be repaired (Reisinger and Krammer, 2007). The Xerox Company has implemented this strategy (Berger and Kopytziok, 2005): it focused its attention on selling fewer copiers, but to rent its machines with a long term support instead. It was an interesting challenge to get consumers to accept this, since often refurbished products are not seen as having equivalent quality.

This approach is accepted by the clients, when they are primary interested in the service provided by the product and not on the product itself. This means that it only works for products that are not a status symbol

Another strategy is to implement **producer responsibility**. In this schema, companies pay a licence according to the weight and volume of their packages. In this way, producer responsibility provides an incentive to reduce the weight of packaging. The EEA (2002) mentions that, since the introduction of the producer responsibility system in Germany, there has been a drop in the weight of tissue packs, beverage cartons, glass bottles and beverage cans. It was also noticed that refills and concentrates became more available.

Schneider and Wassermann (2004), propose the creation of an organization that **passes discarded goods** that can still be consumed **to social organizations** that take care of homeless and poor persons. It was estimated that food products have the largest potential for this kind of reuse, since it is calculated that much food, which is not in perfect conditions or past its date of expiry is disposed – but could still be consumed.

The authors point out that it is important to consider the needs of the persons and organizations that get the products, to make sure they are really used and not only transported to other facilities where they are anyways thrown away. Organizing such a transfer of products requires a lot of organization (to get the buildings, vehicles, labour force). Legal reforms can facilitate this transfer, for example, by limiting the liability of enterprises that give their products away to charitable organizations.

It is interesting to note that the approach mentioned before not only causes a reduction in the amount of waste, but also has a positive qualitative effect. When food retailers throw away food products, they usually do not separate the packages from the content, making further treatment more difficult.

1.3.3 Prevention by changing attitudes

One interesting approach related to the change of attitudes and behaviour was developed by the Wuppertal Institute. They coined the term “sufficiency”, which is defined as “what fulfils the expectations”, “what produces or allows satisfaction” or “what is adequate”. This term is therefore not related to deficiency or scarceness as often assumed (Linz, 2004).

Sufficiency advocates for a change in the relationship to goods and services, which has changed rapidly in the last two centuries. Over long periods of time, people’s wishes adapted to the means to achieve them. Goods acquired only in modern times such a high importance and symbol status, a tendency which has intensified strongly in the last century. Proponents of sufficiency argue that something that was created by technical and social development has a potential to change. They believe, therefore, that changes rendering the symbolic status of consumption less important are possible.

Four main drivers for sufficiency can be observed :

a) Ethic / religious drivers: which state that each society should not occupy more resources than it is entitled to. Unfairness should not be accepted, and every person ought to try to reduce inequality in the world.

b) Self-determination and independence: stresses the value of making personal and individual decisions and not being a “slave” of advertisement, consumption and capitalism. It values and incentives the capacity of making individual, independent decisions.

c) Quality of living. Quality of living is a term that encompasses many dimensions: a material one (cloths, food, income, education, health), a social one (to belong to a group/country, social relationships, to play a role in society) and a personal development dimension (to fulfil oneself, to be able to decide about things that affect life, culture and art). Quality of life depends on a sound mix between these dimensions. Today non-material needs are often supplied with material goods (need for acceptance, self development are fulfilled through consumption). This suggests that it is possible that a more balanced state between all dimensions might lead to better quality of life. Indeed, there are many studies that point out that in western societies, once a certain income level has been reached, happiness does not increase further with income, and that it even can sink due to stress factors associated with higher incomes (necessity to show off, to use all the opportunities that are coupled with a higher income, etc).

d) National safety and peace. Environmental constraints, price fluctuations of raw materials, growth disparity between the different parts in the world pose a risk to national security. The current use of resources in developed countries could possibly not serve as a global model. Substitution of resources, cleaner production and increased efficiency in processes are necessary, but not sufficient. For example the production of energy from renewable sources, still needs resources (e.g. platinum group metals for fuel cells). Thus, it seems as if part of the solution is to use, or need, less resources (Bringzu, 2006).

Sufficiency is a long term strategy, since attitudes toward consumption depend on the society. It is not only or mainly an issue regarding consumers, but requires changes in the whole society. This also implies a change in the companies, whose interest should not only lie the in economic gains but also in producing more sustainable products, in avoiding image damages, in having a better identification with the employees, in higher prestige of the company and in increasing customer loyalty. It is a strategy that needs a change in values of the majority of the population.

A change in attitudes could, for example, result in an increasing service life of products. This could be achieved by either organizing second hand markets or by using the products for a longer period of time. The use-life of many household appliances can be increased by reparation. It has been estimated that this could lead to a 50 to100 % longer use phase, which results in 33 to 50 % less resource use (Reisinger and Krammer, 2007). This is a reasonable way to reduce waste, since often the disposed products are technically sound. The motivation for replacing them lies in the effects of product innovation, which results in products with additional functions or a newer design (Salhofer *et al.*, 2002).

Tucker and Douglas (2007) studied the household waste prevention attitudes and behaviour and came to the conclusion that there is a very fuzzy boundary around people's interpretation of waste prevention. To some it is synonymous to recycling, to others it can be convoluted with water and energy conservation. They affirm that waste prevention appears to be a poorly understood concept and that the majority of surveyed persons did not know where to get further information about recycling. To reverse this, the Waste Strategy for England (DEFRA, 2006) proposes to extend campaigns to increase awareness for recycling and for reducing the waste, to implement zero waste places to develop innovative and exemplary practice, to reduce single use shopping bags through a retailer commitment and to promote reduction of waste and increasing recycling rates in schools.
Tucker and Douglas (2007) also obtained a hierarchy of preferences of waste prevention activities. Donating unwanted goods to charity headed the list, whilst hiring rather than buying and rejecting over-packaging fell significantly below the levels of engagement in other

activities. They suggest that there could be a stronger financial motivation and widespread recognition for not wasting something of monetary value rather than any altruistic motivation to conserve resources. Considering this, it could be an interesting measure to shift the taxing system from the income of work to the use of resources. Increasing the price of natural resources, in a way that they reflect the externalities, is regarded as a good way for reducing the consumption of resources.

The public sector might also incentivate efficient consumption by taking these aspects into account when purchasing goods and services (Reisinger and Krammer, 2007).

To help consumers to achieve an eco-efficient consumption it is possible to introduce a materials and products information instrument that gives details about the environmental impact of the product. This could catalyse actions across the supply chain to improve the environmental performance of products throughout their life cycle.

1.3.4 Substitution

The substitution of materials causes mainly a qualitative reduction of the waste, for example, when toxic components are substituted by less toxic materials. Substitution can, however, also result in a quantitative reduction of waste. This is expected to happen in some applications of "nanomaterials", where it is regarded as possible to get "the same or better property with less material" (Mann, 2006; Kassim, 2005).

Some hazardous substances have already been banned and substituted by other substances. Some examples are the ban of the "dirty dozen" organic compounds, whose utilization was banned worldwide by the Stockholmer Convention in 2001. The EU has restricted the use of mercury (COM (2005)/20), cadmium (EU Directive 91/338/EC) and other heavy metals and organic pollutants in WEEEs (2002/95/EC). In Austria it is prohibited since 1993 to produce or utilise PCB as well as goods and materials that contain PCB. In 1993 the Austrian government prohibited the use of Cd in pigments and stabilisators in plastics. Its use as coating of electric contacts was also banned (BAWPL, 2006).

Mackwitz and Stadtbauer (2001) analyzed the potential for **biodegradable plastic (BDP)**. Biodegradable plastic is already used in many applications and it substitutes conventional plastics in products with a short lifespan (e.g. gardening foils, flower pots, plastic bags for fruits, surgery articles, packages, articles fast-food stores, etc).

BDP can reduce the amount of waste, for example gardening foils that are biodegradable stay in the soil and do not land in the trash. However the more important effects are the changes in the waste management sector. BDP can be composted and therefore collected with the waste of biological origin. This is much easier than plastic recycling, where the plastic waste has to be sorted, cleaned and then send to the appropriate recycling facility.

Biodegradable plastics can be produced from renewable resources (corn, soya beans) or from fossil resources, since the characteristic of being biodegradable depends on the chemical composition and not on the origin of the raw material. It must be noted however that, the overall environmental effect BDP differs according to the raw material (Renewable material have a different effect on the CO_2 balance - they avoid the use of fossil materials - but on the other hand, the production of this resource also consumes fossil energy in form of fuel for the harvesting activities and, indirectly, for the production and transport of fertilizers. Currently most biodegradable plastic is produced from renewable resources, they are however often mixed with additives from fossil origin (Mackwitz and Stadtbauer, 2001).

There are no official estimations regarding the share of biodegradable plastics in the total plastic market, since the market is still in the initial stage. Estimations from the International Biodegradable Polymers Association & Working Groups (IBAW, 2004) state that around 1/1000 of the total plastic market consist of BDP. This indicates that the potential for BDP is very large. This is corroborated when looking at the growth of the BDP consumption in the EU15, which rose from 20.000 t in 2001 to 35.000-40.000 t in 2003.

There has been ongoing research to identify **substitutes for heavy metals** in many applications. Since the development of alternatives depends heavily on the demand for substitutes, it is not easy to state which alternatives will become available at what time. It is estimated, however, that the time necessary for developing new technologies, and the modification of manufacturing equipment, generally does not exceed 10 years (EC, 2002).

1.4 DESCRIPTION AND IMPLEMENTATION OF THE SCENARIO

In the prevention scenario the recycling rate and the waste treatment scheme were maintained constant. The scenarios were defined based on the information presented in the chapters 1.1 to 1.3 and are aggregated by industry.

In this scenario all waste treatment efforts are concentrated on waste prevention. It is expected that the EU and the national governments create a framework favourable for achieving waste prevention targets. Possible strategies are:
- implementing producers responsibility where it is expected that it could provide positive results
- changing the taxing system (e.g. increasing taxes on waste treatment, shift from income taxes to consumer taxes)
- introducing bans for hazardous substances which are still allowed
- coordinate and set targets to countries that produce products imported into the EU in order to create fair conditions for the producers inside the EU
- create a sort of label for products indicating the environmental impact related to its production to allow consumers a more informed decision.

Civil organizations also cooperate in order to motivate consumers to consume in a more efficient way and by this, to reduce the amount of waste.

The figures mentioned in this scenario are expected to be achieved by the year 2015. From 2015 to 2035 a reduction of 25 % of the reduction that took place until 2015 is achieved.

Manure waste (FW 1-3) can be prevented by changing the eating habits of the population. If the consumers reduce the consumption of meat and increase in exchange the consumption of crops, there will be a reduction in the amount of manure produced and in the agricultural emissions from animals. Additionally, the waste arising from slaughterhouses and the meat processing industries will show a related decrease. A reduction in the consumption of meat by 15 %, as proposed by the Compassion in World Farming Trust[1] is considered for the FORWAST scenario. This will not affect the milk production, since a reduction in the number of non dairy cows is assumed. The statistic information from EUROSTAT indicates that cattle stock in the EU-25 is composed of 27 % dairy cows and 73 % non dairy cows in 2003.

To compensate the reduction in meat consumption, there is an increase in the amount of **crops** consumed. This results in a raise of organic waste from crops (FW 3, 4). There is no waste prevention measure implemented for this flows since there are no quantitative studies available about the potential for waste prevention. The reasons for this might be the availability of many alternatives for treating this waste (composting, biogasification, fuel) all of which provide some benefits. It must be also considered that when this waste is adequately treated, there are only minor environmental impacts arsing from it.

For the organic waste from **forest products** (FW 7) and **fishes** (FW 9), there are also no specific reduction measures. Forest products are expected to become more important in view of the climate problems in the future, thus it is unrealistic to expect a reduction of this kind of waste. Also in the consumption of fish, there are no reductions included in the scenario to compensate for the reduction in the meat consumption.

For **coal and oil waste** (FW 10 - 11), which is composed mainly of ashes and flue gas residues, there is no specific prevention measure considered.

For **mining of metals** (FW 12-15) there is no expected reduction in the amount of waste. Because the high grade ores are normally exploited first, there is a decrease in the grade of the ores with time. This means that there is more waste rock accrued to obtain the same amount of metals, and thus implies an increase of the waste. This could be partly compensated by better metallurgy techniques.

[1] Webpage: www.ciwf.org

For the **mining and quarrying products** (FW 16-18) there is an indirect reduction in their use due to the measures applied in the construction industry. There is no additional prevention measure considered in the scenario.

The **food products and beverages** (FW 19 - 27) show different prevention possibilities. Meat waste will be reduced by 15 % due to the reduction in consumption. Dairy products have no specific prevention measure. Fruits and vegetable waste in the processing industry is reduced by 15 %. This is based on the results obtained by Salhofer *et al.* (2008), mentioned before, where it is estimated that 30-40 % of vegetables and salads are wasted during processing. It is expected that this will happen due to a better planning and logistics (avoiding the damage of the product). The waste from other food products: flour, sugar, food preparations n.e.c, animal food and beverages will be reduced by 2.4 %.

For the **beverages packages** (FW code 27) there is a reduction of 10 % mostly due to a better design of the packaging (e.g. weight reduction).

For **textiles, shoes and leather products** (FW codes 29-31) there is a reduction of 6 % caused by a reduction in the consumption of these products. People are motivated to buy less shoes and textile products and to repair them if this is possible in order to use for them for longer periods.

Paper waste (FW code 33-36) will be reduced by 8 %. This will be done by reducing unwanted advertisement. Since advertisement is an important activity for the industry it is expected that such a reduction in house to house advertisement will be compensated by more advertisement on TV and on radios.

Waste from **chemical products and refined chemical products** (FW codes 37-43) will be reduced by 6 % by more a efficient use of these products. This means, that it is expected that cars reduce the amount of fuel needed per km. Cars might become more expensive due to the use of newer technologies, which is compensated by the reduction in consumed fuel.

Waste of **metal products** (FW code 65) will be reduced by 6 % through a more efficient use of metals. This might involve innovations in Ecodesign in order to produce lighter packages, containers and tools. The money saved by the reduction in the metals used in the production is used to finance further research.

Waste arising from **vehicles, equipment, machines and instruments** (FW codes 66-72) is reduced by 6 % This might involve technological innovation, for example by creating lighter products or products that can fulfil more than one necessity (e.g. multifunctional copy machines). The money saved by the producers is invested in more research.

The waste arising from **retail stores** (FW code 82) will be reduced by 2 %, mainly due to better planning and logistics.

Construction and demolition waste is avoided due to different measures. Construction and demolition waste will be reduced by 14 %. This reduction is explained by a better planning of the construction activities, by using some off-site construction methods and also by an increase in lifetime of buildings by 20 %. This, however, involves an increase in reparation and reconditioning activities, since buildings need to be adapted to new necessities during its longer lifetime.

3. WASTE RECYCLING SCENARIO

Although recycling is generally preferred to incineration and landfilling, the actual environmental effect can be different from case to case. In some cases collection and recycling require more energy than the extraction and processing of virgin raw materials. This is why life-cycle assessments and environmental cost/benefit analysis are required to determine the preferred option in each case (EEA, 2002).

Recycling can be classified into different categories (BAWPL, 2006):
- Recycling in the narrow sense, which means that the waste is recycled and used for the production of the same product (glass, metal scrap)
- Downcycling, where waste is recycled to products of a lower quality
- Energetic recycling, when the energy content of the waste is used.

A major obstacle to increasing recycling rates is that recycling asks for higher organisational, legal and communicational requirements than landfilling or incineration, since it is essential for a successful recycling, that the waste fractions are as pure as possible. (EEA, 2002).

Some materials have currently a high recycling rate, for example: packages, iron and copper, among others. There are, however, other materials where the recycling rate can still be increased, such as for construction and demolition waste. To achieve this, it is necessary to create a market for the product and to define clear rules and quality criteria to which the products have to comply, because a long term market can only be created, if the quality of the recycled product is transparent and the risks for the purchasers is low (BAWPL, 2006).

There are economical limits to recycling: with increasing recycling rate there is also an increase in the cost associated with a further increase in the rates. From a systemic point of view, there is an optimum recycling rate for each waste flow, which is however variable and depends, among others, on the prices of the primary resources and disposal fees (BAWPL, 2006).

A study group that analysed the needs and gaps in recycling technologies for four materials (vehicles, electronic scrap, construction waste and plating) identified following common recycling technology issues (CANMET, 2001):
- Need for the development of low cost and on-line separation technologies
- Incentivate design for the environment / design for recycling
- Scalability (scaling down technological options for smaller companies to make recycling economicaly viable)
- Development of technologies for refining (removing impurities)
- Increase of automated processing
- Difficulties in creating products out of recycled materials (e.g. composite plastics) and also

in creating markets for them
- Further development of on-line sensor technology for identifying materials
- Need for developing more cost effective technologies

For the development of the FORWAST recycling scenario an intense literature review was carried out. In the first place, paper recycling was selected as an exemplary process in order to understand the general processes involved in recycling, as well as the problems, issues, trends and development of the industry. Then metal recycling, using copper as an example, was studied in more detail in order to understand the parallels between first and secondary production. In a further step a review of construction and demolition waste recycling, plastic recycling and biological recycling was done. This is followed by an overview of the strategies to increase recycling. Finally, the scenarios were developed using additional information collected for this purpose.

2.1 PAPER AND CARDBOARD RECYCLING

Paper is a thin sheet material made from fibers, mineral fillers and chemical additives. The proportion of fibers and fillers varies strongly according to the type of paper and cardboard considered. The percentage of mineral fillers in paper ranges from 0 to 49 %. The materials used as fillers are mostly clay, talc and calcium carbonate (Laufmann, 1998). The average content of chemical additives is around 3 % (Kleemann, 2003). The fillers and additives provide special characteristics (for improving printability, surface strength, brightness, surface smoothness, for providing superior barrier properties for air and water, antistatics, flame-retardants, fluorescent dyes and miscellaneous chemicals for attracting or repelling various substances) (Ramsden[2]; Laufmann, 1998).

It must be noted that during paper production there are some additional chemical compounds used (for example: biocides, deareating agents, retention aids, cleaning agents and others). They are, however, not "included" in the paper, but discarded and treated with the waste water.

From an economic point of view, recycling depends mostly on the price and availability of waste paper and its substitute (wood pulp). The availability of waste paper depends largely on the consumption of paper and board products, which in turn fluctuates with the level of economic activity, making the waste paper market very volatile (Berglund *et al.* 2002).

Policies for increasing the recycling rates may be very costly or difficult to enforce if they run counter to other economic or environmental goals (Berglund *et al.* 2002). For example,

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[2] Jeremy Ramsden. Potential for nanotechnology in paper production. Online: www.profitthroughinnovation.com/pulp-and-paper/potential-for-nanotechnology-in-paper-production.html

Swedish paper and board producers have imported cheap waste paper from Germany (partly due to subsidized collection) to meet requirements and customer demands. As transport over long distances is required it is not clear that it is a desirable result.

2.1.1 Paper recycling in Europe

The paper and board collection rate of waste paper increased between 2000 and 2005 in all CEPI[3] countries. According to the statistics from the Confederation of European Paper Industries[4], the recycling rate reaches 62.6 % on average and ranges from 35 % (Portugal) to 77 % (Ireland). These are good results, considering that an estimated 19 % of the total paper and board products sold are not collectable for technical reasons (archives, wall papers, hygiene papers, cigarette papers).

The inland recycling rate in CEPI countries has also increased continuously between 1991 and 2005, and reached 54,6 % in 2005. The recycling rate ranges from 111 % (Austria) to 0 % (Ireland). If recovered paper in Europe recycled in third countries is also included, the recycling rate rises to 62.6 %. In the CEPI declaration of 2006 the industry agreed to increase the recycling rate (including waste paper recycled in other countries) to 66 %.

The utilization rate of waste paper has increased in the CEPI countries between 1991 and 2005, reaching currently 47.6 %. It ranges from 108 % (Denmark) to 0 % (Ireland).

With respect to the use of recycled material CEPI 2006 indicates that 62 % of the volume of recovered paper is used for packaging grades and 19 % for newsprint. The utilization of recycled material in household and sanitary paper has decreased to 49 % in 2005, driven by the consumer's choice for non-recycled tissue paper.

2.1.2 Recycling Process

Paper recyclability is be defined as "to be able to be processed in a recovery paper treatment plant that complies with recognized rules and to allow a trouble–free production of new paper with acceptable quality. It also implies that there is no excessive increase in the volume of residues or loading in circuit water and effluents" (Strauß, 2005). In this context it must be noted that not all paper can be recycled, since there are some inks that are not able to be removed with the current technologies.

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[3] CEPI = Confederation of European Paper Industries. The member countries are: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Hungary, Ireland, Italy, Netherlands, Norway, Poland, Portugal, Slovak Republic, Spain, Sweden, Switzerland, United Kingdom

[4] Webpage: www.cepi.org

When talking about paper recycling, only the recycling of fibers is considered (Strauß, 2005). The other components of paper are present either in too little quantities (additives) or are very cheap (fillers), thus making its recycling unattractive. It must be noted, however, that additives, even if present in very small quantities, can disturb the recycling process (e.g. wet web breaking) and reduce the quality of the final product (e.g. specks, holes). Therefore, they should be separated from the fibers at the highest possible degree (Onusseit, 2006).

According to IPPC (2001b) recycling can be classified into:

- processes with purely mechanical recycling (mostly for testliners, corrugated paper and carton board)
- processes with mechanical recycling and deinking (mostly newspaper, tissue paper, printing and copy paper and magazine paper). The purpose of deinking is to increase brightness and cleanliness of the product and also to reduce the amount of stickies during the process.

The main processes involved in paper recycling, are explained with more detail in the following paragraphs:

Sorting. Since impurities and foreign particles (wood, plastics, metallic pieces) can complicate recycling, it is of uttermost importance to separate these contaminations from the fibers[5]. It is also desirable to separate the different paper types (e.g. light waste paper from cardboard), allowing by this to optimize the use of the waste paper and to increase the profit of the recycling industry. This is done by using the waste paper of low quality for products with have low requirements, while using the waste paper of better quality for products with higher requirements (IPCC, 2001b).

Re-pulping or defibring. Its purpose is to separate the waste paper into individual fibres. This is normally done by stirring the waste paper with hot water and chemicals, which results in a fibre slurry (Fricker *et al.*, 2007). During this step it is important to avoid making non-fibre elements smaller, since this makes its future elimination more difficult (Hanecker, 2006).

Screening. During this process the impurities larger than 200um are removed by screening. The pulp is passed down a screen in circular motion. The accepted fibre passes the mesh while rejects are collected at the bottom (Fricker *et al.*, 2007).

Cleaning. The purpose of this step is to remove small particles (100 – 350 um) that passed through the screening mesh. The pulp is spun with a high velocity inside a cleaner, causing the lower density water and fibre to stick to the outer wall, while the more dense particles accumulate in the centre and move downwards where they are eliminated (Fricker et al). The density differences between the pulp and particles to be removed must be “large” for cleaning to succeed (Thompson, 1999).

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[5] Source: EU-Recycling 8/2007, online: www.epaper.eu-recycling.com

Deinking. This process can be separated into two stages: flotation and washing.
During flotation, air bubbles are injected into the pulp slurry. These bubbles get attached to ink particles and carry them to the surface where there are removed as foam. To achieve this, a surfactant is added. This results in the hydrophobic ink particles getting attached to the raising air bubbles and removed in this way particles between 50 and 150 um (Fricker *et al.*, 2007).

Washing allows the removal of particles in the range of 10um and smaller. This process uses very large quantities of water, which can render this step as uneconomic. Furthermore, as legislation requires this water to be returned to the source as clean as when it was drawn off, it implies a large effort in water recycling (to remove ink particles and chemicals added during pulping and flotation). Because of this, washing is banned in some European countries (Fricker *et al.*, 2007).

Refining/Beating. During beating, the pulp is abraded between moving surfaces, thereby subjecting the pulp to high stresses which separate fibre bundles. As a result there is an enormous increase in the material surface area (Ramsden, na).

Bleaching. If white recycled paper is being produced, the pulp may need to be bleached with hydrogen peroxide, hydrosulphite formamidine sulfinic acid or chlorine dioxide. For almost wood-free secondary pulp, the so-called unconventional secondary bleachers ozone or oxygen can also be used (IPCC, 2001b).

Papermaking. In this stage the pulp made of waste paper is blended with wood pulp. The proportion of new wood fiber varies according to the product. Some high quality paper is made only of wood fibre, while for low quality products there is a large amount of variation possible. For example, for producing tissue paper some mills use 100 % of wastepaper; others use 100 % of wood fibre (IPCC, 2001b). The pulp is diluted with water until there is about one part of fibre to 200 parts of water[6]. Then it is sprayed onto a continuous travelling band of wire gauze. A large quantity of water drains and runs through the gauze, leaving the fibres as a mat of wet paper. This paper sheet is carried through pressing rolls to remove most of the remaining water and after that, through heated metal rollers and over drying cylinders (Ramsden, na). This process is very energy consuming. Finally, a coating mixture to give paper a smooth glossy surface may be applied.

2.1.3 Issues in the paper recycling industry / Research areas / New technologies

[6] Source: Tappi (Technical Association for the worldwide pulp, paper and converting industry).webpage. www.tappi.otg. Articles: "Technical Association for the worldwide pulp, paper and converting industry. How is paper recycled?" and."Why recycling ?"

The most important challenges for the paper recycling industry are related to the sorting of waste paper used as input to the recycling process and to the removal of impurities in the pulp. These issues coincide with the research carried out at PTS (Paper Technology Specialist)[7], which currently focuses its research on:

- Methods for raising the use of waste paper

- Techniques for obtaining profiles of different waste paper types in order to define the optimal use of each type.

- Improvement of the recyclability of waste paper by developing new methods for removing non-fibre compounds (new methods for deinking, removing adhesives and other additives, and other foreign elements as plastics, wood and others)

- Methods for reducing the losses caused by rejected material.

The next paragraphs present some new technologies and current developments with potential of improving some processes involved in recycling (sorting, pulping, removal of ink and other impurities, papermaking and waste treatment).

Sorting. Currently most recycling facilities sort the paper visually (Behnsen, 2006). One disadvantage of this are the high costs incurred. For some recycling facilities sorting represents even the most expensive process[8]. Another difficulty is that there exist some paper grades that cannot be distinguished by naked eye, but have very different characteristics in terms of components. This has created an important incentive for industry to search for alternative sorting technologies.

There are new developments based on NIR (near infrared) sensors, a method that has been in use for a long time in the sorting of plastics. One sensor system, which is currently being developed by INGEDE and CTR[9], is able to recognize the "material finger print" of different paper types in the range of near infrared and visible light. Another device targets a precise and strong blast blowing the different paper types into separate shafts. Some plants are already using this technology, which is further being improved. PTS has also developed a similar technique which was used in a pilot plant (Behnsen, 2006). The system was able to separate 95 % of the non-paper particles; 85 % of the cardboard and sack paper and 95 % of newspaper, magazines and office paper. Besides an improvement in paper sorting, it makes it possible to control the waste paper which is accepted in the facility (with respect to humidity, ash content) and also to adapt further processes to the characteristics of the waste paper.

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[7] Webpage: www.ptspaper.de
[8] Weyerhaeuser Paper Recycling Plant, Nashville, TN, USA. www.pulpandpaper-technology.com/project_printable.asp?ProjectID=2144
[9] Source: EU-Recycling 8/2007, online: www.epaper.eu-recycling.com

Optimization of the pulping. The repeated mechanical and physical impacts, as well as the use of additives, cause a degradation of the fibres. This results in changes which affect the processes and performance of the final product. For example, shorter fibres result in slower dewatering, lower strength of the product and in an increased consumption of energy and chemicals. It is expected that a more careful re-pulping process will prevent unnecessary damage to the fibres. This can be a way of increasing the number of times the fibre can be recycled, which currently lies between 5 to 7 times[10].

One way of preventing damage to the fibres is to increase the ratio of the compression/shear forces during the re-pulping, since compressive forces cause less damage to the fibre morphology. In a pilot scale facility it was proved that compressive refining leads to enhanced dewatering and represents therefore an improvement in production capacity, while maintaining the quality of the product (van Kessel and Westenbroek, 2004).

Removal of non-fibrous particles from the pulp slurry. Foreign particles of very small dimensions are not able to be removed from the pulp slurry with current technologies. These thermoplastic impurities (wood resins, coatings, inkbindes, adhesives and others) get sticky at higher temperatures (80-120 °C) and cause problems, especially during drying (Omusseit), when they may agglomerate and grow to larger ones thereby causing disturbances in the recycling process and diminishing the quality of the finished product.

There is a large amount of research carried out for improving pulp deinking and to keep pace with the developments in the ink producing sector. There are two steps in ink removing: first the ink must be separated from the fibres, then it must be collected from the slurry (Thompson, 1999). Many different approaches are being explored. Fricker *et al.* (2007), for example, propose to remove the ink by high intensity ultrasound. For difficult to deink paper it was shown that this resulted in detached ink that was large enough to be removed by traditional flotation and washing methods. This method is still in the research phase.

Research with the aim of producing a system that allows the "cleaning" of used office paper by removal of the ink, is also being done. Such a system would allow reusing the paper by cleaning it in the office, rather than sending it to a centralised recycling facility, where the paper is reduced to a pulp and then reformed. Other approaches currently under investigation are (Counsell and Altwood, 2006):

- Removal by adhesion, where the principle is to press the printed paper against a material that forms a stronger bond with the ink than the paper. This material must form a weaker bond with the paper surface that the bond the paper forms with itself. Different adhesive materials, geometries of presses, approaches for pre-weakening the ink-paper bond and methods for removing the ink from the adhesive are being developed.

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[10] Source: Tappi - Technical Association for the worldwide pulp, paper and converting industry, www.tappi.otg

- Removal by abrasion, where the principle is to use an abrasive surface and break the ink-paper bond through mechanical energy, while avoiding breaking the bond between paper fibres. Different abrasive materials, methods for the removal of the abraded materials, approaches for pre-weakening the ink-paper bond and approaches for strengthening the paper are being researched.

- Removal by ablation, where the principle is to apply energy to the printed paper and turn the ink into gas while keeping the paper surface below 150-230°C (where it turns yellow and burns). Different forms of energy and methods for targeting it are being investigated.

- Removal by solvents, where the principle is to use chemicals that dissolve the ink, but do not affect the paper. Different solvents, methods for agitating the solvent and approaches for protecting the paper from the solvent are being tested.

- De-colouring, where the principle is to cause the pigment to become invisible under a particular set of conditions, which should not occur during normal use. Different chemical compositions of the ink, conditions that target the print to change colour and reversibility of the changes are being developed (Counsell and Allwood).

- Obscuring the print is a technique that hides the ink behind a paper coloured material. This method is widely used to correct print, there is however no commercially launched technique that uses this principle for recycling. Different coatings and areas to which the coating is applied are being researched (Counsell and Allwood).

Much work has been done in the field of mechanical and chemical removal of adhesives. Similar to the difficulties caused by new inks, the formulation and composition of adhesives is both complex and varied which means that a recycling solution for one does not work for others (Thompson, 1999).

Further investigation is carried out in order to improve the washing process. Some novel approaches were tested in a pilot plant, where it turned out that it was possible to further reduce the amount of ashes and fines in the pulp slurry, thus increasing drainability and paper strength. The technical feasibility of an industrial use of this techniques is regarded as good, but the economical feasibility is rather low (van Kessel and Westenbroek, 2004)

Papermaking. Some new enzymes that delaminate the cell wall and thus increase the flexibility of the fibres are being researched. This could result in and increase in paper strength (van Kessel and Westenbroek).

Alternatives for the produced waste. The residues arising from paper recycling are primarily process residues (13 % of the input waste paper). Less than 2% of the input waste paper is rejected during sorting (Presas, 2003). Currently most waste is being incinerated (around 45 %). The remaining waste is landfilled (ca. 20 %), used in other industries (ca. 20

%) or composted (ca. 15 %). There have been initiatives to investigate the possibilities of reusing the waste in the same facility (Hanecker, 2006), to use it as material for the production of plaster composite mixtures (Agullo *et al.*, 2006) or to develop new composting alternatives for the sludge (Gea *et al.*, 2005.).

2.1.4 Past technological developments in the paper industry

Lundmark and Söderholm (2004) analyzed the technical changes in the Swedish paper and pulp industry that took place between 1974 and 1994. The technical progress concentrated mainly in the areas of:

- Fibrous raw material processing, where new high yield pulping processes that allowed widening the range of wood species that could be used for papermaking, were developed. In the paper recycling industry some improvements allowed to increase the proportion of wastepaper, mainly through elimination of contaminants and the use of lower grade paper.

- Energy consumption, where savings in the use of process steam per unit of output, more efficient recovery and combustion of spent liquor, higher boiler efficiencies and an expanded use of biofuels could be observed. Today, a modern chemical pulp mill is independent of outside power sources and often even generates some surplus steam that might be used in the paper production. The primary energy consumption decreased from 1990 by 10 % and the specific CO_2 emissions from solid fuel by 25% (Presas, 2003).

- Environmental impact where the first phase of changes, related to wastewater treatment and air emission control, was observed as a reaction to governmental regulations. Later regulations regarding the use of chlorinated organic compounds (used in the bleaching process) were enforced. This led to a reconsideration of the bleaching process and/or further treatment of the wastewater. As an example of the achievements since 1990 in these areas, Presas (2003) cites: a decrease by 90 % of AOX discharge, a reduction in the BOD load from 35 kg/t to 4 kg/t and in the COD load from 7 kg/t to less than 1.2 kg/t.

Lundmark and Söderholm (2004) affirm that the changes in energy technologies and fibrous raw material processing did not have a large impact on the use of wastepaper. Instead, they argue the most important factor affecting this indicator is the decrease of the wastepaper price (due to government sponsored collection programmes), which increased the demand for wastepaper by the recycling industry.

2.1.5 Current trends in the paper recycling industry

* The collection, utilization and recycling rates have increased continuously between 1991 and 2005 for most EU countries.

* The basic technology to use wastepaper in the production of various paper grades has also improved. The recycled fibres are, however, still mainly used for tissue, liner and newsprint, due to restrictions in strength and purity requirements for other paper grades (Lundmark and Söderholm, 2004).

* The quality of the waste paper used as input has worsened. This can be seen, for example, in the increasing proportion of graphical and difficult to deink waste paper (Hanecker und Faul, 2007).

* It is expected that the amount of recycling residues will increase because of the decreasing quality of the collected paper and because more recycling means that paper has a higher proportion of recycled fibers (which can only be recycled a limited number of times). Therefore, a 5% increase in recycling may cause an increase of 7.5 % of residues (Presas, 2003).

* There is an increasing use of chemicals to achieve: higher paper machine velocities, thinner paper and higher quality of the product. The paper recycling industry has to rely more on chemicals than the primary pulp and paper industry, because wastepaper is not such a high quality input material than fresh wood or virgin fibres (Gruber, 2007).

* The ash content has increased from 1996 to 2002. This indicates that there has been an increase in the proportion of mineral fillers, and implies that the proportion of fibre has decreased. This explains the higher losses in the recycling industry, since there is more waste paper needed to obtain the same amount of fibre. Even when a continuation of this trend was not observed between 2002 – 2005 (Hanecker and Faul, 2007), it is expected according to Gruber (2007), that the proportion of fillers will increase further due to economic incentives (price) and because of the favourable effect on some paper characteristics (opacity).

* Deinking equipment has been getting more complex (and more expensive), but this has not let to a better quality of the product. On the contrary, the effectiveness of deinking and adhesive removal has gotten worse. This is due to the growing amount of these products in the waste paper but also due to changes in the ink and adhesive production, which produce substances that are harder to remove (Hanecker and Faul, 2007). For example, water-based inks, developed due to environmental concerns, are difficult to remove from the aqueous fiber slurry because its hydrophilic characteristics (Thompson, 1999).

* The whiteness of the recycled paper has not increased in the last 10 years, mainly because the higher proportion of filling in the waste paper (Hanecker and Faul, 2007).

* The new landfilling directives will further divert waste paper from the landfills. It is however, not clear to which extent they will be separately collected and thus be available for recycling (Reiche, 2007).

* Collection of waste paper is increasing faster that its utilization, which indicates that a shortage of paper for the recycling industry is not probable in the next years (Reiche, 2007).

* Due to the increasing gap between the collection and utilization of waste paper, there is an increase in the amount of exported waste paper (Reiche, 2007).

2.2 RECYCLING OF METALS

The foremost environmental benefit of secondary metals recycling is the reduction in energy consumption and the saving of non-renewable natural resources. Recycling also results in a product with a high quality, since metals have the characteristic that they can be recycled indefinitely without loosing its properties.

The primary and secondary metal production processes and trends are illustrated using copper as an example.

Because copper recycling is profitable, it has high recycling rates and is an organized sector. Today, copper recycling is a tried and tested process and everything that can be technically and economically processed, is recycled. The recycling rates are, however, not so high when looking at inhomogeneous waste, because the recovery of the copper elements requires in this cases the sorting of the waste, a potentially difficult and expensive process[11].

It is important to note that copper recycling, being an economic process, also depends on the copper price: when the copper price is low, scrap may be hold back or the collection might be delayed. When the prices are high, there are more incentives for the collection and recycling, as well as for the placing of scrap on the market (Ruhrberg, 2006).

As with all recycling processes, a 100% recycling is not achievable. This is because technical processes depend on physical laws and economics: the closer the recovery rate approaches 100%, the exponentially higher the associated economic and environmental costs grow (Ruhrberg, 2006).

Since all streams containing large amount of relatively pure copper are already being recycled, the recycling industry has to focus now on more heterogeneous waste streams (e.g. scrap residues or incineration slag) and find ways to separate the copper from the remaining materials (Ruhrberg, 2006).

Ruhrberg (2006) notes that further potentials for increasing the copper recycling appear to be outside the copper industry. He indicates that they are mostly related to product design and

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[11] Online EEP Newsletter 21st August 2003: http://www.eep.org/newsletters/newsletter030821.htm

end-of-life product collection. Improved product design for recycling may ease selective dismantling of copper bearing products from waste streams such as in end-of-life vehicles recycling or during deconstruction of buildings. Improved collection rates of waste electric and electronic equipment can also increase the amounts of recycled copper.

In this chapter the primary and secondary production of copper are examined in order to understand the parallels and relationship between primary and secondary production.

2.2.1 Copper extraction techniques:

There are many copper ores: different types of copper iron sulphides (Cu-Fe-S) and also oxidised minerals (carbonates, oxides hydroxy-silicates, sulphates). About 80 % of the world's copper ores originates from Cu-Fe-S ores (Davenport *et al.*, 2002). These ores are mostly extracted by pyrometallurgical processes and may have a large amount of other minerals. Sometimes the ores are mined because of these other metals (Ni, Pb, Zn), in which cases copper constitutes only a subproduct.

The British Geological Service (BGS, 2007) mentions three excavation techniques:

Surface mining. This is the most common form of copper ore extraction. It is usually used to mine near surface (< 100m), near surface steeply dipping or massive ore bodies. The ore can be extracted by digging or by blasting with explosives.

Subsurface mining. This was up to 1900 the most commonly used extraction technique. Today it is less used, due to higher cost and safety issues. This method is suitable for the extraction of higher grade, small or deep ore bodies.

In-situ leaching. In this extraction technique, a system of injection and recovery wells is used for extracting copper from deep or low grade ore with minimal surface disturbance. This process can only be applied if the deposit is permeable and the surrounding rock impervious. The process starts when a weak sulphuric acid leach solution is pumped down the injection wells and gets into the ore body. As the leachate flows through the deposit, the copper is dissolved into the solution. This copper rich solution is pumped out through recovery wells surrounding the injection well. These wells also prevent the solution from escaping. On completion, fresh water is pumped around the system for cleaning and the wells are cemented.

2.2.2 Primary Copper processing techniques:

The first phase in ore processing is **concentration**. As the name indicates, this process increases the concentration of copper in the ore. This decreases the amount of material that needs to be heated and melted. It is typically carried out at the mine site and involves crushing and grinding of the ore, followed by physical and/or chemical processing and separation stages. The most effective method for separating Cu minerals from the ore is froth flotation. For this, water is added to the finely grinded ore to produce a suspension. Some chemicals that make the copper minerals water repellent are added. Air is then blown upward, causing the Cu minerals to become selectively attached the rising bubbles. The "floated" Cu-mineral particles overflow the flotation cell in a froth and become thus more concentrated (Davenport *et al.*, 2002).

Once copper has been concentrated, it can be converted into pure copper metal using two techniques: pyrometallurgy and hydrometallurgy.

In **Pyrometallurgical** processes the copper concentrate is fed into a smelting furnace to further separate the copper from impurities. The process can be separated into different stages:
- <u>Roasting</u>, which converts the copper concentrate into oxides and removes most of the sulphur as sulphur dioxide gas. This gas can be captured and converted to sulphuric acid.
- <u>Smelting</u>: A siliceous flux (material added to a furnace to remove impurities, lower the melting temperature and to make the slag more liquid) is added to the copper concentrate and charged into a smelter with a temperature between 1000 and 1500 °C to melt the charge. Impurities are oxidised and form a slag that is skimmed off and discarded.
- <u>Converting</u>: Air is blown to the concentrate to oxidise the iron and copper sulphides
- <u>Fire refining</u>: The concentrate is mixed with another flux and enters an anode furnace at 1100 °C. Air is blown through the mixture and oxidises the copper and any remaining impurities, which are removed as slag. The remaining copper oxide is subjected to reducing conditions to form pure copper (99.5% Cu), which is then cast into anodes. The resulting copper can be used in this way for producing some alloys; for the majority of applications however, a further refining step is necessary.
- <u>Electrolytic refining</u>: The anodes are immersed in a sulphuric acid bath in an electrolytic cell. The anode dissolves and the copper ions move through the solution to the cathode where they are deposited on foils. The impurities precipitate out and accumulate at the bottom of the bath as sludge. The cathodes are removed after one to two weeks with 50-150 kg of copper deposited on each side of the sheets.

Hydrometallurgy: involves chemical or biological leaching of copper from the ore using diluted sulphuric acid. It comprises following steps:
- <u>Leaching</u>, where the copper oxide, low grade copper sulphide ore or tailings are placed in heaps or vats. Weak sulphuric acid is trickled trough the heap to dissolve the copper minerals. Some chemicals and bacteria can be added to accelerate the process. Leaching produces a copper solution that is recovered from drainage tunnels and ponds.
- <u>Solvent Extraction</u>: The recovered solution is mixed with an extractant which selectively removes the copper leaving behind most of the impurities. The resulting highly concentrated copper solution is transferred to the electrowinning stage.

- Electrowinning: The solution is filtered, heated and passed through a series of electrolytic cells. A high voltage is applied to the cells and the copper is reduced from copper sulphate to copper metal, which precipitates then onto sheets.

These two processes can be combined, since smelting pyrometallurgy produces SO_2 (which can be converted into sulphuric acid) and hydrometallurgy consumes large quantities of sulphuric acid for leaching.

- Copper manufacture: the copper cathodes produced from electrolytic refining and electrowinning are sent to mills and foundries where they are cast to different forms.

2.2.3 Secondary copper processing

The way in which copper is recycled depends on its purity. High purity copper or specific alloys mixes can be collected and segregated and then simply be re-melted in a smelter and recast for use in subsequent fabrication. Less pure or mixed scrap can be smelted and directly recast for use in non-electrical application, where purity is not so critical (such as plumbing and roofing). Alternatively, scrap can be mixed with pure copper to dilute the impurities or it can be cast into anodes and then be electrolytically refined, as in the final stage of primary copper processing. If the scrap contains certain specific metals it might be more economic to take advantage of these impurities and use the scrap for making alloys rather than removing the other metals (BGS, 2007).

It is important that the waste streams of copper scrap for recycling are segregated to avoid unnecessary contamination of the copper with impurities, since this would involve additional processing to remove (BSG, 2007).

Scrap can be classified into:

New scrap: includes all scrap arising from processing to manufacturing processes, thus before it enters the consumer market. It comprises:
- Process scrap: processing residues, slag and fines. It is usually 100% reused immediately within the plant.
- Home scrap or run-around scrap: is the copper that primary producers cannot further process or sell (e.g. punching, borings and cutting generated in foundries and mills) it is usually put back into a converter or anode furnace and then electrorefined. It is important to note that industrial producers try to minimize its production of it to avoid recycle expenses (Davenport *et al.*, 2002).
- Prompt, industrial and return scrap: this scrap is generated by the manufacturing industry, when converting the semi-fabricated products into products. The difference with the home scrap is that this scrap may have been adulterated during processing by alloying or by applying coating and covering. The pathway of this new scrap depends on its chemical

composition and the extent to which it has become contaminated with other materials (Davenport *et al.*, 2002).

Old scrap: is all post-consumer scrap derived from worn out or obsolete copper products. It is a huge potential source of recyclable copper, but it is more difficult to collect, separate and process than new scrap, as it is often combined with other materials in a single appliance. The ability to determinate the precise scrap concentration constrains old scrap utilization. For example, the erroneous estimates of bulk concentration made by extrapolating surface composition or through sampling can disrupt optimal production schedules[12]. Old scrap comprises (Davenport *et al.*, 2002):

- End-of-life vehicles: where there is copper in the radiators, engine parts and electronic components.
- Construction and demolition waste: where copper constitutes an important wiring, roofing and plumbing material
- Waste from electronic and electric equipment: Where there is copper in circuit boards and wiring. This amount of copper can be difficult and expensive to separate, as WEEEs may contain hazardous materials.

Currently, the most advanced reprocessing technologies that exist are those for the recycling of wires and cables. Shredding is the dominant technology applied: the scrap cable is chopped and then separated from the insulator. This is usually done using the difference in specific gravity between copper and the insulating plastic or rubber.

When recovering copper from automobiles, there is first a manually disassembling step in which the radiator is removed from the car. It is then smelted and refined to produce pure copper. Copper is also obtained from the non-ferrous metal scrap stream that remains after the car has been shredded and the iron and steel have been magnetically removed. The copper can be separated from the other metals by handpicking, air tables or heavy media separation. Some copper can be assitionally obtained from the shredder residues.

Electronic scrap consists of many materials: plastic, refractory oxides and metals (around 40%). Copper represents about half of the metal fraction and it must be first separated from the other material in order to be recycled. A serious problem is the declining metal content of electronic scrap, which makes scrap increasingly difficult to recycle profitably. Electronic scrap is usually treated following these steps:
- disassembly – aiming at the recovery of large items
- shredding - to reduce the size of the remaining material
- liberation of the metals from plastics and ceramics

[12] Source: Script for lecture "Industrial Ecology of earth resources" Department of earth and environmental engineering. Columbia University. www.columbia.edu/itc/eee/**e4001**y/client_edit/IE**Week10**metals.doc

2.2.4 Technological development

Past technological development

The basic mining and metallurgical technologies are relatively stable, standardized and widely diffused. The development observed since the Second World War has involved primarily changes in the scaling up of equipment and plants, rather than the conception of new technical processes. The move from subsurface to surface mining has resulted in a considerable increase in the production scale. This development was accompanied by progresses in the ore processing technologies. With respect to costs, there has been a decrease in the unitary costs of ore extraction (Yachir, 1998).

King (2007) mentions another important change in the industry, which is the expansion of the activities of the copper producing industry. To improve their profits, the industry started to integrate downstream and value added products by creating subsidiary companies that produced refined metals products.

The changes in processing technologies in the non-ferrous metal industry were driven by technical difficulties that limited their business growth. Faced with the challenges of a relatively mature industry, each company came with its own solution. This resulted in the emergence of a variety of technologies for the generic problems of the industry (King, 2007). One of the more pushing problems was how to process declining ore grades, which were a consequence of the increasing ore extraction. This made it necessary to increase the throughput thus lowering the unitary production costs. This was most easily achieved by increasing the intensity of the processes, improving mechanization and increasing the physical size of the plants (King, 2007).

The need to strive for environmental compliance meant that the companies had started to invest significantly in SO_2 capture in the form of sulphuric acid plants. Aqueous discharges (mine tailings, smelter and refinery eluants) were also of concern.

Future technologies

King (2007) expects new technologies either in the mining sector (which is responsible for the highest part of the cost of producing metal) or in the milling sector (which causes in the greatest losses of metal values e.g. metal send to tailing or rejected material).

It is expected that there will be improvements in process control aiding operational prediction and performance optimization (King, 2007).

Biotechnological innovations could have an important impact. It is known, for example, that bacteria can greatly influence heap leaching. New strains of bacteria which can resist higher temperatures and toxic impurities in ores could accelerate heap leaching (King, 2007).

Methods for reducing the diffusive emissions are being investigated. This can have a large impact, since diffusive emissions can be very significant. The Norddeutsche Affinerie[13], for example, indicates that around 85 % of the dust emissions and 70 % of the metal emissions are diffuse emissions, coming mostly from the production hall ventilation.

Rises in the energy efficiency are expected, as well as some new end-of-the-pipe technologies, allowing meeting more stringent environmental standards (King, 2007).

It is expected that automatised mining will increase. This allows mining in areas unsafe for human miners (e.g. depths with not good ground stability) and there are many ore bodies that are richer at depth (King, 2007).

Currently hydrometallurgy is only used for oxide ores. Sulphide processing as well as copper recycling is done by pyrometallurgical processes. Because hydrometallurgy has many advantages over pyrometallurgycal processes, it is being researched how to modify the hydrometallurgical processes in a way that they are able to compete with pyrometallurgy in the extraction of Cu from sulphide ores and copper recycling. Some advantages of hydrometallurgy are (BGS, 2007):

- It can process ores of lower concentrations
- It is more energy efficient because it requires lower temperatures (although it requires high amounts of electricity in the electowinning phase)
- It has a lower environmental impact because waste streams are liquid, and by this more easily contained and neutralised than, for example, the sulphur dioxide gas that is emitted during smelting.
- It has lower capital and operational costs, making it more economical for small scale operations.

Emerging technologies in other industrial sectors that can affect the copper industry are (IPCC, 2001a):

- Modern fabrics for bag filters which can increase the bag lifetime, improve its performance and reduce costs.
- The capture of fugitive emissions, which might be improved by: using intelligent damper controls that enhance fume capture and reduce fan size.

[13] Norddeutsche Affinerie Hamburg. „Umwelterklärung 2002: Umweltschutz und Ökonomie im Einklang. Hamburg“ and „Aktualisierte Umwelterklärung“.

2.2.5 Challenges in the metal recycling industry

- There are some technical obstacles for recycling some alloys, for example the copper beryllium used in flexible welds. In this situations, the cost of treating beryllium, which is dangerous, is higher than the price of the recycled copper[14].

- In some cases copper migration into recycling loops of other products are unavoidable to ensure the efficient recycling of a broad range of materials (Ruhrberg, 2006).

- Products are getting more complex: they are composed of an increasing number of substances. Johnson *et al.* (2007) show this with the example of circuit boards, which contained 11 elements in the 1980s, 15 elements in the 1990s and potentially over 60 in the 2000s. This affects the potential and feasibility of recycling.

- The concentration of copper in the products is an important factor influencing recyclability. Copper needs to be in a minimum concentration to be profitably recycled. With this aspect in mind, the “ease of disassembly” plays a determinant role. If disassembly is easy, it is necessary to consider the concentration in the individual components and not in the whole product (Johnson *et al.*, 2007).

- “Design for disassembly” can serve to facilitate reuse, remanufacture and recycling. The profitability of recycling one metal may drive the recycling of other metals that would not be otherwise targeted. This indicates that disassembly of components not only affects the item in question, but also no targeted items (Johnson *et al.*, 2007).

- Miniaturization can also affect the recycling potential. When the amount of copper to be recovered by product unit gets smaller, regyling becomes less attractive.

2.2.6 Copper mining and processing: effects on the hinterland (Deutscher geologie…)

The environmental impact of mining, in this case copper mining, depends on numerous factors: the type and concentration of the ore, the excavation type (surface mining, subsurface mining or leaching), the processing method, climate and location, among others (Krauß *et al.*, 1999).

As mentioned before, the most common form of copper ore production is surface mining. This is mostly driven by the lower unitary costs in comparison to subsurface mining. From this is can be concluded, that it might be the only economically method for low grade ores. On the other hand surface mining produces a high amount of overburden (higher than subsurface mining) and have thereby a larger impact on the surroundings.

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[14] Online EEP Newsletter 21st August 2003: http://www.eep.org/newsletters/newsletter030821.htm

Following tables published in Krauß *et al.* (1999) show the flows related to the production of 1 ton of Copper considering different ore concentrations and different locations. When comparing the total energy and material consumption needed to produce one t of cooper, it is seen that subsurface mining has more favourable results, which is, however, also partly related to the higher ore concentration, and not to the type of mining.

Flows related to the production of 1 t of copper (pyrometallurgy)

	Copper concentration in ore (%)		
	2.8	0.99	0.44
Ore (t)	40	125.2	272
Used water (m3)	132	418	902
Steel (kg)	34	90	191
Lime (kg)	50	149	340
Primary energy total (GJ)	14.1	28.19	68.8
Primary energy mining (GJ)	2.9	8.57	21.3
Primary energy processing(GJ)	11.2	19.62	47.5
Chemicals for flotation	4.1	11.8	25.8

It is important to notice that the environmental impact is strongly related to the copper concentration of the ore: This suggests that the impact of mining will increase with time (if technology and environmental protection do not change), because the exploited ores have a decreasing content of Copper.

Flows related to the production of 1 t of copper (pyrometallurgy)

	N. America	S. America	Europe	Asia	Australia	Average
Cu concentration in ore (%)	0.59	1.18	2.19	0.52	1.42	0.99
Ore (t)	214	106	51	255	85	125
Steel (kg)	170	73	47	176	63.3	93
Lime (kg)	257	141	68	336	107	149
Primary energy total (GJ)	56	26	15	66	25	30.7
Primary energy mining (GJ)	16	10	5	14	6.9	8.9
Primary energy processing(GJ)	40	16	10	52	18.1	21.8
Tails (t)	206	103	47	251	82	122
Overburden (t)	351	212	10	229	64	216
Used water (m3)	743	380	181	881	289	418
Exhaust gases (m3)	8200	10195	8750	10030	10475	9565
Emitted SO2 (kg)	200	380	0	470	377	315
Produced H2SO4 (t)	2.82	2.33	3.73	2.95	2.32	2.8
Chemicals for flotation	21	10	5	25	8.8	11.8

2.3 CONSTRUCTION AND DEMOLITION WASTE RECYCLING

Construction and demolition waste is made of a mixture of materials (concrete, wood, plastics, metals, bricks…) in variable compositions.

The major fraction of currently recycled C&D waste is mineral based and used primarily as non-stabilised base or sub-base in highway construction (Masood *et al.*, 2002). This does result in conservation of primary materials, but it should be aimed for a recycling of the aggregate into their original uses. This is still not achieved, since there are some reservations with regard to certain properties of recycled aggregate when used for structures (Masood *et al.*, 2002).

There are some research groups looking for alternative uses for recycled C & D waste, principally as structural material (Masood *et al.*, 2002; Etxeberria *et al.*, 2007). The results show that there is a potential for this product to be used as structural material. Etxeberria *et al.* (2007) show that a substitution of less than 25 % of coarse aggregate by recycled aggregate, scarcely affects the shear capacity of beams if some compensations in dosage are carried out (such as increasing the amount of cement or decreasing the water/cement ratio). This indicates that it might be possible to achieve a recycling of C&D waste at a higher level. For the moment, however, there is still more research needed in order to study the behaviour at service (cracks openings, microcracking due to compressive stresses, short and long term deflections) and at ultimate conditions (fatigue, bond and anchorage) (Etxeverria *et al.*, 2007).

Other concepts, such as the “closed cycle construction”, are based on closing the material cycles, especially for concrete and masonry (Mulder *et al*., 2007). After deconstruction, concrete rubble, masonry debris and mixed stony rubble are separated and treated individually:

- <u>Concrete</u> is treated in a rotary kiln and heated at temperatures above 700°C to dehydrate the cement stone. The concrete rubble pieces disintegrate and the original components are set free. After the treatment, only 2% of the hard cement paste remains attached to sand and gravel grains. The gravel and sand are supposed to be of the same quality as primary gravel and sand, but this still needs to be experimentally verified. The cement stone can be used as a substitute for part of the cement clinker.

- <u>Masonry</u> debris is treated in three steps. First the large pieces of debris are treated thermally at about 550°C in order to set the majority of the original ceramic bricks free. This process is based on the difference in linear expansion coefficients between the mortar and the bricks, which leads to stresses on the brick–mortar interface and produces cracks which set whole bricks free. These whole bricks can be used for the restoration of old buildings. The remaining pieces of brick and mortar are physically separated. The ceramic fraction is then reused as raw material for the production of new ceramic bricks.

- <u>The mixed waste</u> is separated and decontaminated using different density separation techniques that are still under development. The quality of the stony fraction is improved up to a level where it can be used as aggregate for concrete.

An important characteristic of this “closed cycle” approach is that the thermal process steps are fueled with the combustible fraction of the C&D wastes itself.

Another approach focuses on grinding the C&D waste into a fine fraction (Müller, 2003). This has the advantage of improving the mixing and homogeneity of the material from the chemical and also from the mineralogical point of view (Bianchini *et al.*, 2004). The fine grinding has also the advantage of reducing the porosity of the recycled material. The disadvantage of this approach is the high energy input needed.

It is fundamental that C & D waste is sorted into different fractions, preferably at the construction site. If this is not possible, for example due to reduced space availability, it needs to be sorted before treatment.

2.3.1 C & D waste treatment

Treatment of C&D waste has the objective of producing a material with a defined grain size distribution composition (Müller, 2003). There are basically two available treatments for C & D waste: a wet and a dry treatment.

In the dry treatment the first action after the arrival of the waste to the treatment plant is the manual sorting out of large contaminations (e.g. wood, plastic, metal parts). After this the waste is crushed, usually with an impact crusher. The iron components are then removed by a magnet and the crushed material is classified into different size fractions. To finalize the treatment, the different grain size fractions are sent separately to an air separator, which separates the light fraction, leaving a material which is to a large extent free of wood and plastic components.

In a wet treatment plant, the waste follows the same steps as in dry treatment up to the classification into different grain sizes. Instead of the air separation, the wet treatment utilises a "swim-sink" sorting technology, where the lighter fraction (paper, plastics, wood) is taken out with the water flow, while the heavier mineral components sink and are later send to a dewatering screen.

When comparing both treatments it is observed that the dry treatment is cheaper, but it has an end product of lower quality. It is important to note, however, that the factor determining the quality of the end product is for both treatments, is the "cleanliness" of the input material, since neither treatment can improve the quality of a poorly sorted waste. This means, that a well done sorting at the demolition site is crucial for successful recycling (Scheibengraf and Reisinger, 2005).

The most effective way of reducing the amount of hazardous substances in the recycled aggregates is to do a selective demolition and discard the tarboards, chimneys and some gypsum containing components, since these are the parts primarily responsible for the contamination with organic substances and the high sulphate concentrations in the leaching. Hazardous materials can be further reduced by screening and a separation of the finest fraction (for example, less than 4 or 8 mm), since it is in this fraction where the contaminants are enriched (Scheibengraf and Reisinger, 2005).

2.3.2 Street breakup

Asphalt pavement can be successfully recycled, which is illustrated by the fact that it is the most recycled material in the US[15]. The composition of asphalt pavement is around 95 % of aggregate (sand, stone or gravel) and 5 % of asphalt. Asphalt is a product of oil refining and its function is to glue the aggregates together (binder).

Asphalt pavement recycling can be recycled by crushing and screening into an aggregate phase (downcycling) or it can be recycled back into new asphalt pavement. There are many technologies available for asphalt recycling. Only the cold recycling and hot-place recycling techniques are shortly mentioned here.

In cold recycling the recycled asphalt is mostly used as aggregate. The pavement is removed by cold planning to a depth of 7-10 cm. The material is pulverized, sized and mixed with an additive. Virgin aggregates may be used for modifying the characteristics. An asphalt emulsion or recycling agent is added and then the mineral is placed and compacted. An optional additional layer of hot mix asphalt can be further applied[16].

In hot-in place recycling is carried out by a mobile recycling unit that heats, removes, modifies re-paves and compacts the asphalt surface in a single pass. The pavement is softened by the heating, thus permitting the asphalt to be loosened by scarifiers without being degraded. These scarifiers skim of 40 to 60 mm of loosened material. The asphalt is then mixed with binder and/or rejuvenator to restore the desired properties, and finally it is spread to the required profile and compacted. A thin layer of fresh mix may be laid over the recycled mix[17].

2.3.3 Challenges in the C&D waste industry

The separation of the waste into "clean" fractions is the most limiting factor for a better recycling (Scheibengraf and Reisinger, 2005). This indicates that higher recycling rates depend on the possibility of sorting the materials.

The composition of construction and demolition waste changes with time. Currently most buildings being demolished were built with a high share of bricks and without using too many different materials. It is expected that in the future the demolition waste becomes more complicated to treat, since there is a steady increase in the number of materials used

[15] NAPA, 2002. Asphalt Industry undate and overview. Available online: http://www.hotmix.org/view_article.php?ID=10
[16] CIWMB, sa. Asphalt Pavement Recycling. California Integrated waste management board. Available online: www.ciwmb.ca.gov/ConDemo/Roads
[17] GEOPAVE, 2001. Hot in-place asphalt recycling. Technical Note 49. Available online: http://webapps.vicroads.vic.gov.au/VRNE/vrbscat.nsf/e5ff054ca38faf2b052568550077d3e7/70209d6e82981524ca256c6f0019c023/$FILE/tn049.pdf

(Scheibengraf and Reisinger, 2005). This is the effect of, for example, the better insulation in buildings, which lead to the use of spumed synthetic materials or mineral fibre materials.

Other changes in the construction sector also influence negatively the recycling potential. Examples of this are: PVC windows, which are built into the wall (and thus difficult to remove), the increased use of synthetic plaster, the insulation PS, which is usually glued over its entire surface, among others.

2.4 PLASTIC RECYCLING

As when recycling other materials, there is a large difference depending on the plastic input material that is recycled. Residues or scrap from industry, which are relatively economical and simple to recycle, constitute reliable secondary raw material source: The reason for this being that the material is relatively uncontaminated and the chemical composition is known. The other important source for plastic recycling is postconsumer waste, which has to be collected and sorting and is thus generally more complicated to recycle.

Today there are two recycling approaches for recycling plastics (Mariansky, 2006):
- mechanical recycling, that converts the waste plastic into a resin that can be processed to manufacture new plastic products
- chemical recycling, that separates the waste plastic into its constituent monomers which are further used to produce plastic raw material. Only chemical recycling results in a product of identical characteristics than virgin feedstock.

Mechanical recycling is the most common used recycling method. This means that most plastics are not recycled into the original product but into different products of a lower quality.

Different methods are used for different resins by different countries, but the basic steps involved in mechanical recycling are common to most methods:

- Plastic needs to be sorted according to its type and/or colour prior to mechanical recycling. For this, some new sorting technology has been introduced, for example X-ray fluorescence, infrared and near infrared spectrometry, electrostatics and flotation.[18]

- Following the sorting, the plastic might be melted directly and then moulded into a new shape. In most cases, however, they are shredded into flakes after which the contaminants are removed using various methods. The most used ones are washing and floating, by which heavy contaminants are removed. The flakes are then melted and pushed through an extruder,

[18] Source: www.wasteonline.org

cooled and then fed into a pelletizer. The pellets are used as resin for new products (Mariansky, 2006).

Marianksy (2006) mentions, that primary reprocessing is difficult due to two reasons. The first is that plastics are very susceptible to contamination, which might lead to structural defects, inferior mechanical properties and in some cases total breakdown of the polymer structure. The contamination can come from various sources including residual chemicals from the previous use of the plastic that have not been removed during the cleaning process. The most severe contamination occurs when different kinds of resins are mixed. For example, even small amounts of PVC can lead to a breakdown of the structure of polyethylene. The second reason why primary reprocessing is difficult is the sensitivity of plastics to heat and handling. The polymers may show alterations in the structure when subjected to heat and stress during the extrusion process. This implies that each time a plastic is reprocessed; it results in a weaker and more brittle plastic.

Chemical or feedstock recycling breaks down the polymers into its constituent monomers, which can be used again in refineries or in petrochemical and chemical production. The most common methods are methanolysis, glycolysis and hydrolysis. None of these methods can process mixed plastic feedstock, thus the step of plastic sorting is also crucial in chemical recycling. In most chemical methods the polymer is heated under pressure to moderate temperatures (250°C), resulting in the depolymerization of the polymer molecule. The products are often further purified by methods like distillation and recrystallization (Mariansky, 2006).

Froelich *et al.* (2007) present a review of the technological know how of the plastic recyclers in Europe. The main technologies include:

- shredding and grinding for material liberation
- mass gravimetric separation (heavy medium, flotation)
- aerodynamic separation
- electrostatic or triboelectric separation
- eddy current
- magnetic separation

There are also certain specific sorting technologies developed for plastics such as optical automated sorters and chemical dissolution. Optical automated sorters are used mainly for plastic waste in form of bottles. This method allows the separation of differently coloured plastic and also the separation of different plastic grades with near infrared spectrometry. However, it is today still not possible to discriminate different families of black plastics with automated infrared sorting methods. Chemical dissolution is not cost effective for commodity polymers, but it is sometimes the only solution for the liberation of coatings associated with polypropylene.

2.5 RECYCLING OF BIOLOGICAL WASTE

Biological waste is produced by different activities: agricultural waste, waste arising from food production and waste from households and the service sector. A problem which is often encountered (except for agricultural waste) is that the biological material is often still packed. Some research is being carried out to cope with this. For example, INETEC[19] developed a system which couples the "unpacking" of biological waste with its thermal utilisation. The mixed waste is loaded into a processing vessel where it is macerated against itself over a period of around 20 hours. During this time, heat is applied to the base of the vessel. This raises the temperature of the waste leading to the vaporisation of moisture. The vapour is drawn out and condensed into the liquid effluent. What remains after this drying process is a dry, highly prepared biomass fuel. This fuel looks similar to coffee granules, but has a high energy value of between 20-25MJ per gram. This fuel can be used to generate energy in a number of forms. For smaller installations the biomass fuel can be combusted and the thermal energy used to generate steam, hot water or for space heating purposes. On a larger scale the fuel is fed through a gas conversion process, and the resulting gas is used to drive conventional gas engines which generate renewable electricity. This plant is expected to start operating in 2009.

Recycling of biological waste can be classified into aerobic and anaerobic recycling.

UNEP (2005) defines aerobic recycling (also referred as **composting)** as the biological decomposition of biodegradable waste under controlled conditions to a state that is sufficiently stable for nuisance free storage and handling. Composting is very flexible in its requirement and has the advantages of typical biological systems: lower equipment and operational costs. On the other hand, these systems have a slow reaction rate and the retention times are in the order of weeks and months.

The presence of the needed organisms and the existence of favourable conditions for them are prerequisites for a successful composting. The organisms depend on the availability of nutrients (macro and micronutrients, C:N ratio, particle size) and also on adequate environmental factors (temperature, pH, moisture content, aeration).

The renewal of the oxygen supply is a critical factor. This supply of oxygen can be achieved by physically rearranging the composting particles (agitation). This can be accomplished by stirring, tumbling or a combination of both. Aeration can also be achieved by forced-air-systems, which force fresh air into- and simultaneously exhaust spent air from- the composting mass. The odours generated, and also their intensities, depend strongly on the type of waste being composted, the design of the process as well as the operating conditions. An effective method of treating these odours, are biofilters. Today the most common biofilter

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[19] Webpage: www.inetec.co.uk.

medium consists of a mixture of compost and wood chips. In some cases, other materials such as peat, lime, bark, mulch or sand may be added.

As an example of the steps involved in composting, the sub-processes of the composting facility Dithmarschen[20] in Germany are briefly mentioned below:

- **Waste conditioning**: in this phase, foreign particles that influence negatively the composting process are eliminated. This is done automatically for metals with a magnet separator, and also manually by two workers, which separate plastics, glass and stones among other substances. The waste is then mixed with some structure material which enhances the aeration of the waste thus optimising the degradation processes. This material is erected to a composting pile

- **Decomposition**: the material decomposes for 13 weeks. At the beginning, a temperature of 70°C is reached. To regulate the odours and the CO_2 emissions, there is a controlled evacuation of air. This air is treated before being again released into the atmosphere; also the leachate is collected and reused in the decomposition process as far as possible.

- **Post-treatment**: the compost is screened. It is sold to agriculture and might be packed if desired by the client.

Barth (2006) notes that biological waste treatment on the basis of separately collected organic waste, has developed rapidly during the last years in many European countries. This trend will probably go on, since there are many examples that show that it can be done in a qualified and cost competitive way. The main driver for this development is the European Landfill Directive which requires the diversion of the organic fraction from the municipal solid waste streams before landfilling.

Anaerobic recycling of biomass can be achieved by means of **biogasification** or **biofermentation**. The aim of these processes is to transform the biomass into a gas mixture with a high calorific value. The following paragraphs describe some anaerobic recycling approaches as mentioned in Wöllauer (2007).

Biogasification can be achieved by means of different methods, two of which are further mentioned here: pyrolysis and steam reformation. In pyrolysis the waste is decomposed under anaerobic conditions and using high temperatures (which means that an input of heat is needed). It produces three products: gases and volatile substances, tars and charcoal or coke. The tars might be problematic, because they might get deposited on different places on the facilities, stick down of the surface and then disintegrate, leaving crusts and cokings. The tars are the products responsible for most technical difficulties in biogasification. This is why most biogasification methods try to avoid the formation of tars or to transform the tars into

[20] Source: http://www.awd-online.de/fileadmin/inhalte/pdf/10jahre.pdf

burnable gases. The charcoal and coke resulting from biogasification is not further used in the process, and can be burned for heat obtention in other industries.

Steam reformation is the transformation of biomass under high temperatures (700-1000°C) and steam. The biomass carbon is transformed with water into CO or CO_2 (depending on the method used). Hydrogen and methane are the products obtained.

Pyrolysis and steam reformation might be run in two ways:
- **Autothermic**: where there is some input of air into the system. The purpose of this is the burning of a part of the biomass, which produces the necessary heat to run the processes. This makes the equipment less complex, but it dilutes the resulting gas due to the air input.
- **Allothermic**: where the necessary heat for running the process comes from outside the reactor, which means that all the biomass in the reactor is used for the pyrolysis/reformation process. Thus, there is no additionally air coming in or CO_2 produced, which explains why allothermic processes have a higher energetic efficiency.

There are many different technologies that might be used, which depend on the provider and the waste being biogasificated.

Biofermentation is a process where microorganisms convert in the absence of oxygen biological waste into other substances. The end products are mainly biogas and bioethanol. All kinds of biomass might be fermented, but it only makes sense when the biomass has a high water content rendering neither incineration nor biogasification as a reasonable alternative. Fermentation (also when producing cheese, wine, etc.) is a process which depends strongly on the conditions of the process, which need to be closely controlled.

Fermentation occurs where bacteria in anaerobic environment use biological material as energy source. Different populations of organisms are responsible for different steps of the process in which carbohydrates and proteins are converted into CO_2 and methane.

The waste needs to be free from contraries, which means that stones, plastic foils, cans, bones, etc have to be eliminated. This must often be done manually, and represents a potential health risk for the workers. Substrates that might be contaminated need to be sanitised by high temperatures before they are further processed. The next step is the reduction of the substrate into small pieces, as the size of the substrate influences partly the effectivity of the fermentation process. Then, different substrates are mixed together, mixed with water (or manure) and slurried. This slurried substrate needs to be heated until the optimum temperature is reached (35-45°C) and then stored in the reactor.

The gas coming out the reactor must be usually treated in order to separate the hydrogen sulphide and the water content. If the biogas is to be fed into a natural gas pipeline, it is also necessary to eliminate the CO2, an energy consuming process which worsens the energetic balance of the process.

Hupe *et al.* (na) mention that aerobic and anaerobic processes comprise very different processes and have both advantages and disadvantages. Fermentation is used for wastes with high water content and which are easily degradable. Composting is suited for wastes with lower water content and with higher proportion substances that are more difficult to degrade. Anaerobic processes have usually a more positive energy balance and fewer problems with odour generation and odour management than composting. On the other hand, the anaerobic processes are often more complicated. There are also combinations of both processes, where there is first a fermentation of the moist waste, where the substances that are easily degraded, are decomposed. This process takes usually 21 days. The remaining material is then sent to composting, where it is treated for a period of 3-5 weeks.

2.6 STRATEGIES FOR INCENTIVATING RECYLCING

Following strategies for increasing recycling were identified in the literature:

Development of standards for recycling. This would result in a better protection of the environment and would promote recycling by setting a level playing field for recycled material. Quality standards would increase the acceptability of recycled material and result in an increased demand for it. (COM 666) suggests this strategy and affirms that the development of quality benchmarks for composting facilities and for compost will increase the prospects for composting. With respect to recycled construction material, it was suggested to consider limits of hazardous substances in the recycled materials in the standards (Scheibengraf and Reisinger, 2005).

Increase the quality of recycled products. This is specially important in the recycling of C&D waste, where the re recycled products are often used as aggregates and have not the same function than the original product. In countries where the asphalt recycling rate is high, there is not much potential for increasing it, but there is a potential for increasing the quality of the recycled product. This can be achieved if hot recycling technologies are used instead of cold recycling technologies (Schreibreiner and Reisinger, 2005).

Clarify when a waste ceases to be waste and becomes a new or secondary material. This would improve the environmental performance of recycled products, because business would recycle waste in a way that it conforms to these criteria. Having poor quality recycled products generates difficulties for potential purchasers and also for reputable sellers. Also, a definition about energy recovered from waste incineration activities, based on the concept of substitution of resources would be beneficial[21].

[21] EC Communication Taking sustainable use of resources forward: A Thematic Strategy on the prevention and recycling of waste COM(666)

Producer responsibility. Such arrangements place the responsibility for the environmental impact of products on the producing businesses (DEFRA, 2007). Usually in such schemes, a specific company that covers the interest of the whole branch is established. This company organises the collection and treatment of the waste and manages the fulfilment of the producers obligations on behalf of the branch. The collection and treatment activities are financed by the producers and first retailers (EEA, 2002).

Setting higher recycling targets. It is a product specfic strategy used by many European countries.

Deconstruction. Selective demolition results in waste divided into different fractions, which is beneficial for recycling. It is, however, also more expensive and time consuming than traditional demolition methods (EEA, 2002). There are higher space requirement in selective demolition, since "sorting islands" need to be implemented on the construction sites. Pilot projects could contribute to the expansion of selective demolition (BAWPL, 2006). The development of standards for the creation of selective demolition plans is recommended as well as the definition of criteria for the selective demolition of public buildings.

Increase segregation and sorting of waste at or close to the source. This requires further planning for and investment in collection, sorting, reprocessing and treatment facilities. This would lead to larger frations of separated waste, which are easier to recycle.

Request certain proportion of recycled materials. For example, it is possible to require that all new buildings use a certain percentage of recycled material or to define some specifications for a minimum content of recycled material in products made of glass and certain plastics.

Prioritise recycled products in public activities. Recycled construction materials should be prioritized when the construction is financed by the public sector. This could be done, for example, by prescribing a certain share of recycled materials. It is expected that these would strengthen the market for recycled products and also motivate other clients to increasingly use recycled material (Schreibreiner and Reisinger, 2005).

Design for recycling. Could be incentivated by developing eco-design requirements which consider the impact of waste as part of the wider life cycle assessment (DEFRA, 2007). Recycling can be facilitated if the number of compounds used in products and building is reduced. Composite materials pose special difficulties and their use should thus be minimised in order to facilitate recycling. When considering buildings, design for recycling deals mostly to the connections the different components, which should be connected in a way that they can be easily detached (Schreibreiner and Reisinger, 2005).

Financial incentives for households that recycle. It could be possible to introduce schemes where households that recycle their waste receive payments funded by households that do not recycle (DEFRA 2007). During the 1990s, Danish municipalities charged the households for the collection and treatment of waste based on the amount of waste the household produced. This was done with truck that carried out the weighting automatically, and with an electronic plate on the dustbin that identified the owner or it. The fee system then generated individual accounts for every household. This was done in order to incentivate home composting and recycling (mostly of paper and glass, which are “heavy” and thus increase the fee when disposed with the household waste). This reduced the amount of mixed household waste and increased the amount of waste recovered through recycling schemes, but there was no reduction in the waste generated (EEA, 2002).

Creation of exchange sites for recyclable / reusable parts. When buildings are selectively demolished, there are some parts that can be reused. Because the required size, condition and characteristics of these potentially reusable parts must match the necessities, it is expected that reuse is going to be rather an exception (Schreibreiner and Reisinger, 2005). The creation of some markets (e.g. internet platform) where the suppliers and buyers of these products can meet could increase the reuse of parts.

Provide advice and information to business with respect to possibilities for re-use and re-manufacture of products and material resources, increasing by this the resource efficiency (DEFRA, 2007).

Tax modifications. In Denmark, for example, a **tax on landfilling** construction and demolition waste led to an increase in the recycling of these types of waste. In parallel, **taxes on virgin raw materials** were also introduced to make recycled products more competitive. The municipal assignment schemes were modified, in a way that waste can be directed easily to sorting and processing facilities. These measures caused a change in the recycling rate of C&D waste from 25 % in 1990 to 90 % in 1999 (EEA, 2002).

2.7 DESCRIPTION AND IMPLEMENTATION OF THE SCENARIO

In this scenario all waste management efforts are concentrated on material recycling. There is a broad backing of measures facilitating recycling among all involved actors: the consumers, producers and politicians. Their vision is to turn the EU into a recycling society that uses waste as a resource. This raises the efficiency of the use of natural resources and protects the environment by reducing the impact of primary production activities[22]. The key variables that were identified to affect recycling in a society are: market price and demand for the recycled products as well as of the “primary” products that are substituted by the recycled product, quality of the recycled products, quality of the input to the recycling industry (which is influenced by the design and composition of the products), the legal framework and the

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[22] EC Communication Taking sustainable use of resources forward: A Thematic Strategy on the prevention and recycling of waste COM(666)

motivation of the consumers. Therefore, the policies for incentivating recycling concentrate on following areas:

- Activities for increasing the awareness of the importance of recycling and to motivate the industry, consumers and politicians to contribute to recycling. Consumers are expected to be motivated to increase the collection rates of recyclable products and to purchase recycled items and products. An increasing interest on recycling should also increase the pressure on the industry to produce products that are easily recyclable and thus to achieve a better image.

- For some products, where recycling is hindered due to the composition and design of the products, the concept of extended producer responsibility is enforced. This creates an important incentive towards the production of recycling friendlier products.

- The setting of some collection and recycling targets, either through voluntary agreement with the industry or through legislation.

- Market incentives for making recycled products more competitive.

- Enforce standards for recycled products, which would increase the efficiency of the market and incentivate the demand for recycled products. Having clear standards that the recycled products have to meet firstly increases the quality and uniformity of the recycled products. This, in turn, helps in increasing the confidence of the consumers and also facilitates the large scale use of recycled products (since the quality is more uniform).

These activities create an environment that incentivates recycling and that acts as a driver for the development of new recycling and sorting technologies and also for innovations regarding the use of recycled products.

This scenario assumes that the amount of produced waste as well as the treatment of the non-recycling waste is the same as in the baseline.

In the recycling scenario it is necessary to define for each product the relevant materials (components) that should be separately considered. For example, when recycling WEEEs, it is important to separate iron, aluminium, copper, other metals and plastics, since these are the fractions that are recycled and they do not have necessarily the same recycling rate.

For defining the recycling rates of **beverage packages** (FW code 27), a review of the recycling rates in European countries was carried out. There is abundant information about the recycling rates of packages and following rates were identified for the different materials:

- Plastic packages. Comprise a large range of products and different plastics. As an example the PET recycling rates were used. A recycling rate of 74 % was reached in Switzerland in 2004[23]
- Glass packages: a recycling rate of 95.6 % was reached in Switzerland in 2004[24].
- Composite packages: the average worldwide recycling rates of Tetra pack reached 14.6 % in 2002. Another 15 % were used in energy recovery. The industry proposed a target of 25 % recycling rate of beverage packages by 2008[25].
- Aluminium cans: Switzerland has a recycling rate of 91 %[26].

For the scenario, the residuals are disaggregated into the following materials: aluminium, C_oil, sand_gravel_stones and paper. The recycling rates are:
C_oil: 70 % recycling in 2015 and 85 % recycling in 2025
Sand_gravel_stones: 90 % recycling in 2015 and 95 % in 2025
Paper: 30 % recycling in 2015 and 50 % recycling in 2025
Aluminium cans: 80 % recycling in 2015 and 90 % in 2025

For **construction waste**, there are also some estimates about the potentially recyclable waste (Thormark, 2001):

- For metals a maximum recycling rate of 95 % was estimated. The current recycling rates of aluminium in construction and demolition waste are estimated to be around 85 %. For copper there is a detailed study about its recycling in Europe and it is estimated that around 97 % of copper in external building applications, 66 % of copper in internal architectural features, 70 % of copper in plumbing and heating and 42 % of copper in building wire and cable is recycled.
- The situation for plastics depends on the types used in construction. Most plastics (over 80 %) used in construction is PVC (and most PVC is used in construction). Statistics indicate that PVC has a recycling rate of only 2-3 % in Europe. Other plastics used in construction are expected to have a recycling potential of 90%.
- The maximum recycling rate for minerals also depends on the specific material. A recycling rate of 86 % for clay and bricks and of 90 % for rocks seems achievable.
It is estimated that 20 % of the wood might be reused

The current recycling rates for construction and demolition waste are rather low, but very variable among countries, for example it is around 90 % in the Netherland and Belgium, and less than 5 % in Spain, Portugal and Ireland.

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[23] Praktischer Umweltschutz. Abfall und Recycling Merkblatt 8 PET. Webpage http://www.umweltschutz.ch/
[24] Online resource: http://www.verum.ch
[25] Online resource: http://www.tetrapack.de
[26] Online resource http://www.neue-verpackung.de/

For construction waste (FW code 78-80), we suggest disaggregating the residual into: iron, copper, aluminium, other metals, C_oil, sand_gravel_stone, soil and clay, C_fibre. The recycling rates are:
Metals: 85 % recycling by 2015 and 95 % by 2025
C_oil: 7 % recycling by 2015 and 14 % recycling by 2025
Sand_gravel_stone: 40 % recycling by 2015, 80 % recycling by 2025
Soil and clay: 40 % recycling by 2015 and 70 % recycling by 2025
C_fibre: 20 % recycling by 2015 and 40 % recycled by 2025

Agricultural waste arising from crops (FW codes 4-5) can be composted in the same facilities where it is produced. Agricultural waste arising from animal husbandry (FW codes 1-3) can be partially used a fertilizer and also biogasificated. Waste coming from the food production industry (FW code 19-22, 25-26) can be biogasificated. We propose following scenario:
- Composting of agricultural crop waste (FW code 4-5) is increased to 90 % by 2015
- Biogasification of animal husbandry waste (FW code 1-3) is increased to 70 % by 2015
- The biogasification of food and tobacco from the food industry (FW code 19-26, 28) and from households (FW codes 112) is increased to 40 % by 2015 and to 60 % by 2025.

The relevant material in this case is the C_food and C_fibre.

Paper and printed matter and recorded media waste (FW codes 33-36) has already a high recycling rate in Europe. According to CEPI statistics, the countries with the highest collection rates are Ireland (78 %), Sweden and Switzerland (74%). Since all the paper waste which is collected is either send to recycling or exported, the collection rate is a good measure of the proportion of paper waste being recycled.

The collection rates of paper and paperboard (FW code 35) as well as from printed matter (FW code 36-partially) is increased to 67 % by 2015 and 77 % by 2025. The relevant material is the C_fibre

With respect to the recorded media waste, there are possibilities for recycling the aluminium, and glues are separated form the polycarbonate, which is reprocessed to new PC granulates. Today only 1 % of the CDs is recycled in this way.

For CDs (FW code 36-partially) the recycling rate is increased to 10 % by 2015 and 25 % by 2025. The relevant material which is recycled in this case is the polycarbonate: C_oil.

For **ELV**, the ELV Directive requires that 95% of ELV material by weight must go for recovery, re-use and recycling, with at least 85% of ELV material by average ELV weight going for recycling and re-use by 2015. When sending a car to a shredder, around 25 % of the weight of the car is shredder residue. This is composed of around 60% plastics, 10 % Fe, 4 % NE metals, 5% wood and paper and other materials (glass, sand, ceramics, fiber). There are some technologies for extracting the metals. The plastic fraction can also be partly separated and used as mixed granulate. It is estimated that the current recycling rate for aluminium in transportation is of 95 %. For copper it is estimated that around 61 % is recycled.

For ELV (FW code 71) it in necessary to separate the residuals into: iron, aluminium, copper, other metals, C, sand_gravel_stone. The recycling rates are increased to:
Metals: 95 % by 2015
C: 85 % recycling by 2015
Sand_gravel_stone: 85 % recycling by 2015

For **waste electric and electronic equipment** (FW codes 67-70), the EU WEEEs recycling targets apply. There are different targets, depending on the type of products, for the recovery rate (by average weight of the appliance) and also for a component, material and substance reuse and recycling. The targets for 2006 range from 70-80 % of recovery by average weight by appliance. With respect to component, material and substance recycling the targets range from 50-75%.
For recycling of WEEEs it is necessary to separate the residuals into: metals and plastics. The recycling rates are:
Metals: 70 % recycling by 2015 and 85 % by 2025
Plastics: 40 % recycling by 2015 and 55 % by 2025

4. WASTE TREATMENT SCENARIO

The third scenario "treatment options for the residual waste" (also called "waste disposal scenario") deals with the treatment of residual waste, which cannot be prevented nor recycled. In this scenario the amount of waste, as well as the recycling rates are maintained at baseline levels and treatment of the non-recycling waste is the only parameter changed in the scenario. Since biological treatment processes, such as composting and biogasification, are considered in the recycling scenario, following treatment processes remained for the disposal scenario: mechanical-biological treatment, thermal treatment and landfilling.

4.1 EUROPEAN LAW DEALING WITH WASTE DISPOSAL

The general goals of waste management are: protection of human health and the environment, natural resources' conservation, and aftercare-free landfills. These goals should be the essential objective of all provisions relating to waste disposal.

The Landfill Directive (99/31/EC) sets mandatory targets for reducing the amount of biodegradable waste going to landfills by 25% until 2010, 50% until 2013, and 65% until 2020. In the same Directive it is dictated that Member States should take measures in order to make sure that only waste that has been subject to treatment, is landfilled (Art. 6). The Landfill Directive classifies landfills into three classes: landfill for hazardous waste, landfill for non-hazardous waste, and landfill for inert waste and specifies which wastes are to be accepted in each landfill type. It also defines a standard procedure for issuing landfill permits, for accepting the waste in the landfills and for monitoring during the operational and after-care phases.

The framework of the Council Decision 2003/33/EC sets limit values and criteria for the acceptance of waste at landfills.

The Directive 2000/76/EC is on the incineration of waste. It declares that all incineration and co-incinerations plants need to have a permit. It also outlines the procedures for granting the permits. With respect to the operating conditions it states that the plants should be operated in a way to achieve a level of incineration such that the TOC content (Total Organic Carbon) in the slag and ashes does not exceed 3 % or the loss on ignition is less than 5 % of the dry weight of the material. The gas resulting from the incineration should be raised for two seconds to a temperature of 850°C. If hazardous waste with more than 1 % of halogenated organic substances is incinerated, the temperature has to be raised to 1100°C for at least two seconds. The Directive set limits for air and water emissions. Incineration residuals should be minimised and recycled when appropriate. The transport and storage of the residues in the form of dust should be done in a way to prevent dispersion. The applications for permits for new incineration plants must be made accessible to the public so that the latter may comment before the competent authority reaches a decision. Finally, the Directive defines some procedures for control and monitoring of the equipment and processes.

Directive 94/62/EC covers all packaging placed on the market in the European Community and all packaging waste. Directive 2004/12/EC (amending Directive 94/62/EC) requires from Member States to introduce systems for the return and/or collection of used packaging. One of the targets, is to recover or incinerate at waste incineration plants with energy recovery at least 60% of packaging waste (by weight) no later than the 31st of December 2008 (Art. 1). The Directive 2005/20/EC sets a later deadline for the 10 new Member States (the Czech Republic, Estonia, Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Slovenia, Slovakia) to meet the targets of the revised Packaging Directive.

The Directive 75/442/EEC states that Member States should increase the recovery of waste by means of recycling, re-use or reclamation or any other process with the goal of producing secondary raw materials (and thus reduce the extraction of primary materials), or use of waste as a source of energy (Art. 3).

All these directives stimulate the pre-treatment of residual waste and the improvement of the recycling systems, resulting in changes not only in quality, but also in the quantity of disposed waste.

The member states have to integrate the EU specifications and requirements into national legislation. An example of this is the Austrian "Deponieverordnungen". They fulfil the requirements of the Landfill Directive and the Council Decision 2003/33/EC and specify that it is not permitted to landfill waste that contains more than 5% of Total Organic Content (TOC). One of the exceptions is waste after treatment in a mechanical-biological plant. It was planned that the residues meant to be landfilled would not be allowed to have a net calorific value higher than 6000 kJ/kg. Since 1st of March 2008 this value was increased to 6600 kJ/kg in the latest guideline.

4.2 MECHANICAL-BIOLOGICAL TREATMENT

Mechanical-Biological Treatment (MBT) process mixed household waste (but also non-hazardous industrial and commercial waste) by removing mechanically some components and by treating biologically others. MBT encompasses a several types of mechanical and biological processes elements that are combined in a wide variety of ways. The resultant material is more stable and more suitable for a number of uses than the input material into the MBT plant. It is, however, necessary to consider that MBT is only an intermediate treatment technology, which means that a viable end-use or disposal option is still needed for the output from MBT. (Archer *et al.*, 2005)

There has been an increase in the interest of MBT in Europe, driven mostly by the limitations in landfilled waste promoted by the EU. MBT is seen as a viable alternative, since incineration is often difficult to implement due to public pressure.

MBT is very flexible and can be used for mixed municipal waste or for source separated residual waste (*Archer et al.*, 2005). When using it for mixed municipal solid waste the mechanical part of the process needs to be more robust and flexible to separate the biodegradable fraction for further biological treatment. In this case, the objective of the mechanical part of MBT is to prepare the input, rather than to extract recyclables. If used for source separated residual waste, there is much less material that can be easily recycled (which results in lower quantities of waste for treatment), but the waste still contains metals, plastics, glass and paper. Because these remaining recyclables/contaminants are often of a small particle size, more complex mechanical equipment might be required.

MBT is a good way for reducing the greenhouse gas emissions from the landfill and to lower the contamination of the landfill leachate. In contrast to the composting of biological waste, the residual treatment of residual waste in industrialised countries does not produce usually a fraction which can be used in agriculture. This is because the residual waste is often contaminated by heavy metals and hazardous organic substances (Kuehle-Weidemeier, sa).

The mechanical treatment has following objectives when carried out before the biological treatment (Kuehle-Weidemeier, sa):
- Separation of contraries, which is done mostly by manual extraction and also by separation with a polyp.
- Separation of high calorific fractions for using as a refuse derived fuel (RDF). This is mostly done by sieving (e.g. 80-150 mm) and sometimes by air separation.
- Separation of waste components which can be recycled. This is done by magnetic separators for Fe-metals and by eddy current separators for non Fe-metals.
- Disintegration and homogenization of the waste for the biological treatment. This is done by shredding or milling the waste and then using mixing drums.

When mechanical treatment is done after the biological treatment, it usually comprises sieving to < 60 mm or smaller. This is done for example in Germany and Austria, where the upper calorific value and TOC in the dry matter of waste to be landfilled is strictly limited. It seems that the boundary values can only be achieved if the waste gets a second mechanical treatment after the biological one.

Aerobic biological treatment might be carried out in a simple way by using passively aerated piles, which are shifted from time to time, or by using static open air piles with the dome aeration method. These low technical processes need a long treatment time (e.g. 16-20 weeks) and therefore much space. The control of the processes (e.g.) moisture management is difficult and not very precise, but it allows a huge improvement of the landfilled waste at low investment levels (Kuehle-Weidemeier, sa).

More complex treatments are needed when the environmental standards on gas emissions are high or when a homogeneous product quality of the landfilled output is required. In these cases, an active aeration is implemented, the piles are frequently shifted and they are located in halls or tunnels which allow a better process and emission control.

Aerobic treatment might be combined with anaerobic digestion to produce methane gas for energy production. This digestion might be done as “full stream digestion” or as “part stream digestion”. In the first case, the whole stream is biologically treated. This results in high demands on the mechanical properties of the digestion step and the dewatering at the end of the digestion, but is allows the use of the whole methane production potential. The “part stream digestion” only digests the fine fraction, while the coarse rest of the waste, which contains anaerobically poorly degradable substances, goes directly to the aerobic treatment. A namely dewatering is usually not necessary, because water is needed for the aerobic treatment of the undigested fraction.

Different mechanical and biological options might be combined in a different ways, and produce by this, different outputs. There are four main options available for the output from MBT processes:

- Biogas production
- Use in compost applications
- Use in solid fuel applications
- Send to a landfill

It is, however, important to note that regardless of the primary objective, all MBT process produce in addition other output streams. These might be: a range of dry recyclables (e.g. paper, metals, plastics), a variety of reject streams from the mechanical treatment (which are often landfilled) and wastewater and residues from the environmental abatement equipment.

With respect to the availability of commercial solutions, there are many different viable systems suitable for a wide range of waste processing objectives at a variety of scales. The functionality, complexity, cost, environmental performance, standard of engineering and proveness of individual systems shows a large variation. This means, that the selection of the most appropriate configuration, in order to achieve the desired results, is an important aspect that should not be neglected.

4.3 INCINERATION

Waste incineration is the controlled burning at high temperature. It has following objectives:

- Hygenisation, which is reached due to the high temperatures and is the reason because hazardous waste is often burned.

- Reduction of the waste volume. Many early waste incineration plants were build because a limited available place for landfilling the waste (for example an incineration in Frederiksberg in 1903 in Denmark mentioned by Kleis and Dalager (2004)).
- To save resources. Waste incineration reduces the volume of waste to 20 %, saving by this scarce landfilling space. A fraction of this waste might be subjected to further treatment for the extraction of metals, which reduces the volume still more. Part of the heat produced by the plant can be used for the production of electricity, or the heat might be used for district heating, saving primary energy sources. Finally, metal ores can be saved by treating the slags and extracting metals from them.

Modern waste incineration plants comply with high environmental standards. The flue gases are treated in different steps and achieve low concentrations of dust and contaminants. The low amounts of filter ashes filter cake and sludge produced by the incineration plant, in comparison to the volume of waste treated, contain heavy metals and contaminants in high concentrations. They are thus more easily and efficiently disposed than in less concentrated waste.

The available technologies for incineration are: grate incineration, rotary kiln incineration, fluidised bed incineration and other technologies, such as pyrolisis and gasification. Kleis and Dalager (2004) explain that incineration of waste usually means the incineration of mass waste, this means incinerating the waste as it is, except for the shredding of very large items. For the burning of mass waste, grate incineration and rotary kiln (mainly for hazardous waste) are the most commonly used technologies. Fluidised bed incineration might produce a relatively larger gross production of power than the other two technologies mentioned before. But the energy requirements are also higher, because the waste has to be shredded.

For flue gas treatment there are also different techniques, each with its advantages and disadvantages. Kleis and Dalager (2004) mention that on a general level, it is necessary to decide if the treatment should be a wet system, which generates waste water, or a dry system in which wastewater is avoided, but there is a larger amount of the leachate in the residues. If the wet treatment is chosen, for example for SO_2 treatment, it could be removed by lime or sodium hydroxide. The same situation applies to other contaminants, where there are different methods for achieving the necessary cleaning of the flue gas. Thus, it is fair to say, that BAT, which considers technical and economical aspects, differs from project to project.

The outputs of an incineration plant for MSW vary according to the type of waste incinerated, the incineration technology and the flue gas treatment technology. In general, it can be said that the outputs are: energy (in the form of heat or electricity), purified flue gas, bottom ash, metal scrap, fly ash, and filter cake. The last two are defined as hazardous residues (about 3% of the input mass) and should thus be disposed of on a hazardous landfill (underground storage). Fly ash and filter cake arise due to gas purification systems and are considered the only critical aspects (in long-term time horizons as release of heavy metals from the landfilled material) of incineration process (Hellweg *et al.*, 2002).

Bottom ash might be landfilled or used as a substitute of construction material. In France, for example, 15 % is landfilled, 20 % is used in construction and the rest is send to bottom ash treatment facilities (Autret *at al.*, 2007).Treatment in these facilities might include different processes such as: granulometric separation by screening, size reduction by crushing, airstream separation to eliminate light unburned fractions, magnetic sorting to recover ferrous metals and induction sorting to recover aluminium and other non-ferrous metals.

With respect to technological change, it is seen that there have been many changes in technology in the last years. Autret *et al.* (2007) identified four mayor changes during the period from 1993 to 2003. These changes are: (1) the number of incinerators has decreased, but the average plant capacity has increased (2) bottom ashes are better recovered, both in terms of quantity and quality (3) energy is more efficiently recovered (4) the emissions to air and water have decreased (4) as a result of the former points, there has been an increase in the investment and operational costs

Finally, the option of co-incineration in the cement industry is mentioned. Reijnders (2007) explains that the cement industry can consume a variety of different secondary materials and fuels. This replacement of virgin materials by secondary materials is usually based on the lower costs of waste in comparison to virgin alternatives. The wastes used in the cement industry include: ashes, waste form the iron and steel industry sludges, organocarbon wastes (e.g. tyres and waste oil) and toxic wastes.

The toxic materials in waste are broken down by the high temperatures and long time involved in clinker production, however, it must be mentioned that the de novo formation potential of toxic compounds is significant if the processes are not optimised.

The use of secondary materials as fuel might increase the input of heavy metals into the cement kilns. This would mean that the heavy metals are incorporated into the final product. Reijneders mentions a publication where it was found that, although the secondary fuels contributed to 10 % to the overall input of fuel, their contribution to the input of Cd and Cu to the clinker where higher than 50 %. The substances incorporated into the product are not leached if they are immobilised, but there is no information about their long term fate and if this is really the case in cement. Most leaching tests have been developed at laboratory scale and do not take into account some factors (e.g. microbial activity, humic acids) which might increase the mobility of the toxic substances.

When secondary fuels contain heavy metals or other hazardous substances that might volatilise, the might be increased emissions. This is the case, for example, for mercury. Other volatile substances might be incorporated in the cement kiln dust. Even when most cement kiln dust is captured by electrostatic precipitators or baghouse filters, there are still relatively large particulate emissions from cement kilns.

The International Solid Waste Association states in a position paper[27] that there are many reasons which might be responsible for a lower environmental performance when waste is co-incinerated in a cement-kiln in comparison to an incineration in an incineration plant. Some of them are: (1) cement kilns have for some substances higher limit emission values than incineration plants (2) the requirements for measuring emissions are less restricted (cement kilns only need to comply with daily average values, while incineration plants have to comply with half-hourly averages) (3) there are no requirements regarding auxiliary burners, which are used during start-up, shutdown, upset conditions, when burning marginally combustible waste and at any other time as necessary to maintain the minimum incineration temperature (4) Part of the waste co-incinerated is incorporated into the product, meaning that residues are diluted into the final product which can be used without further control and (5) there is a BAT document for waste incineration, but none for co-incineration.

4.4 LANDFILLING

According to information available from Eurostat direct landfilling is the most common method of treating waste in the EU.

Landfills are constructed following a multibarrier approach, where there are different barriers that should result in the containment of emissions from the landfill body. The following barriers can be mentioned (Bothmann, 2004):

- Location: where it should be aimed for an optimal geological and hydrogeological location, wit regards to stability and permeability.

- Liners: where the material and the draining elements need to be considered. The objective of this layer is to avoid diffusion and convection of substances out of the landfill, to increase the bearing capacity of the underground and to act as a geochemical barrier (adsorption, buffering and precipitation). The different materials used to construct liners and covers fall into three categories (1) clayey soil (2) synthetic membranes and (3) amended soil or other admixtures. Bagchi (1990) mentions that geomembranes are made of polymers and additives. There are many formulations using different polymers and additives and new developments in this area are constantly brought to the market. The resins are in general resistant to microbial attack, but the additives are not. Also insects and rodents might damage the plastics as well as certain grass species penetrate through the membrane when they germinate. The amended soil and other admixtures categories include mainly asphalt mixtures and bentonite amended soil.

- Landfill body: which should have a low leachability and biodegradability, a high stability and a low content of hazardous substances. The Landfill Directive addresses these aspects by demanding that all waste to be landfilled must be treated, reducing thereby the leachability

[27] http://www.iswa.org/c/portal/layout?p_l_id=PUB.1.31

and decreasing biodegradability. The lower biodegradability has also a positive effect on stability.

- Landfill cover: which includes the cover, drainage system, gas venting system as well as the restoration layer. The landfill cover has been traditionally used to avoid the influx of water into the landfill body, to avoid the emission of gases and dust, to enable the recultivation of the landfill and also due to hygienic concerns. Today it is expected that landfill covers are able to oxidise low methane concentrations and that they do not interfere with the leaching of pollutants. The convenience of using covers is often questioned because they reduce the inflow of water into the landfill, which decreases the velocity of the biodegradation processes. It is also argued, that it does not offer a long term protection, since the landfill body settles with time, resulting in damages to this layer. These reasons show that the cover might only result in a displacement of the environmental impact into the future.

- Operation: this includes the collection and treatment of gas and leachate and all operational aspects. Some examples of this are: the placing in of the waste in a way that the active area of the landfill is as small as possible, a high compaction of the waste, the control of the landfill access, control and documentation of the waste accepted in the landfill and a proper daily cover of the waste, among others.

- After-care: when the landfill on not in use anymore, the after-care should have low costs and offer the opportunity for an easy monitoring and subsequent improvement. The Austrian landfill legislation requires that landfill operators deposit an amount of money which should cover: the construction of the final layer and the recultivation layer, the gas and leachate collection and treatment systems, supervision of the landfill, monitoring and maintenance activities. The time range for which this is to be done depends on the type of landfill: landfills for inert waste need to do this between 5-15 years, landfills for non-hazardous waste for 30 years and landfills for hazardous waste for 40 years.

Permanent storage in underground mines is an option reserved for special hazardous waste, such as filter ash from waste incinerators. The main characteristic of these types of landfills is that they separate the wastes form the biosphere for geological time periods.

Underground landfills should be organised like warehouses. In contrast to landfill facilities located above ground, waste in underground landfill facilities is essentially packed and stored, for example in barrels or Big Bags. An underground storage operator explains that all waste components are recorded in a declaration analysis that before storage[28]. The collected data provides detailed information about reusable material content, waste storage location and the waste supplier. This information is archived for an unlimited period of time, which means that waste from each producer can be located years later. The waste is separately stored according to its composition e.g. waste containing mercury, waste containing PCB, etc. A mixture of

[28] http://www.k-plus-s.com/en/presse/themen/utd.html

different types of waste should be avoided. The wastes should be placed in an organised way, so that they can easily be taken out if necessary.

There are some existing underground landfills in Europe located several 100 m under the earth surface in former potash salt mines or in separated parts of still existing mines. The waste deposited here might be taken out for a limited period of time, if technical or economical conditions change, making the recuperation of the waste possible. After longer time periods (several hundred years), the salt flows around the waste and wraps it.

Germany is the only country in the EU that also allows the underground stowage of waste. This means that the waste is used during or after mining operations for stabilising the mine. In contrast to underground landfills, stowed waste is not expected to be moved back. According to German legislation this is to be considered as waste recovery if other material is substituted (resource conservation in the context of sustained development). Wastes used in stowage needs to fulfil certain mechanical stability criteria. To reach the necessary mechanical properties, most wastes have to be solidified with a hydraulic binder such as cement. Waste used in stowing has also some metal concentration limits which should ensure that material with higher metal contents, which might be recovered in future, is not stowed.

4.5 DESCRIPTION AND IMPLEMENTATION OF THE SCENARIO

In the waste disposal scenario all efforts are concentrated on achieving an efficient and environmentally friendly treatment and disposal of the waste fraction which is neither prevented nor recycled. This scenario addresses the need for a safe disposal of hazardous waste and waste which cannot be recycled. Even if the economic growth is decoupled from waste generation, there will always be some production of waste. Recycling is a good option for many waste types, but not all waste can be recycled. There are some economic reasons (e.g. a low concentration of metals in the products, which makes recycling unprofitable), technical considerations (e.g. products with a mixture of substances which cannot be easily separated), safety concerns (e.g. heavy metals which should not be reintegrated into the antrophosphere inside products) and market reasons (e.g. there is not a developed marked for recycled materials) which limit recycling. This means that, even when assuming large improvements in waste prevention and recycling, there will be always a need for disposal.

In this scenario, the amount of waste generated is maintained at baseline levels. The waste fractions were aggregated into groups with similar characteristics, and an optimal waste treatment for the different fractions was defined. Initially it was attempted to assign all waste fraction either to MBT, incineration or landfilling. However, it was recognised, that neither of these treatments provided an adequate solution for some waste fractions. Metals, for example, cannot be biologically treated nor burned, which means that the only option would be to landfill those metals. But the landfilling of metals results in a waste of resources, since they can be recycled using only a fraction of the energy required for the production of primary metals. Thus, the streams for which neither of the treatment alternatives represents a desired option were identified: metals and mineral waste. For these streams it was assumed that all EU countries maintain the recycling rates of these streams if they are above the EU-15 average in 2003. For countries where this is not the case, it is assumed that the recycling rate gradually increases until reaching this value.

After that, the disposal alternatives were compared. Landfilling is a final waste activity, which should be used for waste that has already been treated by some processes (fulfilment of the Landfilling Directive) and which can not be further used otherwise. Incineration and MBT are intermediate waste disposal activities, meaning that they treat waste, but also produce a residue that has to be landfilled. The economic performance and environmental impact of different disposal processes have been studied in detail by (Brunner *et al.*, 2001). The results of the study show that thermal treatment options have a better rating than mechanical-biological treatment options. The main reasons for this are that the bottom ash from incineration processes have parameters values that are closer to final storage quality than residues from MBT.

Final storage quality is achieved by goods that show in short- middle and long time frames only environmentally compatible substance flows to the environment. In other words, it can be said that goods with a final storage quality only causes substance flows to the environment which are of the same magnitude than natural deposits and sediments (geogenic reference value). Final storage is still only a concept, but it is a useful approach when comparing waste treatment activities (Baccini, 1989; Brunner, 1992). Waste treated by an MBT has much higher carbon concentration than incineration residues. These higher TOC values, and the consequent higher biochemical activity, are responsible for higher emissions which exceed the geogenic reference.

It must be mentioned here that there are some biological treatments, such as biogasification, that could be used to treat the biological fraction. But since these treatments are considered in the recycling scenario, there were left out in the disposal scenario. In this way, it is possible to compare the thermal and the biological treatment for this kind of waste. The only exception to this is agricultural waste, which might be treated more efficiently in small scale local gasificators specialised on the types of waste generated by each unit, instead of transporting this large amounts of waste to an incineration plant.

The disposal scenario considers that incineration complies with BAT and the Incineration Directive. This implies that any heat generated by incineration should be recovered as far as practicable. It is further assumed that bottom ash is used as a source of secondary metals (mainly iron). Hazardous residuals (fly ashes and filter cake), are on the other hand, safely landfilled.

It is also assumed that the landfilling of waste (in non-hazardous landfills and also in underground facilities) is carried out using state of the art technologies in order to minimise negative environmental effects.

Finally, the treatments for each waste type are summarised:
- Forest and agricultural waste (FW codes 1-7) is either left on the land as fertiliser or send to local small scale biogasificators in order to obtain secondary fuel.
- Food and food processing waste, textiles, paper and chemical products (FW codes 9 and 19-44) are treated in an incineration plant with operates using BAT. The produced heat is recovered as energy as far as possible and the residues which cannot be recycled are safely disposed.
- Mineral waste either produced by the mining activities or construction material (FW codes 12-18, 45-52 and 78-80) is recycled and reused. In countries with a lower recycling rate than the average EU-15 rate in 2003, there is an increase in the recycling rate until this value is achieved. The recycling rates in the remaining countries are maintained.
- Metal waste from metal processing and from products containing large amounts of metals (FW codes 53-72) is also primarily recycled. As with mineral waste, the recycling rates are increased until the average level in the EU-15 for 2003 is reached. Countries that already have higher recycling rates, maintain them.

These goals are expected to be achieved by the year 2015 and maintained until 2035.

It is important to note that this scenario does imply an increase in the separate collection and recycling of mineral and metal waste. This happens, on one hand, due to the increase in the recycling rates in the countries where they are lower than the threshold value of the EU-15 in 2003. On the other hand, even countries that only have to maintain their recycling rates, there will be an increasing amount of waste that has to be recycled, since there is more waste produced with time.

5. REVIEW OF AVAILABLE WASTE MANAGEMENT SCENARIOS

This chapter presents a review of available studies, where different waste management systems were compared by using scenarios. The main objective was to compare the different approaches, assumptions and descriptions of scenarios. In the cases where the results of the studies were useful for the construction of the FORWAST scenarios, the results of the scenario analysis are shortly presented.

1. Waste treatment scenarios for The Netherlands

The main objective of these scenarios was to compare different alternatives in terms of the amount and costs of primary fossil energy saved (Dornburg and Faaij, 2006). The scenarios describe a desirable situation for 2020. Following scenarios were constructed:

Reference scenario: assumes a business as usual development.

Separation scenario: recycling is increased by large scale application of integrated separation of wastes. Waste is collected separately in the same degree as in the reference scenario, but in addition the mixed waste streams (MSW, bulk waste, commercial waste and construction waste) are separated after collection. This separation produces recyclable materials and a high calorific fraction. The separation rates are about 80 % for organic waste, 30 % for paper and cardboard, 95% for ferrous metals, 70 % for non ferrous metals, 80 % for glass and 70 % for inert materials.

No heat scenario: it is assumed that the heat from waste cannot be used. This might happen if the heat demand decreases or if there are cheap alternatives (e.g. natural gas)

Unlimited heat scenario: assumes no threshold for heat utilization and neither energy losses nor costs are limiting factors for heat distribution. This might happen if waste incinerators are located near industrial or residential areas.

Backslash technology development scenario: assumes that the integrated biogasification and hydrothermal upgrading technologies do not reach the expected performance

Maximal electricity and heat production scenario: this scenario excludes the recycling of combustible streams and the use of biofuels. It represents a situation where heat and power production are favoured.

Maximal fuel production scenario: streams that are suitable for fuel production are not allowed for the production for heat and power, but are used as input for bio-or waste-fuels.

Existing capacity Scenario: assumes some currently available biomass and waste treatment installations are still in use in the year 2020 and that installations currently planned or under construction will be still operating.

Waste availability Scenario: assumes that the amount of waste in higher than in the reference scenario. It demonstrates the implications of the uncertainties in waste availability predictions.

2.- Scenarios for comparing the long term effect of disposal alternatives.

This study compared different waste management alternatives with special consideration to their long term implications. Different scenarios were created and it the fulfilment of the goals of the Austrian waste management act was evaluated for each (Brunner *et al.*, 2001).

The considered scenarios are:

L - Maximum landfilling of untreated waste
Inc1 - Maximum incineration without any treatment
Inc2 - Maximum incineration with cement stabilisation of the residual material
Inc3 - Maximum high temperature process
M1 - Maximum MBT treatment with the light fraction from sorting and splitting processed in a fluid bed furnace
M2 - Maximum MBT treatment with the light fraction from sorting and splitting processed in a rotary kiln for use in the cement industry
M3 - Maximum MBT treatment with the high calorific heavy fraction after decomposition processed in a fluidized bed furnace
M4 - Maximum MBT treatment with the high calorific heavy fraction after decomposition processed in a rotary kiln for use in the cement industry.

The results of the scenarios were compared by means of a cost-benefit analysis and also by a modified cost effect analysis. The results of both criteria showed that the best results are obtained by the incineration scenarios, followed by the MBT scenarios.

3.- Scenarios for assessing the recycling and reuse of construction waste in Sweden

This study carried out by Thormark (2001) considers only the recycling of construction waste, but separated into 30 fractions (e.g. concrete, gypsum plaster board, PVC, Clay brick, floor brick, etc…).

Reference scenario: considers current combustion, recycling and reuse rates

Maximal material recycling scenario: it assumes that all sorted materials are recycled. This means that the maximum recycling rate depends on the possibility of sorting the materials.

For most fractions the assumed recycling rate was 90 %. A few fractions had different recycling rates, ranging from 80 % to 95%.

Maximal reuse scenario: The reuse rate of the fraction shows a large variation: for treated wood it is 1%, while natural stone reaches 95 %

4.- Scenarios for analysing the fate of metals in MSW management systems
The scenarios described are (Jung *et al.*, 2005):

Present Scenario: Bulky waste and incombustible waste are landfilled after shredding, and other waste components are incinerated.

Incineration Scenario: Incineration is maximised. All waste compositions are incinerated and the residues landfilled.

Gasification-melting scenario: A gasification-melting system is used instead of incineration. Molten slag is used for construction and as road material

Bio-waste recycling scenario: Food waste is collected and composted. The compost is used as organic fertiliser and the residue is landfilled.

5.- Scenarios for comparing the treatment of MSW incineration residues
The goal of the two scenarios in the study done by Bianchini *et al.* (2005) was to assess the environmental impact of two disposal scenarios for MSWI bottom ash. The scenarios considered were: landfilling and recycling in a subbase layer of asphalted secondary road in Denmark. The results showed that the life cycles assessment resulted in fairy equal environmental impact of the two alternatives. However form the point of view of the waste hierarchy, the recycling option would be preferred.

6.- MSW treatment scenarios for Lithuania
This study only describes the scenarios, but has no further assessment of them. The two scenarios are (Wade *et al.*, 2006):

Scenario A, focusing on separate waste collection with recycling and also on MBT. The recycling quotas considered were similar to the ones actually reached in Germany. The MBT is expected to cause a reduction of 30% of the landfilled amount of mixed waste.

Scenario B, which considers in addition to the increased recycling and MBT the implementation of refuse derived fuel incineration in grate fires. The residues form the recycling and MBT are used for energy production.

7.- Scenarios for comparing different recycling alternatives
Three scenarios were developed in this study (Beigl and Salhofer, 2004):

Recycling with bring system collection: the residual and biowaste is collected by the regional waste management company form the property of the waste generator (kerbside collection). All other wastes however, are brought to the next central collection site by the private households and deposited there (bring system)

Recycling with kerbside collection: in addition to residual waste and biowaste, kerbside collection is also implemented for waste paper, plastic packages and metal packages. Waste glass was not regarded suitable for kerbside collection due to the low collection rate. Thus, waste glass and all other waste types and collected at central collection sites in the bring system.

No Recycling: all waste types are collected kerbside without separation. The only waste types collected in the bring system are those that cannot be collected kerbside (bulky waste, yard waste, cardboard) or are prohibited (hazardous waste).

The results show that the recycling scenarios show advantages in term of the acidification and net energy impact categories. With respect to the global warming emissions, kerbside recycling presents fewer emissions that the non recycling scenario and the recycling in the bring system. The cost comparison shows that there are relatively small differences.

8.- MSW management scenarios in Wales
The scenarios considered in this study were (Emery *et al.*, 2007):
Scenario 1: do-nothing scenario, which considers that all MSW recovered is disposed untreated in a landfill site.

Scenario 2: scenario that meets the 2010 Wales's recovery targets through a combination of recycling and composting. No thermal treatment is considered and all remaining MSW is disposed untreated on a landfill

Scenario 3: This scenario meets the EU - Landfill targets for 2020 through a combination of recycling, composting and incineration. The remaining MSW is disposed on a landfill

Scenario 4: Burn all scenario, which considers that all waste recovered is send to an incinerator. This option does not meet the recovery targets, but it does fulfil he landfill directive target.

The results showed that options 2-4 represented a significant improvement on option 1 as was expected. The scenarios 2-4 were ranked according to the environmental effect category. The burn all scenario had the best results for the indicators eutrophication, greenhouse effect and ozone layer depletion. The scenario 3 had the best result in the air acidification indicator and scenario 2 had the best result in the indicator depletion of renewable resources.

9.- Scenarios comparing recycling and landfilling

This project focused only on three materials: PET bottles, glass containers and steel tin-plate cans. The scenarios are (Grant *et al.*, 1999):

Baseline scenario: it considers the current balance of recycling and landfilling for each material (the recycling rates are: 76% PET, 77 % glass and 39 % for steel tin-plates)
100 % Recycling scenario
100 % landfill scenario

10.- Environmental assessment of municipal waste management scenarios. Part I data collection

Following scenarios were considered in this study (JRC, 2007):

Baseline: The current levels of recycling, composting and incineration are used. All remaining MSW is sent to landfill.

Compliance with packaging and landfill directives I: The recycling rates are increased by bring collection systems and improved collection of commercial waste to comply for the packaging directive. The composting rate is increased to comply with the landfill directive. Incineration stays at baseline level and the remaining waste is sent to landfills.

Compliance with packaging and landfill directives II: the difference between this scenario and the former is that this scenario increases the incineration rate instead of the composting rate to comply with the landfill directive.

Intensive recycling: 80% separate collection of recyclables through bring collection systems (paper, plastic, metal and glass). Composting and incineration at baseline levels. The waste not recycled, composted or incinerated goes to landfilling. This scenario does not comply with the landfill directive, since there is too much biodegradable waste going to the landfill.

Intensive composting of biodegradable waste: 80% of organic waste is composted (food plus garden waste) as well as some paper fractions (mainly dirty paper). Recycling and incineration rates as in the baseline scenario, the remaining waste is sent to landfills. This scenario does not comply with the packaging directive, as there is insufficient recycling.

Intensive incineration: recycling and composting rates as in the baseline. Intensive incineration with energy recovery of 80% of all solid waste that is neither recycled nor composted. This scenario does not comply with the packaging directive.

Recycling, composting and RDF facilities: The recycling rate is increased to comply with the packaging directive. The composting rate is also increased to comply with the landfill directive. All waste that is neither recycled nor composted is sent to RDF conversion and followed by incineration with energy recovery. The residues separated during sorting or screening are sent for biological treatment (where appropriate) or landfill. No waste is landfilled without pre treatment.

6. INTERPLAY OF MACROECONOMIC AND WASTE MANAGEMENT SCENARIOS

The FORWAST project aims to develop future scenarios regarding waste management by crossing policy options and macroeconomic hypotheses. The scenarios stem from changes in the variables contained in the IPAT (Impact = Population × Affluence × Technology) equation. Although such equation has been already criticized because of its simplicity, it represents a useful tool to compare the different trends in economics, waste production and management in the old and new members of the European Union.

To quote the words of Donella H. Meadows about the IPAT equation (Meadows, 1999): "It counts what is countable. It makes rational sense. But it ignores […] a factor that scientists have a hard time quantifying and therefore don't like to talk about: economic and political power. IPAT may be physically indisputable. But it is politically naive. […] Population growth and consumption and technology don't just happen. Particular people make them happen."

Within the FORWAST project several data -such as the growth of population, GDP, primary production and net imports, final energy demand and CO_2 Emissions- have been collected for the time span between 1990 and 2035 and are useful to trace the different trends in old and new members. At a first glance it is possible to notice that the population is not a significant variable, since it does not change dramatically. Moreover, as it was pointed out by the economist Donella H. Meadows: "a car emits more pollution than a bicycle, and so the 10 percent of the world's people rich enough to have cars cause more environmental impact in their transport than do the much more numerous bicycling poor. But a car with a catalytic converter is less polluting than a car without one and a solar car even less" (Meadows, NA). Such statement leads to acknowledge the large role played by affluence and technology of a nation, which apparently is confirmed by the data about economics and technological development in the EU countries. It could be easily stated that the old members, which are generally richer, have also developed ways to reduce the environmental impact. However, it is worth to raise some critical points on the issue. First of all the correlation between affluence and technological development should not be taken for granted and when it can be observed, as it happened in the richer European countries, other variables, such as the political choices of the governments and the involvement of the civil society, play a fundamental role. Secondly it must be noted that the newest technology is not always the solution of environmental problems.

Looking at the two groups of the old and new European countries from the economical perspective, the older ones could be generally defined as "stable", since their GDP keeps on growing slowly but steadily. The new ones have gone through the collapse of the industrial production since the breakdown of the communism, which was followed by a severe inflation and a high unemployment rate. After some years of harsh crisis, liberalisation of the market started. These states are nowadays at different steps of "economical transition", since a rapid growth has started and is foreseen to rush in the next twenty years (e.g. Romanian GDP is supposed to grow +243,6% between 2010 and 2035).

From the historical point of view most of the old European countries laid the foundations of the future environmental policies in the seventies. These policies were mainly aimed to increase the production efficiency, reduce the urban air pollution and to improve the management of the water and waste systems. Moreover, a growth in the ecological consciousness in the civil societies (especially in the Central and Northern European countries) can be observed. The former communist states, on the other hand, present nowadays severe environmental problems, such as pollution of surface waters and contamination of soil. The pollution is increased by the waste management systems which have been neglected in the past and which remain underdeveloped in many areas. One example of this is, for example, numerous uncontrolled and illegal waste dump sites. As it is stated in the 1999 report of the Regional Environmental Center for Central and Eastern Europe, the environmental standards required by the EU to new members, would push them to spend around 120 billon EUR only in the air, water and waste sectors, that is to say, an annual environmental investment of up to 2-4 percent of GDP over 10-20 years (Klarer *et al.* 1999).

At this stage there would be the risk for new European countries to be uncritical in adopting the technologies that are now used in the "stable" countries and to leap over fundamental steps of the waste management system. Moreover, as was pointed out by some researchers, the "waste hierarchy" of prevention, recycling and disposal does not constitute everywhere an appropriate strategy. Basing on the comparison of different case studies, it was possible to conclude that in some regions that are nowadays spending not more than 10 euro per capita per year for waste management, the improvement of the disposal systems is the most cost-effective method to reach the real objectives of solid waste management (protection of human health and the environment, the conservation of resources) (Brunner and Fellner, 2006). The authors of the study also recommend that each region first determines its economic capacity for waste management and then designs its waste management system according to this capacity.

Finally, it is worthy to mention a by-product of the affluence of the "stable" European countries: the new waste management technologies in which they invest are getting always more expensive for the privates and especially for the enterprises. This might lead to illegal shipments of waste to countries or regions where the waste management system is less developed and controlled. Although an international treaty was designed in 1989 to reduce the movements of hazardous waste between nations and specifically to prevent transfer of hazardous waste from developed to less developed countries (Basel Convention on the control of transboundary movements of hazardous waste and their disposal), such shipments are still documented. The return back of the illegal waste to the country of origin, as was decided by Slowakia in 2006 (1300 tons of municipal waste were sent back to Austria) is still an unusual practice, that should be encouraged on one hand, by an appropriate legislation and on the other by economic policies for the entrepreneurs in more developed countries (Corporate Social Responsibility).

As could be seen from the paragraphs above, the relationship between economical development and environmental protection (and in this case, specifically waste management) is influenced by many variables and there are many approaches and theories that could be used to describe this relationship.

For dealing with this issue in the FORWAST project, the assumptions made for the selection of the macroeconomic scenarios were reviewed. To maintain the consistency of the scenarios, these assumptions were used to derive a relationship between the economic and waste treatment scenarios.

In the meeting in September 2007 in Vienna, it was agreed to select a scenario with a high economic growth and a high level of environmental protection and a scenario with a low economic growth and a low level of environmental protection.

The waste management scenarios are primarily described by targets that are met at a specific time period. In the waste prevention scenario, for example, it is defined that the amount of metal waste will be reduced by 6 % until 2015. Similar targets were defined for the recycling and waste management scenarios. One way of adapting these values to lower or higher levels of environmental protection, is to define longer time periods for meeting the targets in economies with a lower economic growth.

Based on this it, was decided to modify the time period for reaching the targets defined in the waste treatment scenarios. The years suggested in the text are assumed to be valid for the baseline. For the high and low growth scenarios the target is met 2 years earlier and 2 years later, respectively.

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