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Sub-Study Series

⑮ Analysis of Waste Paper Recycling and Disposal Options in Germany

L. Göttsching, U. Hamm,
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ANALYSIS OF WASTE PAPER RECYCLING AND DISPOSAL OPTIONS IN GERMANY

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Analysis of Waste Paper Recycling and Disposal Options in Germany

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Substudy No. 15

Case Study: Analysis of Waste Paper Recycling and Disposal Options in Germany

PREFACE

At the request of the International Institute of Environment and Development (I.I.E.D.), London, the Department of Paper Science and Technology (IfP) at the Darmstadt University of Technology in Germany has prepared this substudy in the framework of the subjects 'Recycling, Energy Recovery and Final Disposal'. The substudy focuses on the current situation and future trends in Germany with respect to the following areas of the paper chain which are marked in Fig. 0:

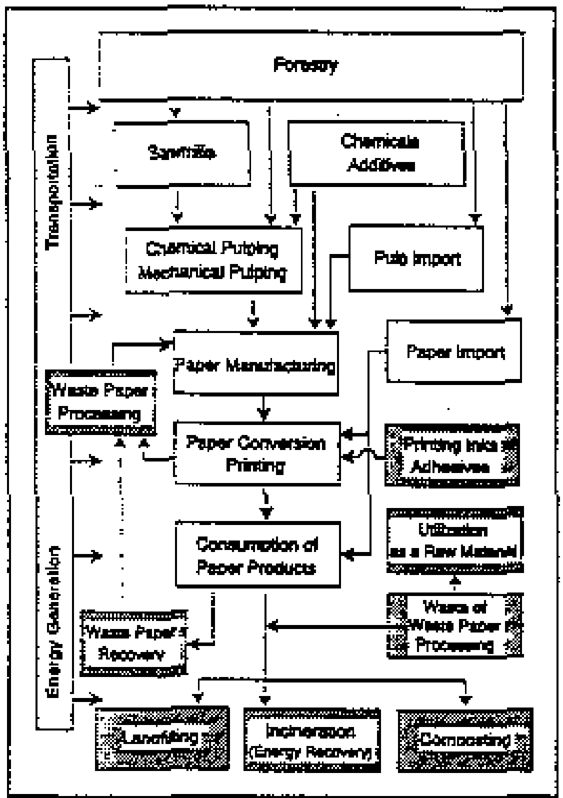


Fig. 0 The Paper Chain from Cradle to Grave IfP 1996

- Recovery (collection) and recycling (utilization) of waste paper with particular reference to its processing in the paper industry.
- Energy recovery based on non-recyclable waste paper as well as the waste material from waste paper processing in the paper industry.
- Utilization of the waste material from waste paper processing in other industries and agriculture.

- Disposal of non-recycled waste paper and waste of private households as well as waste material from waste paper processing paper mills by dumping, incineration and composting.

Germany was chosen as a case study because of the following features of particular relevance to industrialized countries:

- Following the USA and Japan, Germany is the third-largest country with respect to the volume of waste paper collected (9.7 million tonnes in 1994) and utilized by its paper industry (8.2 million tonnes). The German waste paper utilization rate of 56 percent is even higher than in Japan (53 percent) but at the same level compared with the European Union (12 member states) before its expansion by Austria, Finland and Sweden in 1995.
- In Germany legislation on recovery and recycling of waste paper and waste management issues including landfilling, incineration and its emissions is regarded as demanding and advanced in the global context.
- The requirements of environmentalists and particularly of Greenpeace Germany regarding the total paper chain including recovery and recycling of waste paper and final disposal of waste are most stringent.
- German society, as well as local authorities, the governments of the 16 Federal States (Länder), and the Federal Government are demanding environmental protection measures. These cover the paper chain with regard to nature-oriented forestry, chlorine-free pulping, environmentally sound papermaking, based on a high proportion of recycled fibers, and the disposal of industrial waste and non-recyclable waste paper, which cannot be landfilled at the latest by the year 2005. (This requires combustion of any organic waste prior to landfilling of the ash.)

Regardless of the external forces directed towards an intensified recovery and recycling of waste paper, the economy of the German paper industry is significantly affected by the availability of cost-competitive waste paper as its most important raw material by volume. Local pulpwood is not cost-competitive on the international scale and power costs are extremely high, compared with international competitors. Consequently, mechanical pulping became increasingly uneconomic and recycled fibers as a substitute for virgin mechanical pulp therefore improved the economy of newsprint and other wood-containing (that is mechanical pulp containing) papers. Furthermore, manufacturing of packaging paper and board is only economic when recycled fibers are used to a high extent because there are, apart from a few sulfite pulp mills, no kraft mills in Germany. Almost 90 percent of chemical pulp required by the German paper industry must be therefore imported.

Generally speaking, the demands of legislation and environmentalists as well as of the public and political forces support intensified waste paper recycling by the paper industry. Based on the utilization of recycled fibers to a high extent, the German paper industry keeps and strengthens its competitive position on the European market place thanks to the availability of waste paper as raw material. This raw material is permanently generated within short distances of the waste paper processing paper mills by recycling-minded end-consumers and further sources such as industry and trade.

EXECUTIVE SUMMARY

Waste paper is an indispensible raw material for the global paper industry. Its utilization is mainly driven by economic forces. More recently, legal and ecological factors are playing an increasingly important role in different countries. In 1993 about 100 million tonnes of waste paper were used globally for the production of 250 million tonnes of paper and board. This corresponds to a waste paper utilization rate of 40 percent.

Since 1980 the growth of waste paper consumption was more significant than the growth of the consumption of virgin pulps. The waste paper utilization rates differ by country in a range between 10 percent (e.g. Finland, Norway, Sweden) and 100 percent (e.g. Denmark, Hongkong, Singapore, Taiwan). However, the growth of waste paper consumption realized in the past will not continue in the medium- to long-term because of the shortage of suitable waste paper grades, further increasing prices of waste paper and its effect on the quality of paper produced, based on recycled fibers. Therefore, it is supposed that in the next decade there will be achieved a balance between recycled fibers and virgin pulps in paper manufacturing in those regions of the world (e.g. Europe, Japan) where a high utilization rate is already attained.

Germany is the third-largest consumer of waste paper (8.2 million tonnes in 1994) characterized by a waste paper utilization rate of 56 percent starting at 30 percent in 1950. A realistic final level will be reached at almost 65 percent in the next decade. Germany is an interesting case study because of its network of legal requirements supporting intensified waste management and a comprehensive product responsibility of the total paper chain due to legislation. Furthermore, waste management and saving of resources (primary energy, raw materials, water) and environmentally compatible processes are demanded by environmentalists and finally requested by the public, affecting politicians and governments.

In the framework of the still valid Waste Management Act (1986), followed by the Recycling and Waste Management Act (1996), the Federal Government is empowered to issue regulations with reference to waste management. One of the first ordinances issued in 1991, is the Packaging Ordinance, followed by the Voluntary Agreement of the graphic paper chain concerning to products made of printing and writing paper in 1994. According to these regulations, at least 60 percent of packaging material (in terms of sales packaging) and 60 percent of printed matter (news, magazines etc.) and office waste must be collected and used by the paper industry at home as well as abroad. Taking other packaging material into account (transport packaging such as corrugated containers) the collection rate must be on average as high as 80 percent. Already in 1994 the target figures have been realized or even exceeded as in the case of printed matter and office waste (62 percent collection rate).

According to the Municipal Waste Management Provision (1993), landfilling of any organic matter, including non-recyclable waste paper or waste material from waste paper processing and paper manufacturing, will not be permitted at the latest by 2005. Landfill sites must be regarded as uncontrolled (anaerobic) bio reactors with their emission of methane and leachate polluting the atmosphere as well as surface and ground water. The alternatives to landfilling are incineration for the benefit of energy recovery- either in municipal incineration plants or in industrial power plants - and the utilization of non-recyclable waste paper and waste material of the paper industry as a raw material for the cement industry or brick works. A smaller proportion of the waste material as well as of non-recoverable wast paper can be converted into compost together with co-substrates (e.g. biowaste from households).

As far as the waste material from waste paper processing is concerned (one million tonnes air-dry substance in 1994 which corresponds to a proportion of 12 percent related to the total volume of waste paper processed), it is percentagewise of the same order as in mechanical pulping (e.g. bark) and much less than with chemical pulping (e.g. bark, spent liquor). The challenge of the waste material from waste paper processing is to ensure its freedom from harmful substances such as heavy metals and chloroorganic compounds (e.g. PCB, PCP, PPCD/PPCF). Nowadays, the most significant source of heavy metals are fillers and pigments used in previous papermaking, because printing inks became increasingly cleaner in the last two decades with the exception of copper-containing blue pigments. Chloroorganic compounds are also of minor importance thanks to the introduction of ECF and TCF pulps or of wet-strength agents with a low AOX content (epichlorhydrine compounds). A remaining source of AOX are yellow diaryl pigments which are, however, characterized by an extremely stable matrix, restistant against any microbiological attack.

Affected by legislation and the establishment of the private organisation named Dual System Germany DSD (responsible for packaging material) Germany is covered with a very dense network of collection systems for paper, plastics, composite materials, glass and metals. Thanks to that strategy, a waste paper collection rate of 59 percent (1994) has been achieved. Private households and small commercial enterprises contribute a major proportion to the total volume of collected waste paper. The collection rate with respect to the industry (paper converting and graphic art industries) is almost as high as 100 percent as is also the case with distribution. Not yet fully exploited waste paper sources are offices and private households.

In one possible future scenario, it is supposed that an ultimate collection rate will approach 70 percent which is, however, equivalent to a practical collection rate of 82 percent considering that 17 percent (2.9 million tonnes) of used paper products is not at all recoverable such as products made of sanitary papers and specialty papers and a small proportion of graphic paper stored in archives or libraries.

In the context of waste paper collection it must be emphasized that the collection of packaging material is subsidized by licence fees (Green Dot fees), in the first place paid by the packaging chain and ultimately by the end-consumers. It is not yet decided how the collection of printed matter will be finally organized and financed by the graphic paper chain. So far, graphic papers are collected and traded along with the subsidized packaging materials by traditional waste paper dealers as well as by the more recently established waste management industry. The collection of this proportion of waste paper recoverd from households is partly financed by the communities.

Industrial processing of the 40 different waste paper grades in Germany became a rather sophisticated but cost-competitive technology which aims in the first place at careful cleaning and screening procedures in order to eliminate different types of impurities including printing inks (by deinking) and stickies besides plastics, metals etc.. Apart from investment costs, energy consumption (mainly in terms of power consumption) is an important cost-relevant feature. The main target of waste paper processing is the upgrading of recycled fibers at low energy costs and a minimized proportion of waste material generated by stock preparation. The recycled fibers in many paper and board grades are the only stock component and they must fulfil high quality requirements because the paper produced has to compete with paper made totally or partly of virgin fibers.

In the last decade optical and mechanical characteristics of recycled fibers, based on the predominant (by volume) waste paper grades (e.g. sorted mixed waste, department store waste) did not decline. In fact they show a trend of quality improvement due to a certain change of the fiber composition of such waste paper grades. Waste paper for DIP (roughly 50 percent news and 50 percent magazines), being almost totally the furnish for newsprint or recycled graphic paper manufactured in Germany, is characterized by optical and mechanical properties in the range of those of high quality mechanical pulps since they contain a significant proportion of (recycled) chemical pulp fibers.

Thanks to paper import, mainly from the Nordic countries, the German recycling system is refreshed by pulp fibers of the first generation. For example, in the case of newsprint more than 50 percent of the German consumption is imported containing much less recycled fibers than newsprint manufactured in Germany. Because of that permanent stream of imported paper Germany can realize a higher waste paper utilization rate (currently 56 percent) than Japan (stagnation at 53 percent) which is a closed national system with almost no paper or waste paper imports. On the other hand, the German paper industry, being in competition with other papermaking countries has to meet high quality standards for paper made of recycled fibers, serving a demanding market in terms of the packaging material and the graphic art industries.

The proportion of recycled fibers varies significantly between the main groups of the German paper production. Packaging paper and board have almost reached their saturation point (94 percent waste paper utilization rate) as well as specialty papers (44 percent waste paper utilization rate). In the case of sanitary papers (69 percent waste paper utilization rate) a further increase of this rate approaching approx. 80 percent might be realistic. A further increase is supposed with respect to graphic papers (28 percent waste paper utilization rate) approaching an average of 40 percent waste paper utilization rate in the medium-term. Newsprint is already made of 108 percent waste paper which corresponds to a proportion of about 90 percent recycled fibers due to a yield of 85 percent and a material loss of 15 percent, respectively. In the longer term, wood-containing printing papers (e.g. SC- and LWC-papers) might use approx. 25 percent waste paper or contain 20 percent recycled fibers.

Rejects and sludges from waste paper processing lead to a volume of waste material of one million tonnes air-dry substance and two million tonnes with a dry content of 45 percent, respectively. So far, 40 percent of this waste material is burnt in industrial plants in combination with other residues for the benefit of energy recovery. A further volume of 40 percent is used as a raw material for manufacturing construction materials (bricks, cement) or for composting or other biological utilization. Not more than 20 percent of the waste material must be still dumped on landfills which is the most expensive disposal procedure. Because of the requirements of the Municipal Waste Management Provision landfilling must be substituted by (industrial) incineration making use of the heating value of organic waste.

Today still 70 percent (three million tonnes) of non-recyclable waste paper is going to landfilling. In the future a proportion of this dumped waste paper volume will be partly treated by municipal incineration and partly by industrial combustion making use of the heating value of waste paper, which is half of that of hard coal. Alternatively, the volume of waste paper intended for industrial combustion might be used as raw material for paper manufacturing at home and abroad. A smaller proportion of non-recyclable waste paper will serve as a raw material for composting (0.8 million tonnes), as a co-substrate of biowaste from households (five million tonnes) contributing to an improved performance of the material for composting. According to one scenario, it becomes evident that there is no necessity to control excess waste paper by industrial combustion with energy recovery.

The effect of recycling on mechanical characteristics of recycled fibers and paper made of recycled fibers is marginal as long as the fibers are not recycled more than about six times. This is the case with furnishes consisting of mechanical pulps or a mixture of chemical and mechanical pulps. On the other hand, optical characteristics are affected to a certain extent as long as no effective multi-stage upgrading measures in waste paper processing are applied (e.g. multi-stage deinking, dispersion, bleaching).

With respect to deinking the type of printing inks plays an important role. Waterborn flexo inks are unsuitable for an effective deinking by flotation. Furthermore, natural vehicles of printing inks (e.g. soybean oil, rape oil) are more deinking-resistant than mineral oils. Recyclability of waste paper is impaired by certain types of adhesives which become stickies in the pulp slurry and the paper made of that pulp. Further research work is required particularly with respect to adhesives which should be transformed into particles suitable for their removal by cleaning and screening technology.

Environmentalists call for a further intensified waste paper utilization by the paper industry. Particularly Greenpeace Germany sets a target figure of a waste paper utilization rate of 75 percent to be achieved in a period of time of five years, at the latest by 1996. Furthermore, Greenpeace demanded a reduction of the paper consumption in the range of 15 percent, criticizing the intensive use of paper for advertisement. However, currently the green movements give priority to forest issues and are currently to a lesser extent involved in campaigns related to waste management or waste paper issues. They are aware that legislation sets new waste paper recovery and recycling targets and that the paper industry makes progress with further increased utilization of waste paper.

In 1994 the situation of waste management in Germany and in the German paper industry is characterized by the following figures:

- 56 percent waste paper utilization rate (58 percent in 1995)
- 59 percent waste paper collection rate (66 percent in 1995)
- 1.5 million tonnes waste paper net export (1.9 million tonnes in 1995)
- 4.2 million tonnes of waste paper to be disposed of by landfilling (3.0 million tonnes) and municipal incineration (1.2 million tonnes)
- 2.0 million tonnes of waste material from waste paper processing.
- About 40 percent of this waste material is burnt and 40 percent used for composting and soil spreading or as a raw material, so that only 20 percent is left for (costly) landfilling.

Scenario 1 aims at an intensified waste paper collection approaching a rate of 70 percent. Because landfilling of organic matter is not anymore permitted in the future, the volume of non-recyclable waste paper must be burnt partly in industrial combustion plants and partly in municipal incineration plants. With reference to the heating value and price of hard coal and taking the costs for waste paper pre-treatment (pelletizing) into account, the price of waste paper to be burnt in industrial power plants must be very low or even negative, which is much less than can be recovered in the market place in the case of waste paper as a raw material for the paper industry. This means that waste paper as a fuel is not cost-competitive compared with its sales price in the market place. In the case of waste material from waste paper processing it is, however, economic to burn it in industrial power plants because the costs for landfilling (if permitted) are in most areas significantly higher and further increasing. Even at a high ash content up to 50 percent and at a dry content of 50 percent waste materials can be burnt without any additional (fossil) fuel contributing to energy recovery.

Considering legal and economic forces in the framework of future waste management issues, scenario 2 sets the following targets:

- 65 percent waste paper utilization rate
- 70 percent waste paper collection rate
- 2.0 million tonnes waste paper net export
- 0.8 million tonnes of waste paper for composting
- The remaining waste paper volume of 1.7 million tonnes for municipal incineration.

The overall costs for waste paper disposal are finally less with scenario 2 compared with the current situation. The environmental impacts of scenario 2 are advantageous compared with the current situation as far as air-born and water-born emissions are concerned, whereas the generation of waste material from waste paper processing is increased by 40 percent. However, two thirds of that waste material will be burnt in industrial boilers and one third used as raw material for building material or other purposes, avoiding any disposal by landfilling.

In the case of lower waste paper grades, which dominate by volume, the costs of collection and sorting are exceeding the market price of most waste paper grades paid by the paper industry. In this context one must bear in mind that a proportion of waste paper, namely from households as packaging material (sales packaging), is subsidized by the corresponding paper chain which means by the end-consumers. This subsidy is organized by the Dual System Germany which charges licence fees from the corresponding paper chain. On the other hand the communities are financing the collection of products made of graphic papers (e.g. news, magazines) avoiding costs for more expensive disposal of waste by landfilling or municipal incineration.

The German public is quite familiar with separate collection of waste paper thanks to the establishment of containers in public places (carry system) or of bins in individual households (pick-up system). Most communities are equipped with household bins for the joint collection of packaging material, news and magazines which must be then separated by manual sorting to be used as raw material for the manufacturing of graphic papers and sanitary papers. On the other hand the producers of packaging papers and board require unseparated waste paper mixtures, which benefit the properties of these grades produced. The private households must not only be regarded as consumers of paper products but at the same time as producers of waste paper as a raw material. They are prepared to intensify waste paper collection even to the extent that there has to be on-site separation into different paper grades according to the requirements of the paper industry.

The progress of the German paper industry depends to a significant extent on the availability of large volumes of cost-competitive waste paper. Legislation requires, apart from waste avoidance, increasingly intensified recycling of used products including waste paper, aiming at the saving of resources (energy, raw materials, water) and the reduction of emissions (to air and water) and controlled generation of solid waste which has to be disposed by incineration or utilized as a raw material in other industries (manufacturing construction materials).

In Germany there are excellent prerequisites for intensified collection and recycling, because it is a densely populated country with a highly developed infrastructure and short distances between waste paper sources and waste paper treatment sites. The German paper recycling system makes use of a large quantity of imported paper made of a higher proportion of virgin pulps. The imported paper contributes to a permanent refreshment of the recycling system resulting in paper made of recycled fibers which fulfils adequate quality characteristics and therefore the requirements of a demanding market and quality-minded end-consumers.

INTRODUCTION

For more than 2000 years paper has been made of natural fibers, both virgin as well as recycled fibers. In the past, European papermakers recycled fibers from rags which were themselves based on flax, hemp and cotton. Later they recycled handmade writings for the manufacturing of lower paper grades (Fig. 1.1-1). Increasing demand for raw material, caused by growing paper consumption and more productive paper manufacturing on the then newly developed Fourdrinier machines, led to a shortage of rag in the nineteenth century. This limited availability of the traditional fiber material stimulated inventors in Western Europe as well as in North America to search for alternative fiber sources. The researchers concentrated their efforts on readily available wood aiming at its separation into single fibers, which resulted in the development of wood pulps. The first to succeed in the defibration of wood by means of a stone grinder was the Saxonian KELLER. This mechanical pulp was a poor substitute for the almost lignin-free, non-yellowing and long rag fibers due to its inferior strength properties and optical performance. Probably independently from each other, the American TILGHMAN, the Swede EKMAN and the German MITSCHERLICH had been successful in the treatment of wood with chemicals such as calcium or magnesium bisulfite, which resulted in a delignified pulp with superior strength properties compared with mechanical pulp.

Papermaking in Europe

1250-1875	Recycled Fibers (Rag: Flax, Hemp, Cotton)
Since 1860/75	Virgin Fibers (Mech. and Chem. Woodpulps)
Since 1950	Increasing Utilization of Recycled Wood Fibers

Recycling in Germany

1950	30 % W.P. Utilization Rate
1965-1988	45 % W.P. Utilization Rate
1994	56 % W.P. Utilization Rate
2000	**> 60 % W.P. Utilization Rate**

$$\text{W.P. Utilization Rate} = \frac{\text{Waste Paper Used}}{\text{Paper Production}} \cdot 100\ [\%]$$

Fig. 1.1-1 Recycled Fibers as Raw Material IfP 1995

- **Economy of Recycled Fibers**
  (First and globally valid priority)
- **Ecological Issues**
  (Medium priority, e.g. energy saving compared with mechanical pulping)
- **Legal Requirements**
  (Globally low priority, but in individual countries high priority as in Germany)
- **Eco-Marketing**
  (In certain countries increasing significance)

Fig. 1.1-2 Driving Forces for Waste Paper Utilization IfP 1995

The German DAHL perfected the sulfate process, with the recovery of chemicals and energy, originating from the soda process. However, this kraft process became the most prominent pulping technology only after chlorine dioxide, identified as a selective and strength maintaining bleaching agent, was first applied in the 1940s .

Since the middle of this century, these virgin pulps have been increasingly replaced by recycled wood pulp fibers, because of their availability and cost-competitiveness in terms of waste paper prices and processing costs in multi-stage treatment in the paper mills. The economy of processed recycled fibers plays the key role in most parts of the world (Fig. 1.1.-2).

Nowadays, ecological issues, legal requirements and marketing are becoming more significant as additional factors. This is particularly the case in Germany since the eighties. In certain countries the collection of waste paper and utilization of recycled fibers is not only driven by economic, ecological and legal forces, but also by demands of environmentalists - amplified by the media - who are affecting politicians as well as the public. Considering this network of different driving forces, including emotions, Germany is one of the countries which strongly believes in the necessity and feasibility of perfectly controlled waste management in a recycling-minded society and an industry aiming at sustainable development. In this context one must bear in mind that Germany was faced with severe shortage of many resources during and after both World Wars. Shortage of raw materials at the beginning of this century (1914 - 1925) and in the forties (1939 - 1948) gave impetus to effective recovery efforts collecting textiles, paper, glass, metal, and further used material. The former GDR continued such politically stimulated recovery and recycling activities for another forty years until reunification in 1990.

1 Current Situation and Future Trends

1.1 Legislation on Recovery, Recycling and Disposal

Fig. 1.1.-3 and Fig. 1.1.-4 show the current legal background with reference to

- Recovery and recycling of waste paper
- Municipal waste management
- Industrial waste management

in Germany. These legal measures will be discussed in the following sections.

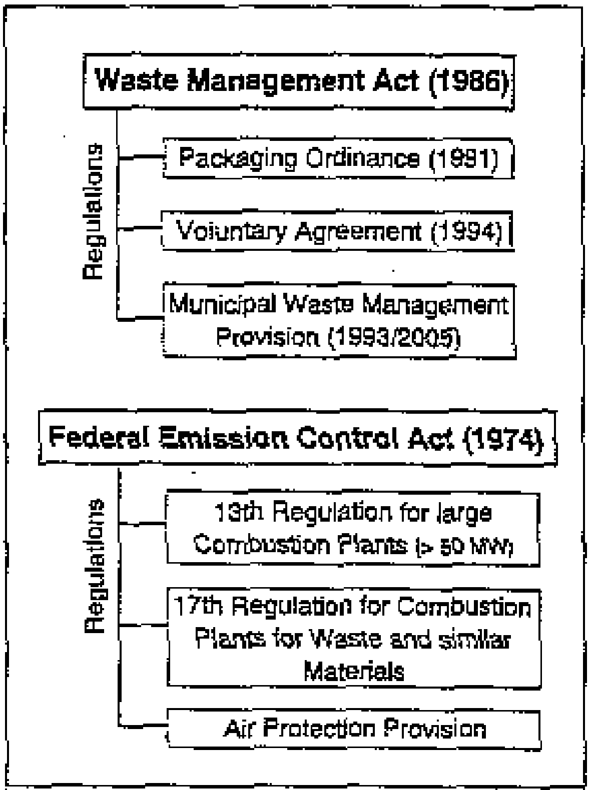


Fig. 1.1.-3 Legal Background for Waste Management in Germany (1995) IfP 1995

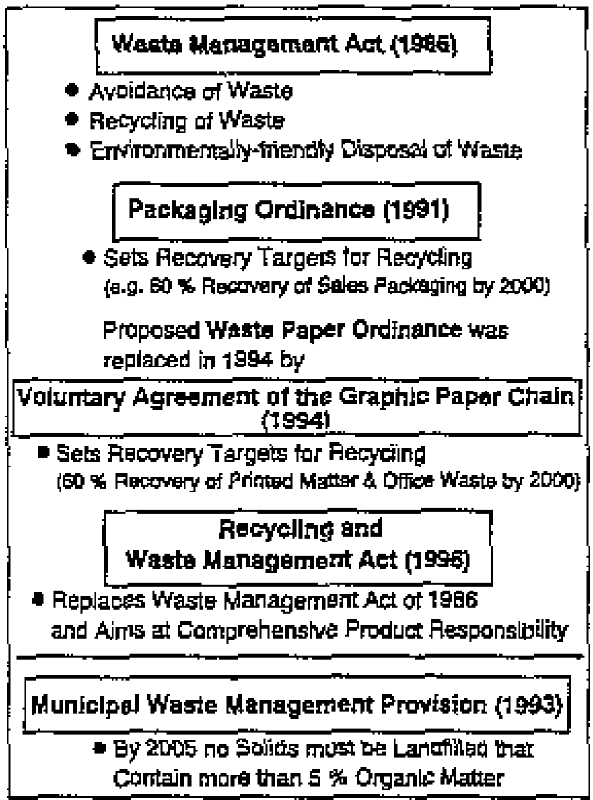


Fig. 1.1.-4 Legislation on Recovery and Recycling of Waste Paper IfP 1995

1.1.1 Waste Management Act (Abfallgesetz) (1986)

In Germany the still valid legal reference for waste management, including waste paper issues, is the Waste Management Act, in force since 1986, focusing on the following targets:

- Avoidance of waste
- Recycling of waste
- Environmentally-friendly disposal of (residual) waste.

Already in 1972 the **Waste Disposal Act** (Abfallbeseitigungsgesetz), which must be regarded as the precursor of the Waste Management Act, was enacted. Not until 1986 had the above mentioned targets of avoidance, recycling and disposal of waste been incorporated in this original act in the framework of its fourth amending law (Vierte Novelle). Thanks to these modifications the precautionary principle was given first priority in order to strengthen the philosophy of waste avoidance. This principle of precaution must be translated into action, for example, by separate collection of recyclable components of household waste, such as paper, plastics, glass and metals. This principle of separation into recyclable components refers also to any industrial waste, including waste generated by waste paper processing, paper manufacturing and paper converting.

1.1.2 Packaging Ordinance (Verpackungsverordnung) (1991)

In the framework of the Waste Management Act, the Federal Government is empowered to issue ordinances. In 1991 the Packaging Ordinance was enacted, requiring the collection, recovery and recycling of 100 percent of pre-consumer packaging waste (broke and cuttings of converting plants as well as transport packaging) and 64 percent of post-consumer waste in terms of sales packaging at the end of this decade. Currently, the ordinance is under revision because of the implementation of the **EU Packaging Directive** and because of complaints from German industries and trade as well as from the Federal States.

With reference to the total volume of consumed packaging material, based on paper and board, this means finally a compulsory recovery rate of more than 80 percent to be achieved at the latest by 2000. Recycling of the recovered volume of pre-consumer and post-consumer packaging waste is permitted to be undertaken in German industries (even outside the paper industry) as well as abroad. If 80 percent of the consumed packaging is exclusively utilized in the German manufacturing packaging paper and board industry, the recycling rate would exceed 100 percent because Germany is a net importer of such paper and board grades.

The responsibility for the collection of other waste paper - such as printed matter (e.g. news or magazines) from private households and small commercial enterprises - remains with local authorities whereas the collection of used packaging is no longer within the communities' responsibility. Collection of sales packaging - made of paper and board, composite materials, plastics, glass, metals - must be organized and financed through a private organization named Duales Deutschland GmbH

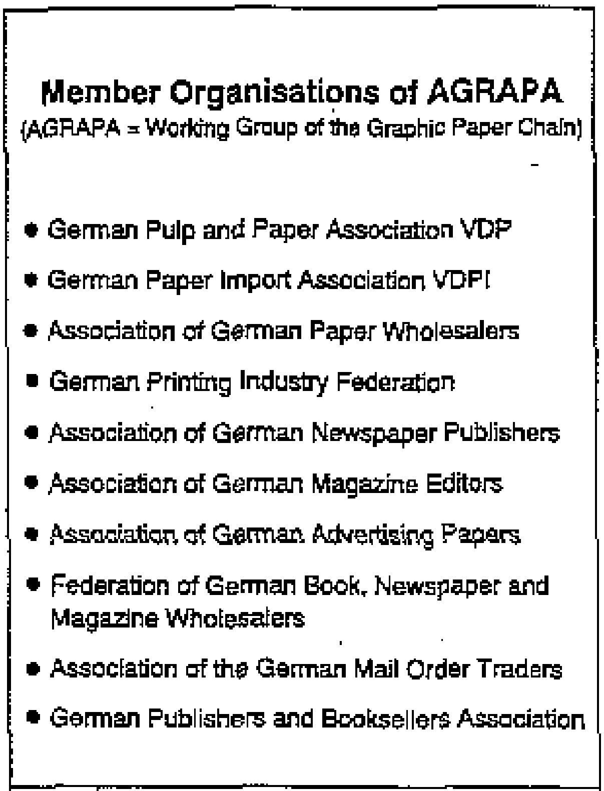
(DSD). This agency was established in the early nineties by industry, wholesale trade and retail organisations for that purpose. DSD signed contracts with different types of waste collectors who run the collection and recovery business and are satisfying the domestic as well as the international markets.

In the next step the Federal Government issued in 1994 a further act which the authors of this substudy call Recycling and Waste Management Act and which is entitled 'Closed Substance Cycle and Waste Management Act' (Kreislaufwirtschafts- und Abfallgesetz) (see chapter 1.1.6). This act with its 64 paragraphs is much more comprehensive in its regulatory scope than the Waste Management Act, which will be replaced in 1996, although some articles already came into force in 1994. Aiming at a comprehensive product responsibility, the object of the new act is to implement a further improved recycling management in the Ecological and Social Market Economy of Germany. The product responsibility of manufacturers and distributors of consumer goods should guarantee the development and production of environmentally sound products. To accomplish these targets the Federal Government is authorized to issue recovery and recycling regulations, as already laid out in the Packaging Ordinance.

1.1.3 Voluntary Agreement (Freiwillige Selbstverpflichtung) (1994)

In the early nineties the Federal Government and its Ministry for the Environment, respectively, contemplated a further, exclusively paper-related ordinance setting goals for recovery and recycling of graphic paper (news and magazines, office paper). However, this intensively discussed **Waste Paper Ordinance** was not enacted because the German graphic paper chain (Fig. 1.1.-5), represented by the associations of German paper manufacturers, of paper importers and wholesalers, printers, publishers and others, succeeded in negotiations with the German Government in producing a Voluntary Agreement on recovery and recycling of used graphic paper in terms of printed matter (news, magazines, directories, catalogues, brochures, inserts, direct mail etc.) as well as office waste (e.g. copy paper and computer printouts).

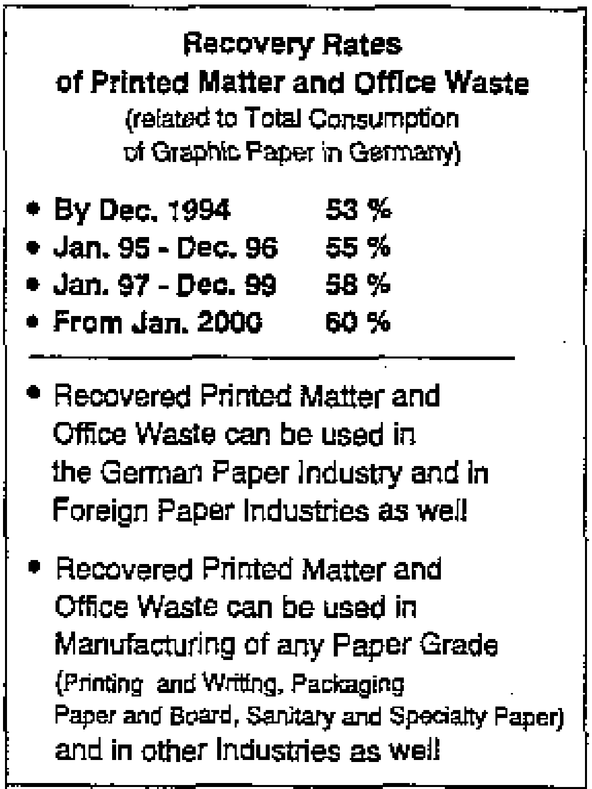
This three page agreement, signed and enacted in 1994, sets targets in collection rates for recycling as a percentage of the annual consumption of graphic papers (Fig. 1.1.-6). According to this Voluntary Agreement, the recovery rate of used graphic papers and office waste must be increased from 53 percent in 1994 to 60 percent in 2000 which seems to be an easily attainable schedule. In 1994 the recovery rate of used graphic papers and office waste already exceeded 60 percent achieving 62 percent. Therefore, it must be expected that the voluntarily agreed recovery rates will be reviewed by the Federal Government and its Ministry for the Environment.



Member Organisations of AGRAPA
(AGRAPA = Working Group of the Graphic Paper Chain)

- German Pulp and Paper Association VDP
- German Paper Import Association VDPI
- Association of German Paper Wholesalers
- German Printing Industry Federation
- Association of German Newspaper Publishers
- Association of German Magazine Editors
- Association of German Advertising Papers
- Federation of German Book, Newspaper and Magazine Wholesalers
- Association of the German Mail Order Traders
- German Publishers and Booksellers Association

Fig.1.1.-5 The German Organisations involved in the Voluntary Agreement IfP 1995



Recovery Rates
of Printed Matter and Office Waste
(related to Total Consumption
of Graphic Paper in Germany)

• **By Dec. 1994**	**53 %**
• **Jan. 95 - Dec. 96**	**55 %**
• **Jan. 97 - Dec. 99**	**58 %**
• **From Jan. 2000**	**60 %**

- Recovered Printed Matter and Office Waste can be used in the German Paper Industry and in Foreign Paper Industries as well
- Recovered Printed Matter and Office Waste can be used in Manufacturing of any Paper Grade (Printing and Writing, Packaging Paper and Board, Sanitary and Specialty Paper) and in other Industries as well

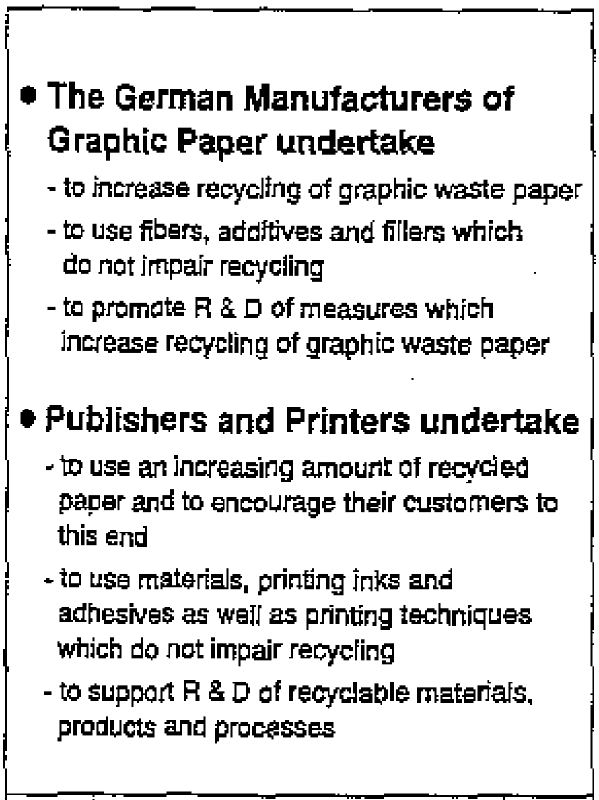
Fig. 1.1.-6 Voluntary Agreement on Recovery and Recycling of Printed Matter and Office Waste IfP 1995

The collected products based on used graphic paper can be reused for paper manufacturing either in Germany or abroad. Furthermore, recycling can be performed in any paper and board grade or in further materials such as moulded products or particle board. Considering these goals, the approach of the Voluntary Agreement can be regarded as liberal because it does not force the paper industry to produce paper and board with set waste paper utilization rates of individual paper and board grades. To avoid alternative (unlimited) utilization of recovered paper - particularly for energy recovery - the Voluntary Agreement is a positive tool beneficial for the paper industry as long as the collection and recycling targets are realistic. Apart from the main aim of that agreement, the further goals include the following items which are specified in Fig. 1.1.-7a, Fig. 1.1.-7b and Fig. 1.1.-7c.

- In manufacturing graphic papers and printed products, fibers, additives, fillers and pigments, printing inks and adhesives should be used, which do not affect recycling.

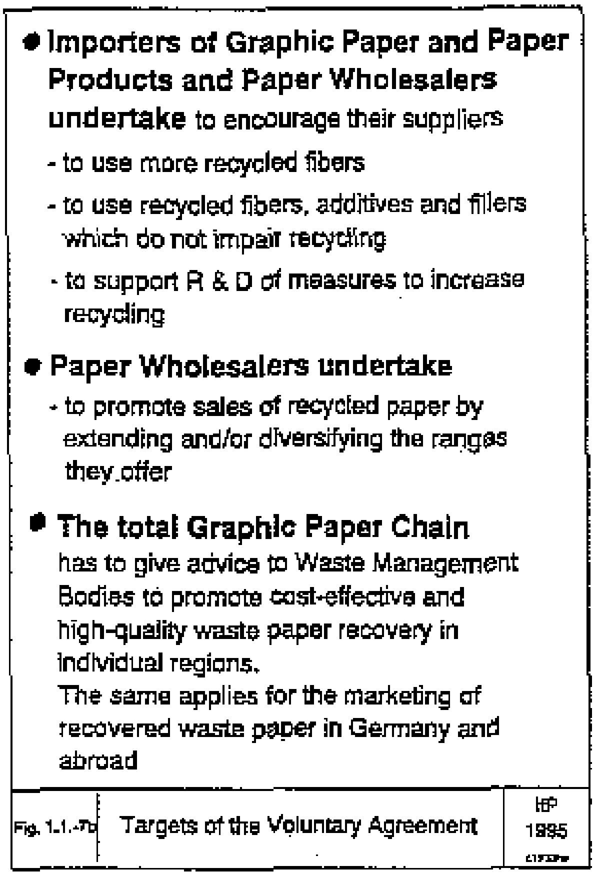
- Research and development should be promoted as a contribution towards intensifying the recycling of used graphic paper.
- The importers of paper and paper products should encourage their suppliers to use recycled fibers and to conduct research and development in order to increase recycling of graphic waste paper.
- Between 1995 and 1997 **AGRAPA,** Bonn, the responsible group for the implementation of the Voluntary Agreement arranges collection trials in cooperation with five local communities in different parts of Germany in order to gain detailed information on costs of collection, effectiveness of recovery procedures and quality of recovered paper with respect to its composition of original paper grades, amount of impurities, chemical and physical characteristics. (The characterization of composition and physical as well as chemical properties of waste paper samples taken several times in different locations is performed by the Department of Paper Science and Technology at the Darmstadt University of Technology.)

The establishment of the Voluntary Agreement must be regarded as a political and economic success especially when compared with the Packaging Ordinance. It should improve the recovery of waste paper from households and commercial enterprises in three specific areas: economy, quality and utilization.



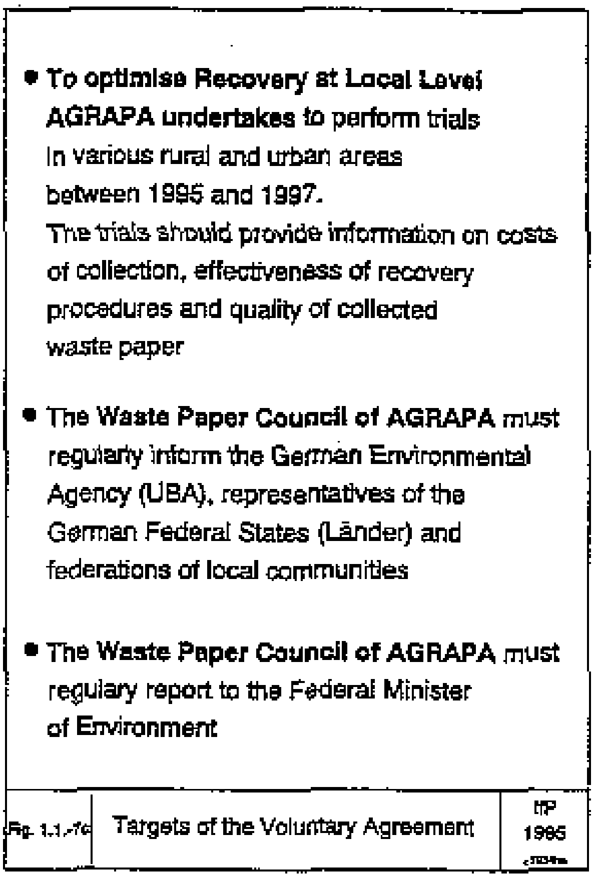
- **The German Manufacturers of Graphic Paper undertake**
  - to increase recycling of graphic waste paper
  - to use fibers, additives and fillers which do not impair recycling
  - to promote R & D of measures which increase recycling of graphic waste paper
- **Publishers and Printers undertake**
  - to use an increasing amount of recycled paper and to encourage their customers to this end
  - to use materials, printing inks and adhesives as well as printing techniques which do not impair recycling
  - to support R & D of recyclable materials, products and processes

Fig. 1.1-7a Targets of the Voluntary Agreement IfP 1995



- **Importers of Graphic Paper and Paper Products and Paper Wholesalers undertake** to encourage their suppliers
  - to use more recycled fibers
  - to use recycled fibers, additives and fillers which do not impair recycling
  - to support R & D of measures to increase recycling
- **Paper Wholesalers undertake**
  - to promote sales of recycled paper by extending and/or diversifying the ranges they offer
- **The total Graphic Paper Chain** has to give advice to Waste Management Bodies to promote cost-effective and high-quality waste paper recovery in individual regions. The same applies for the marketing of recovered waste paper in Germany and abroad

Fig. 1.1.-7b Targets of the Voluntary Agreement IfP 1995



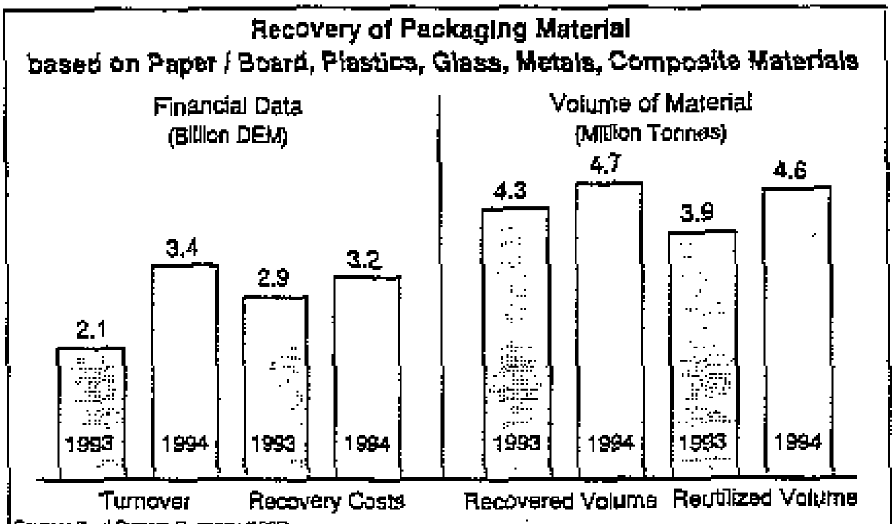
- **To optimise Recovery at Local Level AGRAPA undertakes** to perform trials in various rural and urban areas between 1995 and 1997. The trials should provide information on costs of collection, effectiveness of recovery procedures and quality of collected waste paper
- **The Waste Paper Council of AGRAPA** must regularly inform the German Environmental Agency (UBA), representatives of the German Federal States (Länder) and federations of local communities
- **The Waste Paper Council of AGRAPA** must regulary report to the Federal Minister of Environment

Fig. 1.1.-7c Targets of the Voluntary Agreement IfP 1995

1.1.4 Dual System Germany (DSD)

The Packaging Ordinance brought about the establishment of a private but monopoly-like and much criticized organisation: **Duales System Deutschland GmbH DSD** (Dual System Germany). This organisation is responsible for the collection of packaging material (based on paper and board, plastics, composite materials, glass, metal) but only in respect to sales packaging. The collection and recovery costs have to be paid by the corresponding packaging chain, which means, however, ultimately by the end-consumers. For the recovery of transport packaging such as corrugated containers, other organisations are responsible which charge their own clients, e.g. the manufacturers of corrugated board, by a licence fee.

In 1993 the DSD budget of 2.1 billion DEM financed by the Green Dot licence fees (Fig. 1.1.-8) did not cover the collection costs of 2.9 billion DEM because a large number of manufacturers and commercial customers of sales packaging did not contribute to the budget of DSD, although their packaging material entered the recovery system ruled and financed by DSD. The situation was improved in 1994 when the budget amounted to 3.4 billion DEM because 3,800 further clients (companies) paid for the licence fees. With reference to the packaging material recovered on behalf of DSD, commercial recycling is guaranteed for paper-, glass- and metal-based products but not for the total volume of composite materials and plastics, which are difficult to reuse and therefore partly used as a carbon source e.g. in blast furnaces replacing coal. Energy recovery from sales packaging is not in accordance with the philosophy of the Packaging Ordinance which requires recycling of used material for manufacturing new products.



Source: Dual System Germany (1995)

Fig. 1.1-8 Dual System Germany (DSD) IfP 1995

The contractors of the Dual System are traditional waste paper merchants, more recently established waste management companies and municipal waste collectors. Locally there is almost no competition between such contractors whereas in the field of recovery of pre-consumer waste from industrial and commercial outlets - which is outside the responsibility of Dual System Germany - a sharp competition has led to a restructuring between groups of traditional waste paper dealers and of waste management companies as efficient newcomers in this field.

In 1994, almost 50 percent (4.8 million tonnes) of all recovered paper in Germany (9.7 million tonnes) was collected from households. Approximately two thirds of that total of 9.7 million tonnes was collected and commercialized by traditional waste paper dealers whereas the majority of the household waste paper is commercialized by the waste management industry. Most of the overcollected waste paper was exported by this industry (2.2 million tonnes).

The paper collection business is not now driven by supply and demand, but purely supply-driven due to legislation. The key driving force is to reduce the volume of solid waste to be disposed of by landfilling. The capacity of landfill sites is permanently reduced and this significantly affects (growing) dumping costs. Furthermore, dumping of organic waste by landfilling has no future in Germany because of ecological issues (emission of methane-containing biogas and polluted leaching water). In order to control the environmental problems of landfills - including their effect on landscape and public acceptance - a further regulation in terms of a so-called technical guideline (in legal terms: provision) was issued in 1993.

1.1.5 Municipal Waste Management Provision (TA Siedlungsabfall) (1993)

The Municipal Waste Management Provision for disposal of municipal and industrial waste foresees, that at the latest by the year 2005, no solids that contain more than five percent organic matter can be landfilled. Hence, the highly organic sludges and other residues of the paper industry must be incinerated before being dumped in the form of ash. This refers only to that proportion of sludges and other residues which can neither be reused in other industries, e.g. cement industry and brick works, nor be composted. Included in this category should be excess waste paper that can neither be reused domestically nor be exported. The recovery of energy from non-recyclable waste paper and other lignocellulosic residues should save certain amounts of fossil fuels. Moreover, incineration guarantees the minimization of hazardous substances, even though the amounts present in paper and biomass waste are generally insignificant and non-critical. Although biomass combustion does generate carbon dioxide emissions, the renewable fuels do not contribute to the greenhouse effect.

1.1.6 Recycling and Waste Management Act (Kreislaufwirtschafts- und Abfallgesetz) (1996)

The most current and comprehensive legislation refers to the Recycling and Waste Management Act issued in 1994 and coming into force in 1996. Firstly, according to this act, the production of waste should be avoided, as far as practical, particularly by reducing its amount and noxiousness. Secondly, waste must either be subjected to recycling or used for energy recovery. From the point of view of the paper industry the option of energy recovery is regarded as counter-productive if it affects the availability of sufficient volumes of recovered paper as a raw material for paper manufacturing.

According to the act, however, priority should be given to that type of utilization of waste which is more environmentally compatible. The Federal Government is authorized to issue ordinances giving priority to recycling or energy recovery for certain types of waste. If priority for either recycling or energy recovery is not defined by a regulation in force or to be issued, then energy recovery is only permissible when

- the heating value of the waste in question is at least 11 MJ/kg (11 GJ/tonne);
- a combustion efficiency of at least 75 percent is achieved;
- the resulting heating is either used by the entity recovering the energy or supplied to a third party;
- the additional waste occurring as part of the energy recovery can be disposed of with no further treatment.

Waste from renewable raw materials can be used for energy recovery if the prerequisites of the last three items are met. This means that energy recovery must take place by co-generation, the traditional technology of power plants of the paper industry. It wishes to ensure, however, that legislation does not interfer with the availability of recoverable paper for recycling. The paper industry agrees to the principle that non-recyclable and excess waste paper can be used for energy recovery.

1.1.7 Federal Emission Control Act (Bundesimmissionsschutzgesetz) (1974)

Waste generated by production facilities, e.g. paper mills, is not covered by the Waste Management Act but by the Federal Emission Control Act. According to this act production facilities must aim at the following priorities:

- Avoidance of industrial waste
- Recycling or energy recovery of industrial waste
- Environmentally-friendly disposal of industrial waste but only if its generation cannot be avoided and if recycling or energy recovery cannot be carried out.

In principle, recycling and energy recovery of industrial waste are measures of the same rank.

The emissions of combustion plants must fulfil stringent requirements according to various regulations and provisions in the context of this act. The **13th Regulation** of the Federal Emission Control Act refers to large combustion plants, characterized by an energy generation of more than 50 MW, whereas the **17th Regulation** is valid for plants incinerating waste and similar matter. The emission standards of the 17th Regulation are extremely stringent compared with the standards of the 13th Regulation (Table 1.1.-1). Due to the legal requirements, the lower emission standards of the 17th Regulation must be met in the case of energy recovery based on waste of the paper industry as well as on (non-recyclable) waste paper.

Tab. 1.1.-1 Emission Standards for Combustion Plants according to the Federal Emission Control Act (FECA)
(Figures refer to daily Averages)

Parameter	13th Regulation of FECA	17th Regulation of FECA
	(e.g. coal. wood)	(e.g. paper mill waste, waste paper)
	mg/m³	mg/m³
Dust (Particles)	50	10
Organic Carbon	n.s.	10
CO	250	50
NO_x (as NO_2)	800	200
SO_x (as SO_2)	400	50
Cl (as HCL)	100	10
F (as HF)	15	1
Cd + TI	n.s.	0.05
Hg	n.s.	0.05
Sb + As + Pb + Cr + Co + Cu + Mn + Ni + V + Sn	n.s.	0.5
PCDD + PCDF (in ng I-TE/m³)	n.s.	0.1
Based on dry gas, m³ normal (273 K; 1013 hPa)		

n.s. = no standard

I-TE = International Toxicity Equivalent

1.1.8 CO_2 Emission Tax and Energy Tax (CO_2-Abgabe und Energiesteuer)

The increased emission of certain trace gases since the beginning of the industrialization last century, especially CO_2 from burning of fossil fuels, but also from the destruction of tropical rain forests, has led to an enhancement of the natural greenhouse effect with still controversially discussed consequences for the world's climate.

In reaction to the expected world-wide threat to the climate, the Federal Government of Germany put forward concrete goals in 1991:

- Reduction of German CO_2 emissions - compared with 1987 - of 25 percent to 30 percent by 2005.

The CO_2 emission in 1987 in the former Federal Republic of Germany (West Germany) was about 3.5 percent of the global man-made CO_2 emission at that time. About a third of this emission originated from power generation and district heating plants. Industry and traffic represented 24 percent and 17 percent, respectively. Small consumers and households together produced a quarter of the total CO_2 emission.

The Federal Goverment will aim at the reduction of CO_2 until the year 2005 by supporting more efficient energy utilization and energy-saving programs for industry, power plants, traffic and private households. Currently, controversial discussions take place with respect to a possible taxation of the consumption of fossil primary energy (energy tax) and/or to a CO_2 emission tax which are supposed to contribute to a faster realization of CO_2 reduction. These issues are dealt with on the national scene as well as in the European Union.

The German paper industry agrees with the target of the Federal Government to improve the efficiency of energy utilization. However, the German paper industry is aware that an energy tax and/or a CO_2 emission tax will have a substantial financial impact on production costs. Considering this, the German paper industry voluntarily agreed in 1995 to reduce the specific energy demand by 20 percent and the specific CO_2 emission by 22 percent by the year 2005, with 1987 as reference. (Specific emission refers to a tonne of pulp or paper produced.)

In order to approach these voluntary targets, the German paper industry refers to the following options:

1. Substitution of carbon-rich fossil energy by less carbon containing and CO_2 neutral fuels, respectively.
2. Further optimization of production processes, e.g. by intensified waste paper utilization and increased efficiency of energy utilization in papermaking and paper converting.
3. Reduction of the consumption of purchased electrical power, realized by a further expansion of the capacities of co-generation.

The German paper industry is prepared for such a voluntary agreement, if the following prerequisites are fulfilled:

- Energy recovery, based on industrial waste and non-recyclable waste paper, should not be hindered.
- No regulations should be issued which restrict the utilization of recovered paper in the paper industry (e.g. by national measures which would cause a significant increase of costs for the disposal of waste generated by waste paper processing).
- No regulations should be issued such as a **Regulation on the Utilization of Thermal Energy** (Wärmenutzungsverordnung), an amending law of the **Regulation on large Combustion Plants** (Novelle zur Großfeuerungsanlagen-Verordnung) or a national energy tax, related to the utilization of fossil fuels.
- The Federal Government must take care in discussions on an EU-wide energy tax that all those industries which have already issued a voluntary agreement on energy saving should not be considered for an energy taxation.

1.2 Waste Paper Recovery and Utilization of Recycled Fibers

1.2.0 Global Background

Waste paper as the source for recycled fibers plays an increasingly significant role in most parts of the world, even in papermaking countries with abundant forest resources, e.g. in Canada, the USA or Northern Europe. Within the eighties and the nineties the waste paper utilization rate - defined as the tonnage of waste paper processed related to the tonnage of paper produced - has grown from 30 percent (1980) to 40.5 percent (1994) world-wide (Table 1.2.-1) without affecting the share of both semichemical pulp and non-wood fibers. Table 1.2.-1 also shows that the proportion of mechanical pulp was reduced from 15 percent to 12 percent and that of chemical wood pulp dropped from 48.5 percent to 41 percent between 1980 and 1994. Besides the well-known waste paper utilization rate the proportions according to Table 1.2.-1 refer to the input of virgin pulps and waste paper related to the total tonnage of fiber material used.

Fiber Material		1980	1990	1994
• Chemical Wood Pulps	[%]	48.5	42.5	41.0
- Sulfite Pulp	[%]	(6.5)	(3.0)	(3.0)
- Sulfate Pulp	[%]	(42.0)	(39.5)	(38.0)
• Semichemical Pulp	[%]	4.5	3.0	2.5
• Other Fibers	[%]	4.5	6.5	6.0
• Mechanical Pulp	[%]	15.0	14.5	12.0
• Waste Paper	[%]	28.0	34.0	38.5
• Total Fiber Material	[%]	100	100	100
• Waste Paper Utilization Rate	[%]	30.0	36.0	40.5

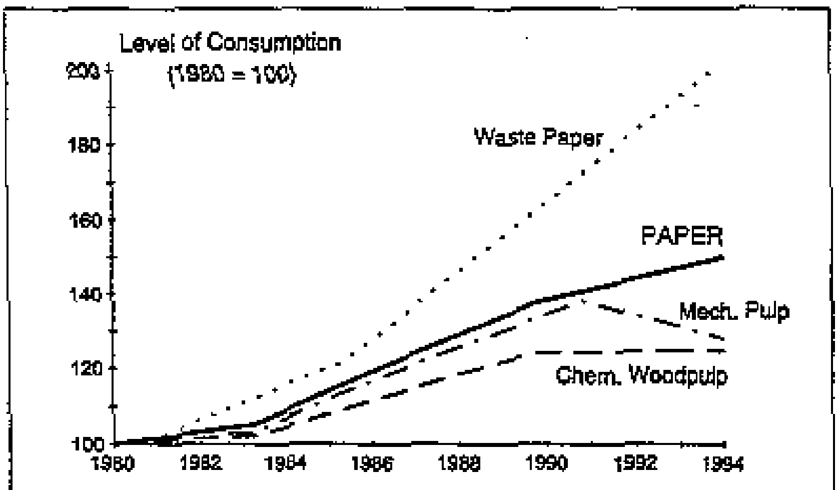
$$\text{Waste Paper Utilization Rate} = \frac{\text{Waste Paper Demand (M Tonnes)}}{\text{Paper Production (M Tonnes)}} \cdot 100\ [\%]$$

Source: FAO, Rome (1995)

Table 1.2.-1 Proportion of Different Fiber Materials and Waste Paper Utilization Rate (World-wide)

IfP
1995

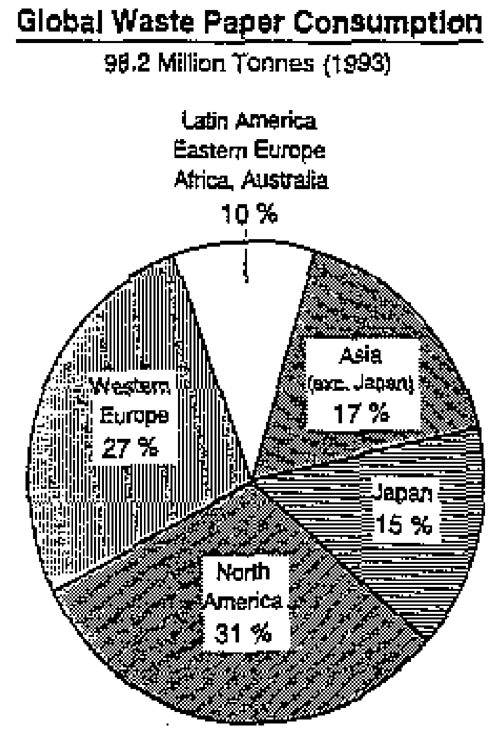
Fig. 1.2.-1 illustrates the relative development of the world-wide consumption of paper, wood pulps and waste paper up to 1994 using 1980 as reference. The considerable increase in waste paper use was seen in developed as well as in developing countries, most particularly by recycling efforts of the European Union (12 member states before its expansion in 1995) and the United States.



Source: FAO, Rome (1995)

Fig. 1.2.-1 Relative Development of the Consumption of Woodpulps, Waste Paper and Paper (World-wide)

IfP 1995

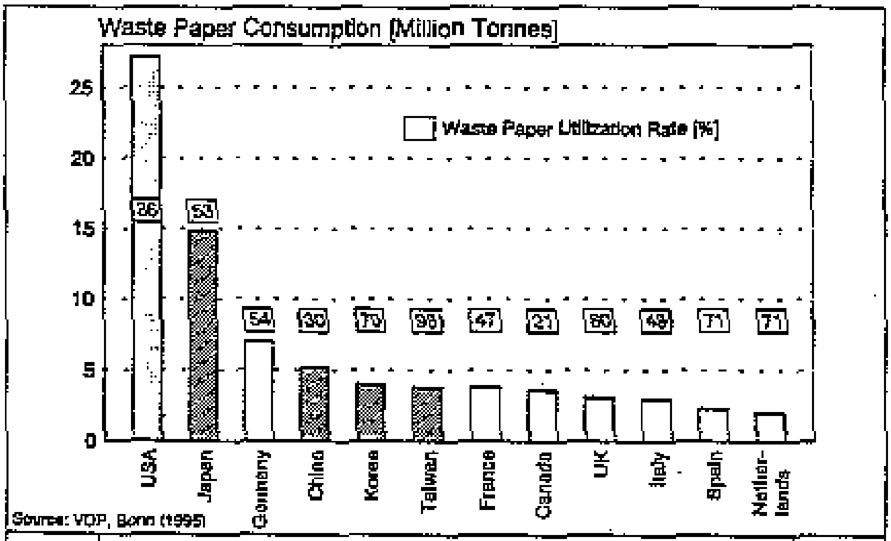


Source: VDP, Bonn (1995)

Fig. 1.2-2 Global Waste Paper Consumption by Regions

IfP 1995

Fig. 1.2.-2 shows the distribution of the global waste paper volume recycled in 1993 by the regions of Western Europe (16 countries), North America, Japan and Asia (Japan excluded), Eastern Europe, Latin America, Africa and Australia. Because of the achieved levels of the waste paper utilization rate particularly in the 12 states of the European Union (55 percent) and in Japan (53 percent) the proportion of the waste paper demand will further increase in North America and Asia (Japan excluded) significantly, but for different reasons: North America has a 'hidden', not fully exploited waste paper resource, Asia is running short in virgin fiber resources which must be compensated by (imported) waste paper.

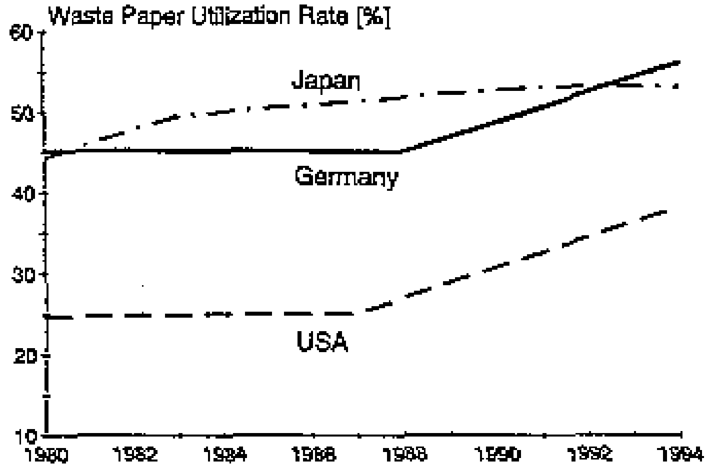


Source: VDP, Bonn (1995)

Fig. 1.2.-3 Leading Countries in Respect to Waste Paper Consumption (1993)

IfP 1995

According to Fig. 1.2.-3 the waste paper utilization rates vary widely between the globally leading countries processing waste paper. Following USA and Japan, Germany is in the third position as far as the tonnage of domestically used waste paper is concerned. This is also the case in respect to the volume of recovered waste paper (9.7 million tonnes = 59 percent waste paper recovery rate in 1994), which, of course, depends also on the amount of net paper imports as an other feature of a country paper industry. Some other countries have attained a waste paper utilization rate which is above the present German level of 56 percent. Apart from Japan, the economically prospering Far East countries of China, South Korea and Taiwan have - due to their poor fiber resources - a significant raw material demand satisfied by increasing volumes of waste paper mainly imported from the USA and more recently from Germany.



Source: VDP, Bonn (1995)

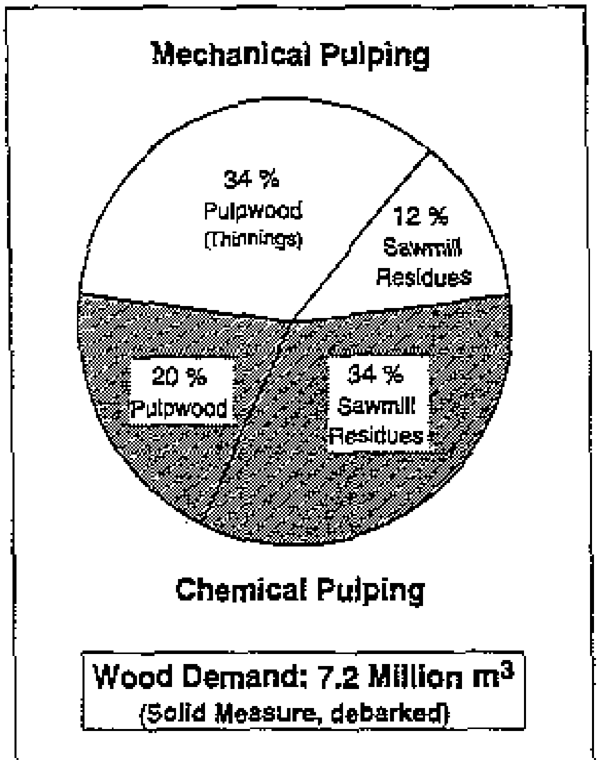
Fig. 1.2.-4 Utilization Rate of the Leading Countries Recycling Waste Paper (by Volume) IfP 1995

The USA, Japan and Germany together have utilized constantly 65 percent of the global waste paper demand for more than one decade (Fig. 1.2.-4). Compared with Japan, Germany and the European Union, the USA is characterized by a lower utilization rate of not more than 40 percent. This rate was already achieved in Japan, Germany and Western Europe (Scandinavia excluded) in the fifties or sixties. However, due to this low utilization rate of the USA the domestically processed waste paper, as well as the exported, is of high quality and well received by countries of the Pacific Rim (Japan, Korea, Taiwan) and by Mexico, poor in forest resources.

1.2.1 Paper Production and Consumption in Germany

1.2.1.1 Germany and its Paper Industry

Germany is a densely populated and highly industrialized country. The total area of 357,000 square kilometers is populated by 80 million inhabitants, which corresponds to 225 capita per square kilometer. Thirty percent of Germany is covered by forests (10.4 million hectares) characterized by an average annual growth of at least five solid cubic meters per hectare, which corresponds to a total growth of at least 50 million cubic meters solid measure under bark in terms of spruce, pine, fir, beech, oak, birch, and further species of softwoods and hardwoods.



Source: VDP, Bonn (1995)

Fig. 1.2.-5 Pulpwood Demand of the German Pulp and Paper Industry (1994) IfP 1996

According to the existing pulping processes mainly spruce can be utilized for chemical and mechanical pulping apart from marginal volumes of pine (for mechanical pulping) and beech processed in one pulp mill. The total volume of timber and pulpwood harvested amounts on average to about 30 million cubic meters solid measure under bark per year (timber wood: 20 million m³, thinnings: 10 million m³) of which about seven million cubic meters (solid measure, debarked) of thinnings and sawmill residues are used by the pulp industry (Fig. 1.2.-5).

The pulp and paper industry comprises 170 companies (230 mills) producing

- 0.7 million tonnes chemical pulp (5 integrated mills)
- 1.2 million tonnes mechanical pulp (14 integrated plants)
- 14.4 million tonnes paper and board (230 mills).

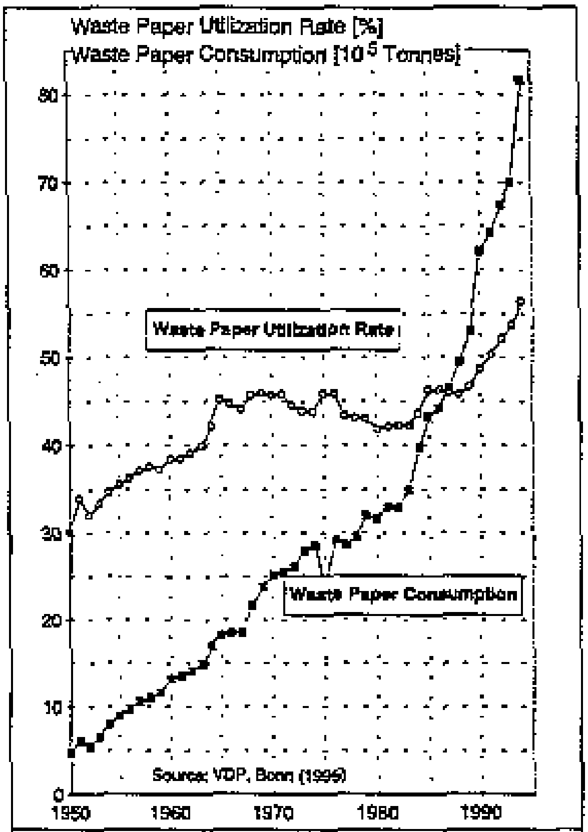
In 1994, 5.7 million tonnes paper and board were exported (40 percent export rate related to production), whereas 7.6 million tonnes paper and board were imported (47 percent import rate related to paper consumption), mainly from Scandinavia (3.4 million tonnes) and Western Europe (3.4 million tonnes). More relevant for waste paper and its recovery is the volume of consumed paper and board which totals 16.3 million tonnes. Germany is the fourth-largest market place for paper in the world following USA, Japan and China. In respect to the per-capita consumption of paper and board Germany keeps globally the tenth position (200 kg/cap in 1994) affected by reunification and the lower living standard in East Germany (former GDR) with a former per-capita paper consumption of not more than 85 kg/cap which, however, was then by far the highest of the former communistic countries.

One of the most significant handicaps of the German paper industry is the fact that only five paper mills are integrated with chemical pulp mills, based on the sulfite process. This results in the necessity to import about 90 percent of the required chemical pulp, mainly as bleached sulfate pulps (3.6 million tonnes). On the other hand Germany has abundant pulpwood resources at its disposal which correspond to a volume of about four million tonnes of bleached kraft pulp almost equivalent to the tonnage of pulp imported from Scandinavia (45 %), North America (31 %), Latin America (8 %), Portugal, Spain (10 %) and further countries (6 %).

The strong position of the German paper industry depends to a large extent on the opportunity to make use of the large, continuously increasing volume of cost-competitive waste paper which is permanently generated within short distances of the paper mills by recycling-minded end-consumers, which make increasing volumes of post-consumer waste available, mainly in terms of printed matter (news, magazines, catalogues, directories, brochures, inserts, direct mail etc.) and packaging material made of paper, board and composite material (e.g. PE-coated liquid board).

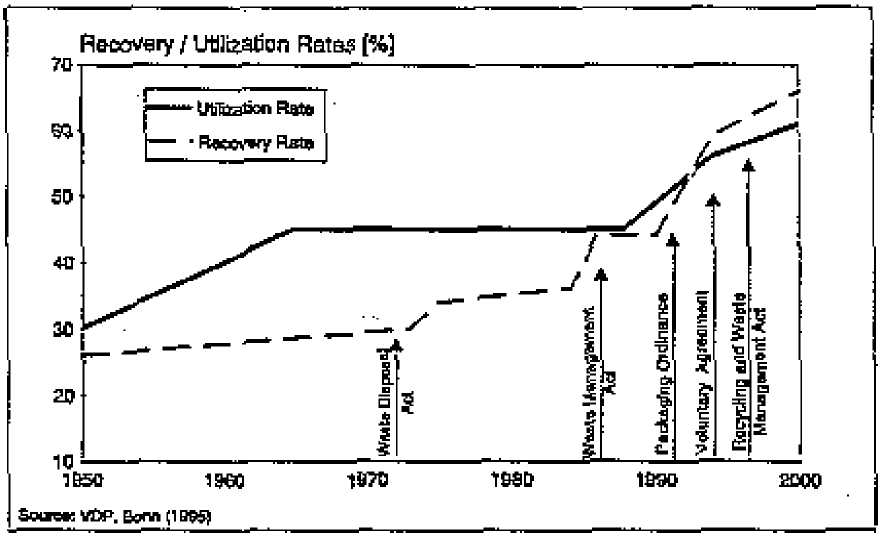
1.2.1.2 Waste Paper Recovery and Utilization

The West German waste paper utilization rate was at 30 percent in 1950 and reached a level of 45 percent in the mid-sixties (<u>Fig. 1.2.-6a</u> and <u>Fig. 1.2.-6b</u>). This level remained almost constant for more than two decades, followed by a significant increase since 1988, which resulted in a rate of 56 percent in 1994. It is assumed that at the end of this decade the rate will approach at least 60 percent which is supposed to be close to the saturation point should the production ratio between graphic papers (48 percent), packaging papers and board (39 percent), sanitary papers (6 percent) and specialty papers (7 percent) be kept roughly at the current level. If the technology of waste paper processing is going to be modified substantially, e.g. by further improved upgrading measures in stock preparation, which consequently lead to increased volumes of rejects and sludge, the waste paper utilization rate will then exceed this forecast level.



Source: VDP, Bonn (1996)

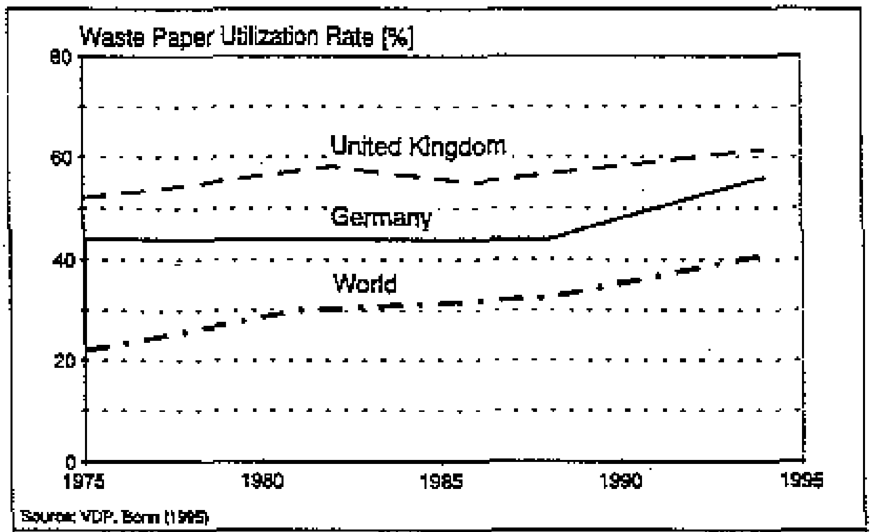
Fig. 1.2.-6a Waste Paper Consumption and Utilization Rate in Germany IfP 1995



Source: VDP, Bonn (1995)

Fig. 1.2.-6b Waste Paper Recovery and Utilization Rates in Germany IfP 1995

Limits to the utilization of recycled fibers are set by the availability of suitable waste paper grades at competitive prices, and by quality requirements of recycled paper produced which compete with paper made of virgin fibers. It must be emphasized that recycled fibers cannot be re-used too many times because of their mechanical deterioration (by hornification and cutting) and their loading with organic substances and residual printing inks. In order to avoid impaired characteristics of paper, a permanent input of fresh fibers is required either in terms of pulps or of paper made of virgin fibers manufactured at home as well as abroad.



Source: VDP, Bonn (1995)

Fig. 1.2.-7 Waste Paper Utilization Rate in United Kingdom, Germany and World-wide IfP 1995

Germany regards itself as a frontrunner in waste paper recycling, because of its high waste paper recovery and waste paper utilization rates, taking into account that half of the paper production consists of graphic papers with their low utilization rate of 28 percent (1994). As shown in Fig. 1.2.-7 the waste paper utilization rate of Germany is still below the corresponding rate of, for example, the United Kingdom (60 percent). However, the comparison of these figures is misleading because the waste paper utilization rates are affected, amongst others, by the distribution of grades within national paper and board production as shown in Fig. 1.2.-8. Compared with Austria, Belgium, France, Italy and Portugal, the highest utilization rates are realized in Germany, Great Britain, Spain and the Netherlands, apart from Denmark and Ireland with their insignificant volumes of paper produced. (Ireland produces not more than 35,000 tonnes of corrugating medium and testliner, the Danish paper production amounts to 0.3 million tonnes of packaging paper and recycled graphic paper.)

In Germany the biggest volume of waste paper is traditionally used in packaging papers and board, followed by newsprint manufacturing, which is now almost totally based on recycled fibers. Currently, progress is being made with the application of recycled fibers in SC- and LWC-papers, whereas woodfree printing and writing papers are in a different position because of a shortage of suitable and cost-competitive waste paper grades.

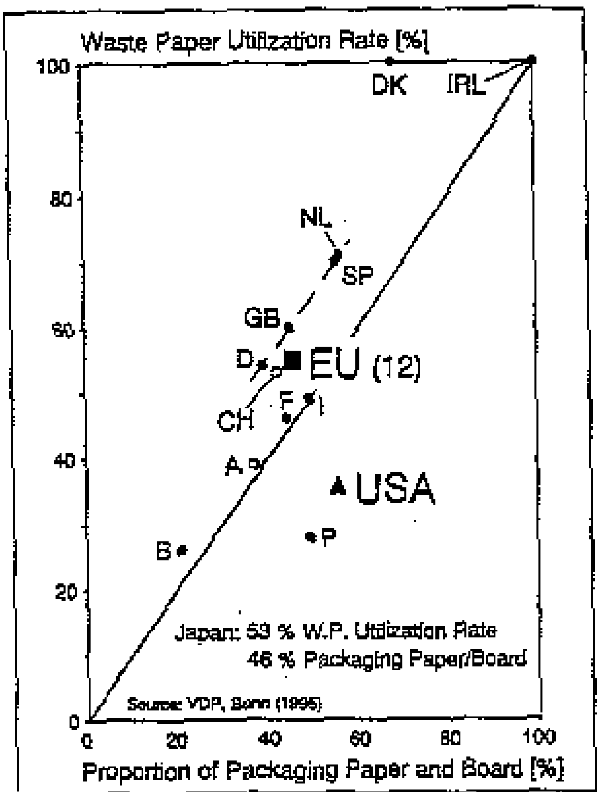
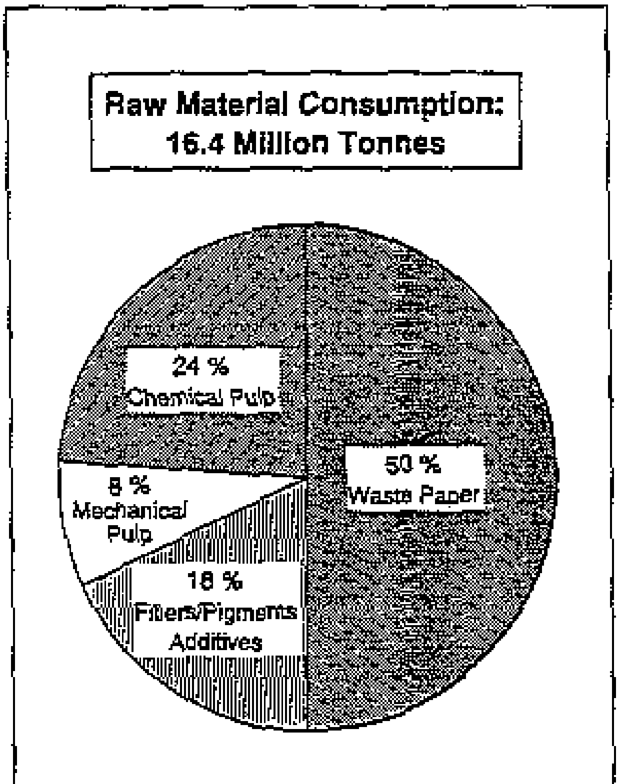


Fig. 1.2-8 Waste Paper Utilization Rate versus Proportion of Packaging Paper and Board Related to Total Paper Production (1993) IfP 1995



Source: VDP, Bonn (1995)

Fig. 1.2-9 Raw Material Input of the German Paper Industry (1994) IfP 1995

So far, 26 deinking plants process one third of the total waste paper volume of 8.2 million tonnes. This means a significant increase of deinked pulp in two years affected by three newsprint greenfield mills which came on stream in 1993 and 1994 and which are totally based on waste paper and recycled fibers, respectively.

1.2.1.3 Waste Paper Utilization in Different Paper Grades

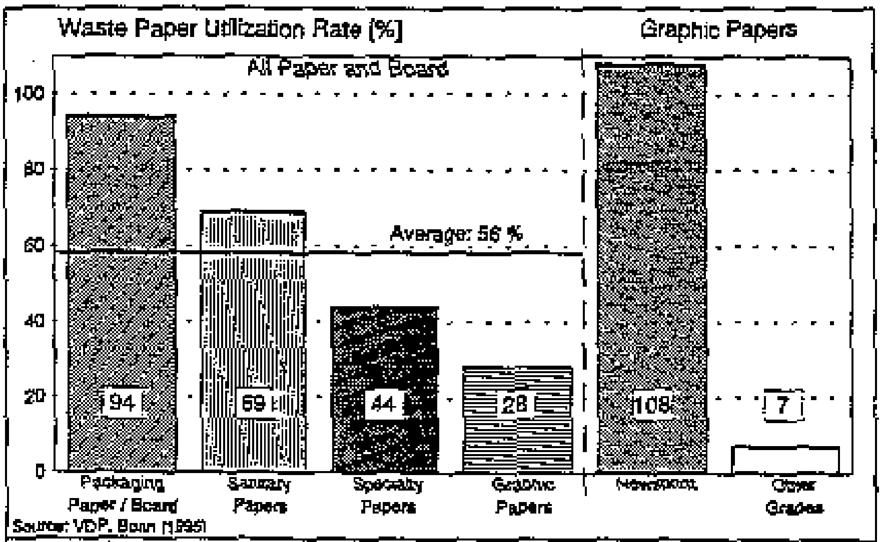
The material input (16.4 million tonnes) of the German paper industry is divided into the following components and their proportions as percentage and by weight (air-dry) (Fig. 1.2.-9):

- Waste paper: 50 % = 8.2 million tonnes
- Chemical pulp: 24 % = 3.9 million tonnes
- Mechanical pulp: 8 % = 1.3 million tonnes
- Fillers and pigments: 14 % = 2.3 million tonnes
- Chemical additives: 4 % = 0.7 million tonnes

The portion of waste paper utilized (8.2 million tonnes) corresponds to a waste paper utilization rate of 56 percent, which is related to the tonnage of paper and board produced (14.4 million tonnes). The total production of paper and board comprises:

• Graphic papers:	7.0 million tonnes	(48 percent)
• Newsprint:	1.5 million tonnes	(10 percent)]
• Packaging papers and board:	5.6 million tonnes	(39 percent)
• Sanitary papers:	0.9 million tonnes	(6 percent)
• Specialty papers:	1.0 million tonnes	(7 percent)

In the context of this substudy the waste paper utilization rates of these paper and board grades are highly relevant (Fig. 1.2.-10):



Source: VDP, Bonn (1995)

Fig. 1.2.-10 Waste Paper Utilization Rates by Main Groups and Grades of Paper Production in Germany (1994) IfP 1995

- Graphic papers: 28 % waste paper utilization rate = 2.0 million tonnes waste paper
- Packaging papers and board: 94 % waste paper utilization rate = 5.2 million tonnes waste paper
- Sanitary papers: 69 % waste paper utilization rate = 0.6 million tonnes waste paper
- Specialty papers: 44 % waste paper utilization rate = 0.4 million tonnes waste paper

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- **Total Production: 56 % waste paper utilization rate = 8.2 million tonnes waste paper**

Most heterogeneous is the utilization of waste paper in graphic papers which are commonly divided into the following grades:

• Newsprint:	108 % waste paper utilization rate	= 1.6 million tonnes waste paper
• Recycled paper:	115 % waste paper utilization rate	= 0.3 million tonnes waste paper
• Wood-containing paper (coated+uncoated):	< 5 % waste paper utilization rate	= <0.1 million tonnes waste paper
• Woodfree paper (coated+uncoated):	< 5 % waste paper utilization rate	= <0.1 million tonnes waste paper
• Total:	**28 % waste paper utilization rate**	**= 2.0 million tonnes waste paper**

Out of 8.2 million tonnes of the total waste paper volume processed, 2.0 million tonnes waste paper are used for deinked pulp (DIP) for manufacturing graphic papers. The production of 1.5 million tonnes of newsprint requires 1.6 million tonnes of waste paper. The remaining volume of (2.0 - 1.6 =) 0.4 million tonnes is mainly processed for so-called recycled graphic paper (0.3 million tonnes waste paper) and, to a small extent, used for manufacturing wood-containing and woodfree (coated and uncoated) printing and writing papers (together about 0.1 million tonnes waste paper).

With a production of 5.5 million tonnes of wood-containing and woodfree graphic papers (including recycled graphic paper but with the exception of newsprint), the average waste paper utilization rate is not more than seven percent. Therefore it is evident that any substantial increase of the overall waste paper utilization rate would have to occur in the main group of high-quality graphic papers. It would occur to different extents in wood-containing and woodfree printing and writing papers because of the availability of adequate waste paper grades at economic prices and because of requirements on the quality of paper.

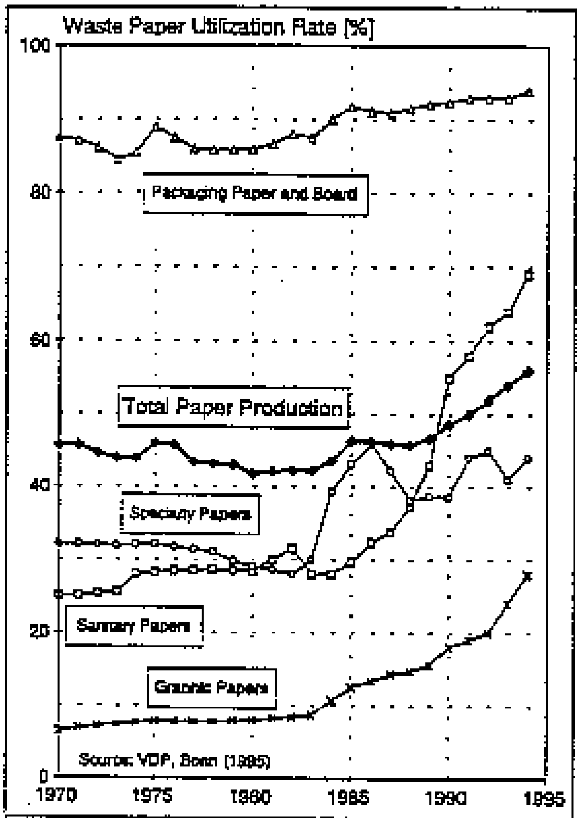
If there is no further increase of the waste paper utilization rates of packaging paper and board , sanitary and specialty papers the average utilization rate of the total German paper industry might not exceed the assumed target figure of 60 percent (8.7 million tonnes waste paper) at the end of this decade. In this case a further waste paper volume of (8.7 - 8.2 =) 0.5 million tonnes must be used for wood-containing and woodfree printing and writing papers. This would then result in a waste paper utilization rate for them of [(0.4 + 0.5)/5.5 =] 17 percent, which seems to be a realistic, possibly a resigned approach.

In the case of a foreseen waste paper utilization rate of the total German paper industry of 65 percent (9.4 million tonnes waste paper) the utilization rate for these grades would amount to [(0.4+0.5+0.7)/5.5 =] 30 percent. This rate has to be regarded as a challenging level taking into account that recycled fibers must be used predominantly in wood-containing paper grades and to a lesser extent in woodfree papers. Considering this, wood-containing paper grades (in the first place SC- and LWC-paper) would be forced to realize a utilization rate of about 40 percent.

Packaging papers and board with their present waste paper utilization rate of 94 percent (5.2 million tonnes waste paper) have reached their definite saturation level although the theoretical limit is about 108 percent because 8 percent rejects are generated by waste paper processing. However, a certain amount of virgin fibers must be further used for packaging material getting in contact with wet, fatty or dry foodstuff which has to fulfil stringent requirements according to national and international regulations. The national regulation refers to the so-called **Recommendation XXXVI** (Empfehlung XXXVI), issued by the former Federal Health Agency (BGA) and continued by its new organisation, which is named Federal Institute for Consumer Protection and Veterinary Medicine (Bundesanstalt für gesundheitlichen Verbraucherschutz und Veterinärmedizin BgVV). Internationally the European Council is currently involved in the establishment of Recommendations on this issue, too.

The waste paper utilization rate of 69 percent (0.6 million tonnes waste paper) in the case of sanitary papers seems to be rather high. However, one must bear in mind that at least one third of the waste paper volume processed in such mills becomes sludge (deinking sludge) and rejects (0.2 million tonnes waste from waste paper processing). Therefore, the real content of recycled fibers is on average not more than (69 % - 23% =) 46 percent. Considering this, there is still a potential of increased waste paper utilization which might approach a range of 80 percent (55 percent content of recycled fibers). However, an increase of the waste paper utilization rate by ten percent in sanitary papers leads only to an increase of the average German waste paper utilization rate of not more than one percent. Therefore, sanitary papers are of marginal significance as far as intensified waste paper utilization of the total paper industry is concerned.

The group of specialty paper with its utilization rate of 44 percent (0.4 million tonnes waste paper) has probably reached its final level. Many of the specialty papers can never be manufactured with recycled fibers either because of technical requirements (e.g. filter papers, capacitor tissue paper, photographic base paper, decor paper) or because of health issues (e.g. household filter papers, cigarette tissue).



Source: VDP, Bonn (1995)

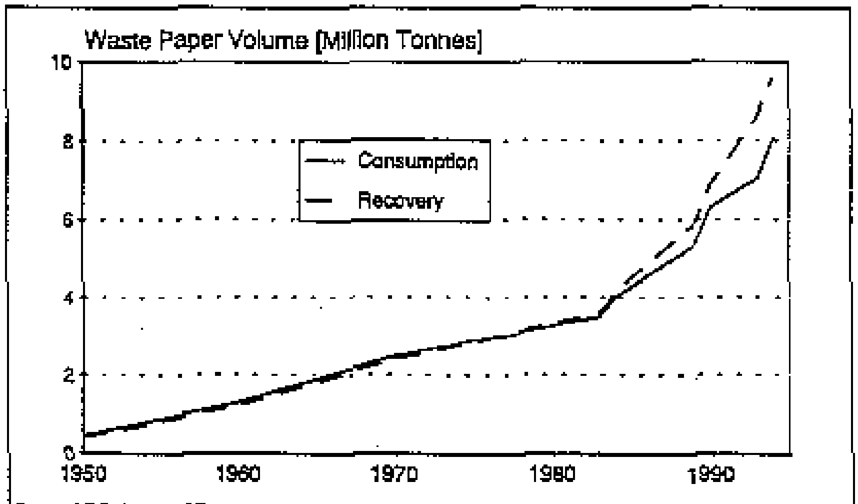
Fig. 1.2.-11 Waste Paper Utilization Rates by Main Groups of Paper Production in Germany

IfP 1995

Fig. 1.2.-11 shows the development of the waste paper utilization rate of the four groups of the German paper production between 1970 and 1994. In relative terms the increase of the utilization rate was most significant with graphic papers starting at six percent in 1970 which means an increase of more than four times in less than 25 years mainly affected by newsprint and recycled graphic paper, whereas the other graphic paper grades did not significantly contribute to that increase of the utilization rate. In the same period of time the increase of the waste paper utilization rate of sanitary papers was nearly three times from 25 percent to 69 percent. On the other hand packaging papers and board just edged up from 88 percent to 94 percent.

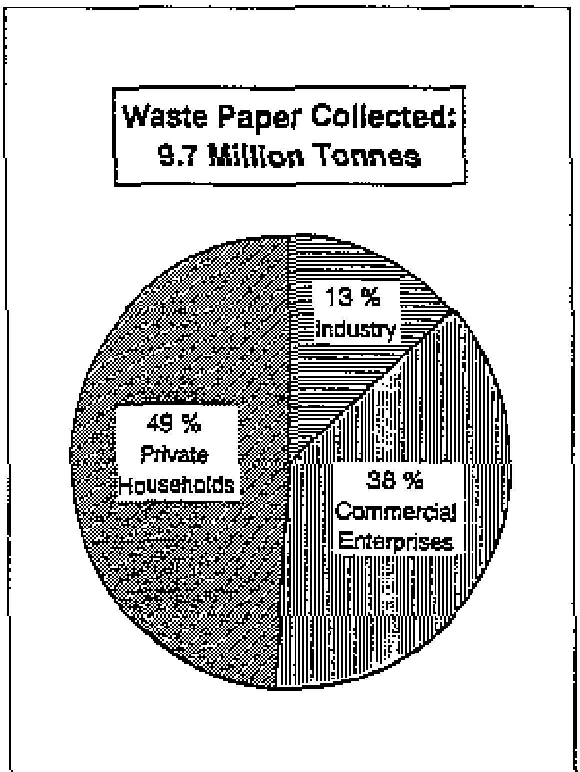
1.2.2 Recovery, Export and Import of Waste Paper

Fig. 1.2.-12 shows the development of recovery and consumption of waste paper in Germany from 1950 to 1994. For more than 30 years there was a balance between demand of the domestic paper industry and recovery, followed by a period of surplus of collected paper. This excess waste paper occurred already in the eighties and was originally not the result of any paper-specific legislation, which did not come into force until 1991 in terms of the Packaging Ordinance. Nowadays, legislation increasingly stimulates the recovery efforts for the benefit of the paper industry in Germany and abroad.



Source: VDP, Bonn (1995)

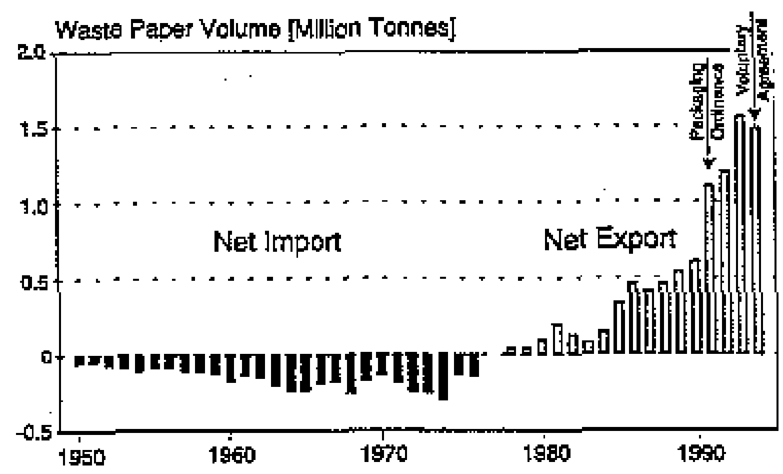
Fig. 1.2.-12 Recovery and Consumption of Waste Paper in Germany (1950-1990: West Germany) HP 1995



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 1.2.-13 Sources of Recovery of Waste Paper in Germany (1994) IfP 1995

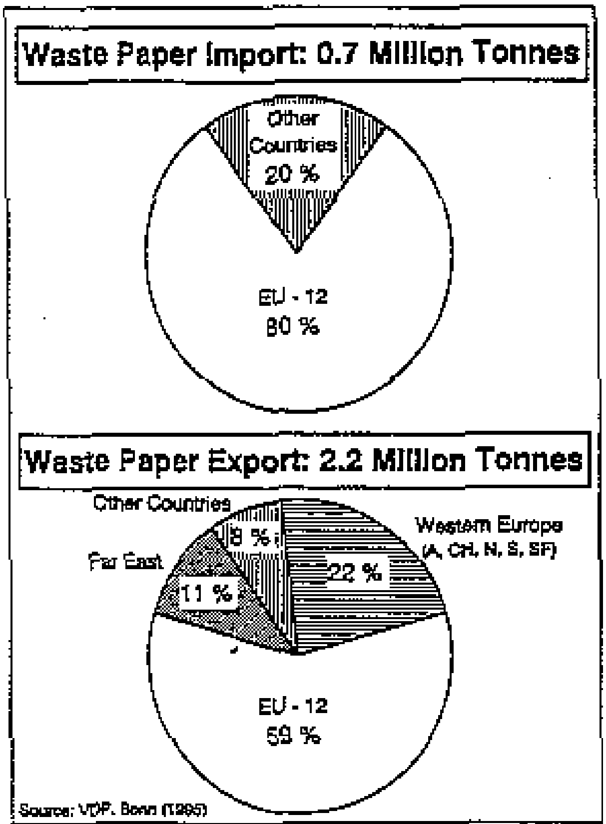
With respect to collection of waste paper, the most relevant statistical treatment refers to the total recovered volume of 9.7 million tonnes which must be divided into both categories as pre-consumer and post-consumer waste. Pre-consumer waste is generated by the industry (e.g. printing shops or paper converting plants), characterized by single paper grades and by a negligible content of impurities. Fig. 1.2.-13 shows the main sources of waste paper in three categories: industry (pre-consumer waste), commercial enterprises and private households (including small commercial enterprises) (post-consumer waste). Office waste is not documented separately, but belongs to the post-consumer waste paper generating sources. The consumption of office paper (woodfree paper made of virgin pulp, wood-containing paper made of virgin pulp as well as recycled fibers) totals 1.3 million tonnes. It is supposed that about 50 percent is recovered.



Source: VDP, Bonn (1995)

Fig. 1.2.-14 Waste Paper Export and Import in Germany IfP 1995

Fig. 1.2.-14 refers to import and export of waste paper in Germany between 1950 and 1994. The figures given do not represent the total volumes of imported and exported waste paper but refer to net tonnages. In the post-war period the continuously growing paper industry could not be totally satisfied by domestically recovered waste paper, particularly in the case of high-quality grades. Because of permanently improved and intensified recovery efforts since the beginning of the eighties, Germany was in a position to increase the volume of exported waste paper, mainly delivered to countries of the European Community and, in the beginning of the nineties, to overseas countries such as Thailand, Indonesia or Taiwan (Fig. 1.2.-15). For the most part the biggest portion of the exported waste paper consists of lower grades such as mixed waste, supermarket waste, news and magazines (household waste paper for deinked pulp (DIP)). Taking into account the permanent import of mainly high-quality waste paper grades, it must be underlined that in the previous years the total volume of exported waste paper exceeded already two million tonnes. Consequently, Germany became the second-largest waste paper exporter after the United States.



Source: VDP, Bonn (1995)

Fig. 1.2.-15 Waste Paper Export and Import in Germany by Countries and Regions (1994) IfP 1995

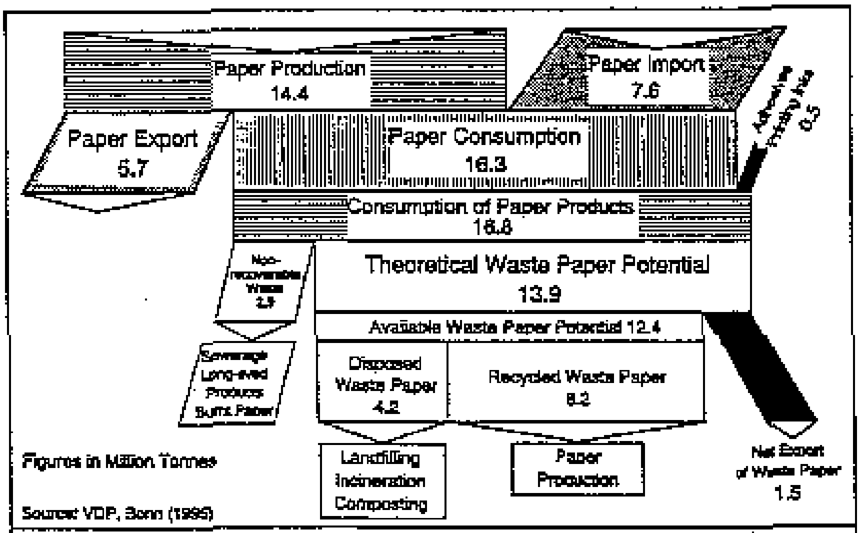
Recently, consideration has been given to incinerating a part of the overcollected waste paper volume for the benefit of energy generation by co-generation, preferably in the paper industry, replacing fossil energy by that biomass. At this moment, there are no discussions on combustion of excess waste paper because it seems to be irrelevant due to the increasing volume of exported waste paper. However, it must be considered that at a recovery rate of 60 percent about half of the other 40 percent of used paper products has to be disposed of either by landfilling or municipal waste incineration or composting (see chapter 1.4). For economic, environmental and legal reasons (Municipal Waste Management Provision of 1993 coming in force in 2005), combustion of non-recyclable waste paper must replace landfilling in the medium-term.

1.2.3 Collection of Waste Paper

1.2.3.1 Mass Balance of Paper, Waste Paper and Waste

Fig. 1.2.-16 clarifies the generation of waste paper which amounts to a collected volume of 9.7 million tonnes of which 1.5 million tonnes (net) are exported. Related to the total consumption of paper products (16.8 million tonnes) the theoretical waste paper potential totals 13.9 million tonnes (83 percent) because 17 percent of

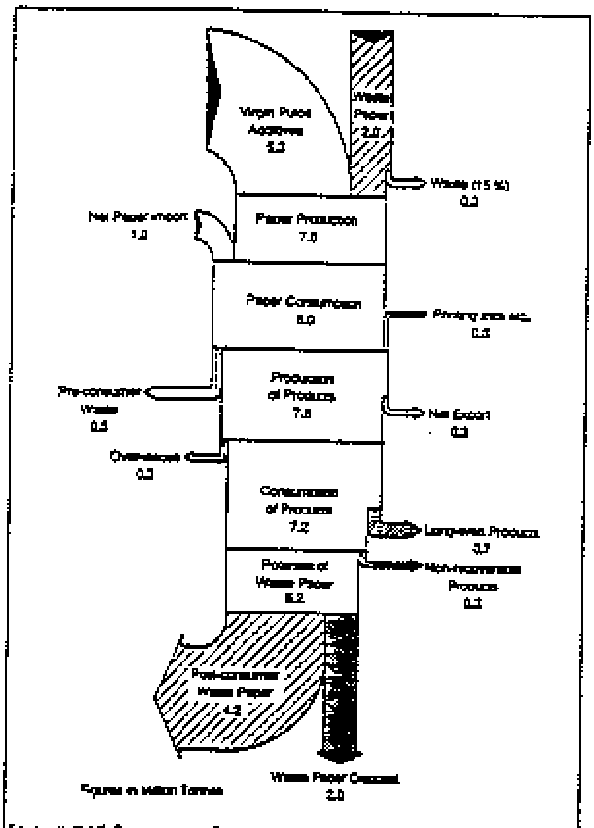
the consumption of paper products (2.9 million tonnes) is non-recoverable waste. This volume 'disappears' in the sewerage system and as long-lived products or in private households and in small commercial enterprises as burnt paper, apart from a certain volume of documents and books stored in archives and libraries. Out of this theoretical potential of 13.9 million tonnes only 12.4 million tonnes must be regarded as the available waste paper potential because 1.5 million tonnes are exported. Finally, a portion of 4.2 million tonnes of waste paper has to be disposed of, mainly by landfilling and partly by incineration in roughly 50 municipal incineration plants in Germany whereas only a marginal volume is treated by composting. The volume of waste paper utilized in the German paper industry amounts to 8.2 million tonnes.



Source: VDP, Bonn (1995)

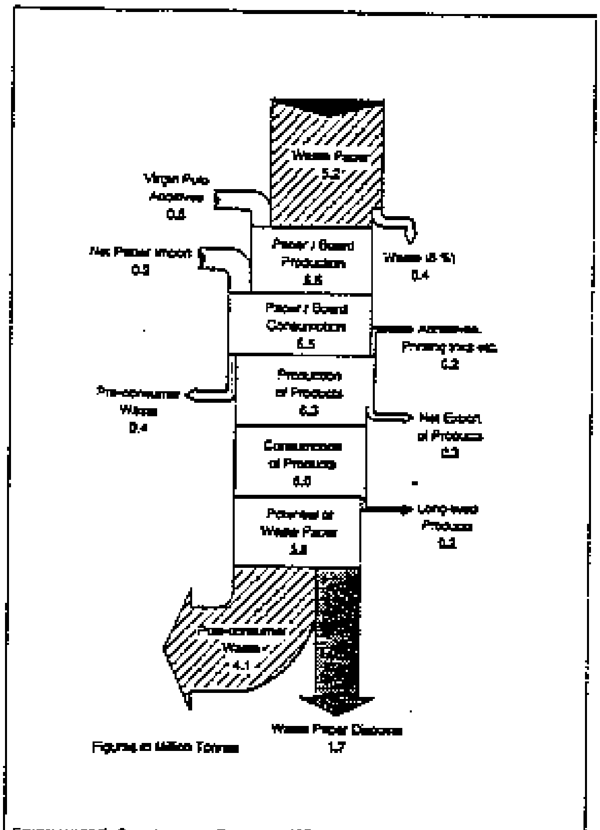
Fig. 1.2.-16 Paper and Waste Paper Balance in Germany (1994) IfP 1995

Fig 1.2.-17 to Fig. 1.2.-20 show the mass balances of graphic papers, packaging papers and board, sanitary papers and specialty papers from cradle (domestic paper production and paper net import) to grave (recycling and final disposal). The volume of pre-consumer waste totals 1.2 million tonnes with reference to these four sectors of graphic papers/printed matter, packaging paper and board/packaging material, sanitary papers/sanitary products and specialty papers/specialty products. The following volumes of pre-consumer and post-consumer waste are generated by the individual groups of domestically produced and consumed products made of paper and board.



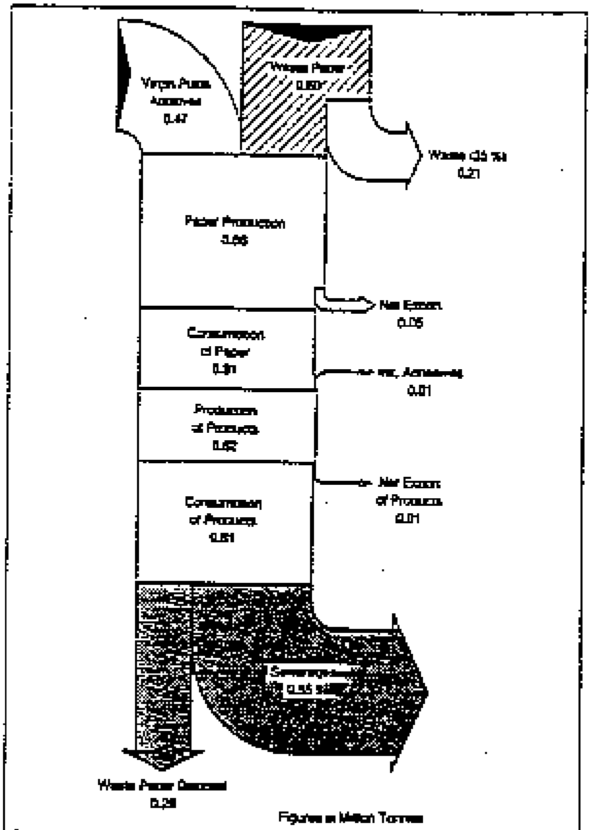
Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 1.2-17 Mass Balance of Graphic Papers (1994) IfP 1995



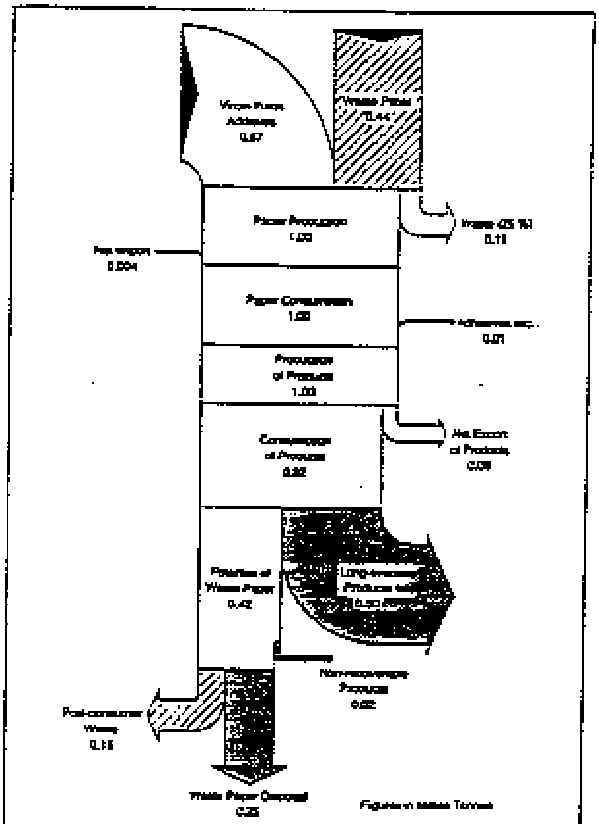
Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 1.2-18 Mass Balance of Packaging Paper and Board (1994) IfP 1995



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 1.2-19 Mass Balance of Sanitary Papers (1994) IfP 1995



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 1.2-20 Mass Balance of Specialty Papers (1994) IfP 1995

Paper Grades/Products	Pre-consumer Waste	Post-consumer Waste
Graphic papers/printed matter	0.8 million tonnes	4.2 million tonnes
Packaging paper and board/ Packaging materials	0.4 million tonnes	4.1 million tonnes
Sanitary papers/products	0 million tonnes	0 million tonnes
Specialty papers/products	0 million tonnes	0.15 million tonnes
Total	**1.2 million tonnes**	**8.45 million tonnes**

The recovery rate of pre-consumer waste approaches 100 percent even in the case of waste paper grades difficult to process as, for example, composite materials such as PE- and/or aluminium-coated liquid board generated as cuttings and further broke in converting plants.

The recovery rate of post-consumer graphic paper reached 52 percent and in total 62 percent including pre-consumer waste. In the case of packaging paper and board the corresponding figures are 73 percent with respect to post-consumer waste and 80 percent with reference to both pre-consumer and post-consumer waste.

The partly exploited waste paper sources are offices and private households whereas the recovery of waste paper from supermarkets and small commercial enterprises reached almost 100 percent. Due to the Packaging Ordinance, transport packaging material must be recovered completely. In the case of sales packaging consumed by the end-consumers. 60 percent must be recovered. controlled by DSD. Printed matter is also recovered by 100 percent in the case of over-issues (news, magazines, catalogues etc.).

Printed matter consumed by private households is collected to a high extent thanks to the blue bins in each household, containers located on public places and by collection actions of private organisations, focusing on collection of bundled news and magazines.

- Total per-capita waste paper volume recovered: 120 kg/cap
  (= 59 percent recovery rate)
- Average per-capita waste paper volume recovered in households and small commercial enterprises: 60 kg/cap
- Pre-consumer waste recovered corresponds to a per-capita waste paper volume of 15 kg/cap.
- The average per-capita waste paper volume collected in distribution and offices: 45 kg/cap.

1.2.3.2 *Collection of Household Waste*

The most important prerequisites for intensified recycling and manufacturing of competitive and high-quality recycled papers are effective and sound collection systems for both pre-consumer and post-consumer waste. For a long time paper waste has been most professionally recovered, up to almost 100 percent, from printing shops, corrugated board industry, folding boxboard plants or distribution (e.g. supermarkets and retailers). A further, but not completely exploited recovery source is to be found in offices as well as private households and commercial enterprise.

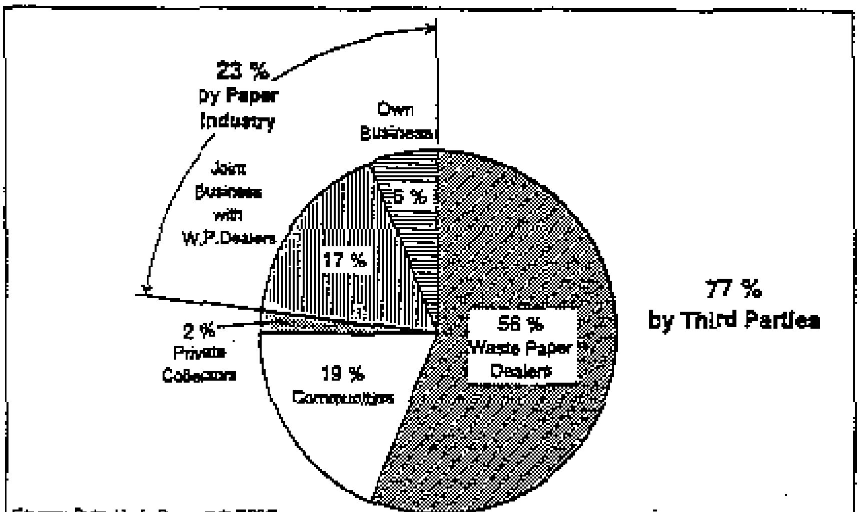
In the nineties the recovery of any waste of private households was significantly driven by legal requirements. Nowadays, Germany is totally covered with a network of different collection systems which are classified into pick-up systems (blue bin in almost each household and small commercial enterprise) and carry systems which comprise mono- or multi-component containers located on public places and municipal collection centers.

1.2.3.3 *Management of Collection of Household Waste*

Based on an inquiry in 1994 the following structure of waste paper collection with reference to pre-consumer as well as post-consumer waste paper was established (Fig. 1.2.-21): More than three quarters of the total waste paper volume is collected by third parties, dominated by traditional waste paper dealers, followed by local government organizations (communities) and by private collectors such as sports clubs or charitable organizations. One quarter of the waste paper volume is collected under the direct or indirect responsibility of the paper industry because some paper companies are running a joint business in cooperation with waste paper dealers.

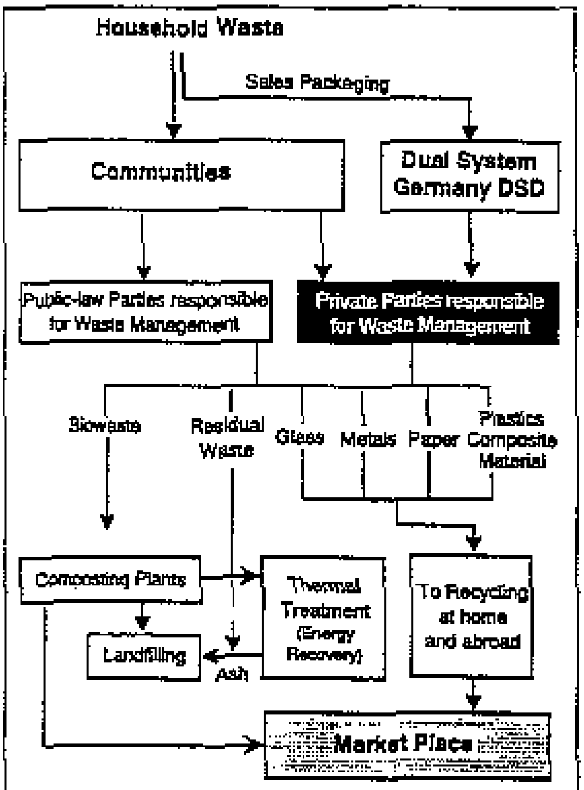
With respect to collection and recovery of household waste, which covers only a part of the above mentioned structure, Fig. 1.2.-22 shows the scheme of the municipal waste management system in Germany. It is called dual system because of the separated responsibilities of communities and the independent private organisation Dual System Germany (DSD). Household waste consists of recyclable material (paper and board, plastics, composite materials, glass, metals), biowaste for composting and finally of so-called residual waste which should be free of the mentioned recyclable and compostible components. Stimulated by the Packaging

Ordinance, the Dual System Germany DSD, financed by the Green Dot licence fees, is responsible for the recovery of sales packaging.



Source: Putz, H.-J., Darmstadt (1996)

Fig. 1.2-21 Waste Paper Collection in Germany (1994) IfP 1995



Source: Informationszentrale der Elektrizitätswirtschaft, Frankfurt (1994)

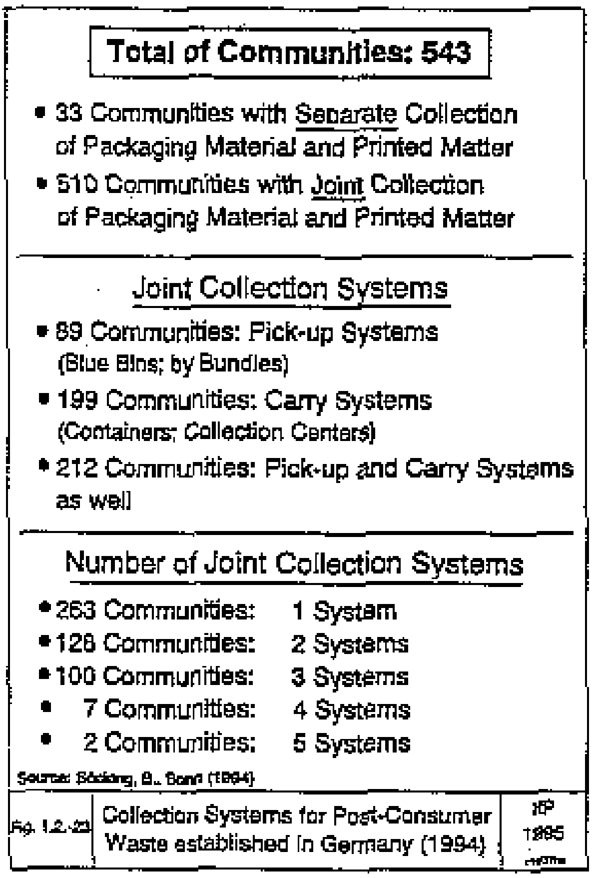
Fig. 1.2-22 Scheme of the Dual Waste Management (Paper refers to Post-consumer Waste) IfP 1995

Sales packaging is collected separately from each household and small commercial enterprises by contractors of DSD to be sorted and partly pressed to bales by waste paper dealers and waste management companies. Taking into account that, in most cases, packaging material, based on paper and board, is collected together with printed matter, it follows that DSD and its contractors are also indirectly responsible for that category of paper products such as news or magazines. However, DSD is not charging for printed matter. Therefore, waste paper dealers and other contractors do not get paid anything for that part of the collected waste paper volume by DSD, but by the local communities.

Local government organizations (communities) are in the first place responsible for compostible biowaste as well as residual waste. Residual waste should be totally treated by incineration, followed by landfilling of the ash of the municipal waste incineration plants. The residues of composting are either burnt in municipal incineration plants or (still) dumped on landfills which also happens with a part of residual household waste.

The domestic manufacturers of packaging paper and board are interested in non-separated, mixed waste paper from private households and they promote therefore joint collection systems. The producers of printing and sanitary papers, being interested in a clean fraction of white waste paper, favour separate collection systems for household waste paper which deliver two categories: (white) printed matter and (brown) packaging material. These differing collection approaches are affecting the quality as well as the costs of the recovered paper which must be carefully sorted in the case of joint collection of both waste paper categories. In Germany most of the waste paper is collected with one bin per household or multi-component containers. These procedures result in mixed waste paper (packaging material and printed matter) whereas only 33 communities out of 543 have established collection systems for separate recovery of printed matter and packaging material. As shown in Fig. 1.2.-23 the majority of communities are equipped either with carry systems or with pick-up as well as carry systems for joint collection. Apart from density and social structure of the local population, the costs and effectiveness of waste paper recovery are driven by the collection system.

The costs of separate collection of printed matter have been analyzed in three differently populated areas with reference to various collection procedures such as mono-bins (joint collection), two-component bins (separate collection), by bundles (news, magazines) and by containers (Table 1.2.-2). Collection costs comprise the costs for bins or containers (including their maintenance and eventually fees for their placement), costs for transportation from the pick-up place to a sorting or pressing enterprise, including the corresponding personnel and overhead costs. The level of the collection costs differs significantly but it would definitely be more costly if a subsidized organisation would be responsible for that business.



Total of Communities: 543

- 33 Communities with Separate Collection of Packaging Material and Printed Matter
- 510 Communities with Joint Collection of Packaging Material and Printed Matter

Joint Collection Systems

- 89 Communities: Pick-up Systems (Blue Bins; by Bundles)
- 199 Communities: Carry Systems (Containers; Collection Centers)
- 212 Communities: Pick-up and Carry Systems as well

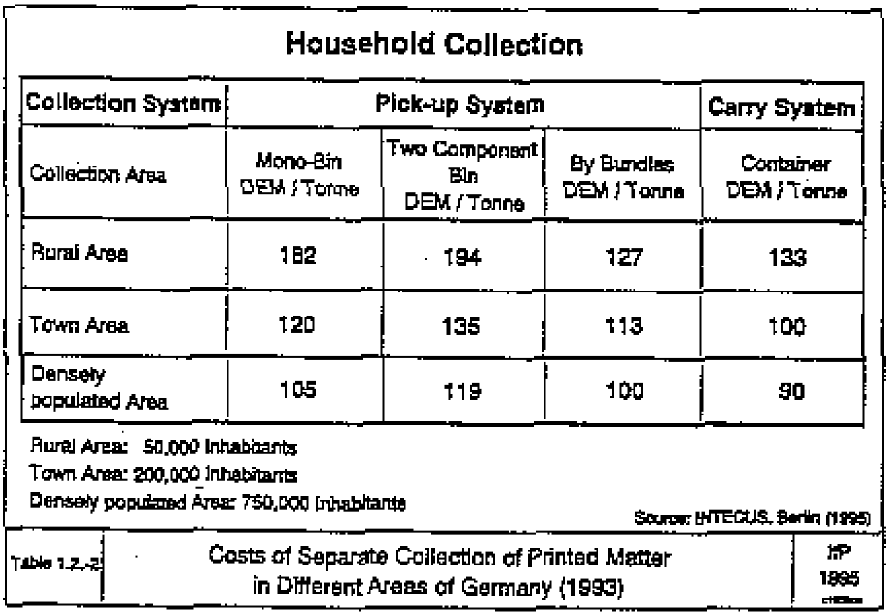
Number of Joint Collection Systems

- 263 Communities: 1 System
- 128 Communities: 2 Systems
- 100 Communities: 3 Systems
- 7 Communities: 4 Systems
- 2 Communities: 5 Systems

Source: Böcking, B., Bonn (1994)

Fig. 1.2-23 Collection Systems for Post-Consumer Waste established in Germany (1994)

IfP 1995



Household Collection

Collection System	Pick-up System			Carry System
Collection Area	Mono-Bin DEM / Tonne	Two Component Bin DEM / Tonne	By Bundles DEM / Tonne	Container DEM / Tonne
Rural Area	182	194	127	133
Town Area	120	135	113	100
Densely populated Area	105	119	100	90

Rural Area: 50,000 Inhabitants
Town Area: 200,000 Inhabitants
Densely populated Area: 750,000 Inhabitants

Source: INTECUS, Berlin (1995)

Table 1.2-2 Costs of Separate Collection of Printed Matter in Different Areas of Germany (1993)

IfP 1995

1.2.4 *Waste Paper Grades*

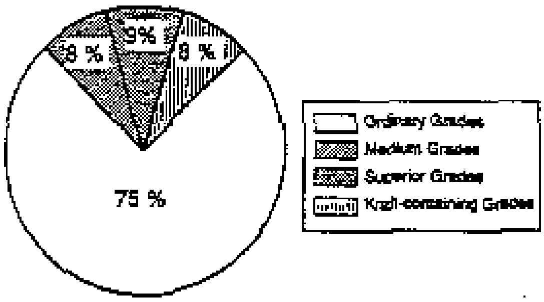
The total volume of collected and utilized waste paper is divided into 40 individual grades according to the **German Waste Paper List**, issued by the Federation of the German Pulp and Paper Industry (VDP), Bonn, in cooperation with the former

Federation of Secondary Raw Materials (bvp) (Appendix 1). This German list affected the structure and specifications of the European Waste Paper List, issued by the European Federation of the Pulp and Paper Industry CEPAC in Brussels (nowadays named CEPI). Both lists are attached as an appendix. The codes of both lists are not identical despite the fact that the individual waste paper grades are identical in many cases. In this substudy reference is made to the German codes.

According to the German Waste Paper List the individual waste paper grades are classified into four categories:

- Ordinary waste paper grades
- Medium waste paper grades
- Superior waste paper grades
- Kraft-containing waste paper grades

Fig. 1.2.-24 shows that the dominant waste paper grades are ordinary grades with a volume of 75 percent (6.0 million tonnes), related to the total volume of the utilized waste paper, whereas the volume of the three other groups is in the range of eight percent to nine percent each.



1) Ordinary Grades:
- Mixed Waste
- Supermarket Waste
- Household Waste
(News and Magazines)

2) Medium Grades:
Wood-containing Grades
(e.g. Over-issued News)

3) Superior Grades:
Woodfree Grades
(e.g. White woodfree Shavings)

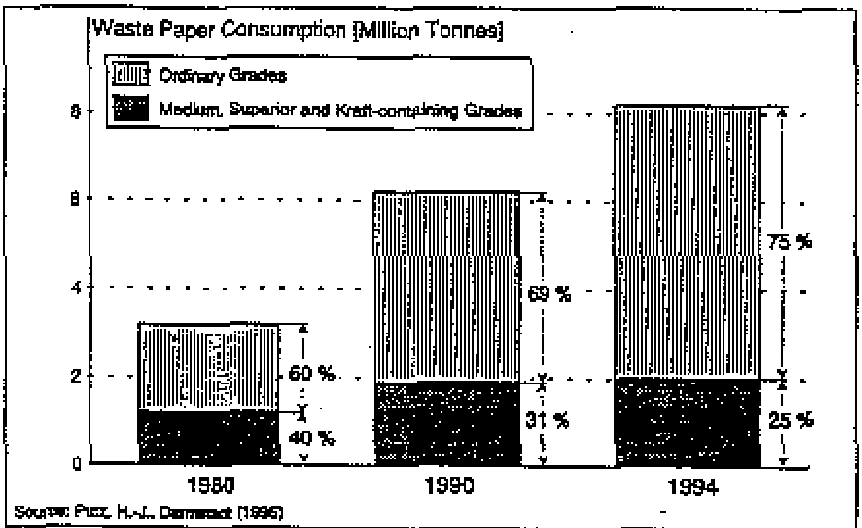
4) Kraft-containing Grades:
Brown Packaging Material
(e.g. old Corrugated Containers)

Source: VDP, Bonn (1995)

Fig. 1.2.-24	Waste Paper Grades in Germany (According to the German Waste Paper List)	HP 1995

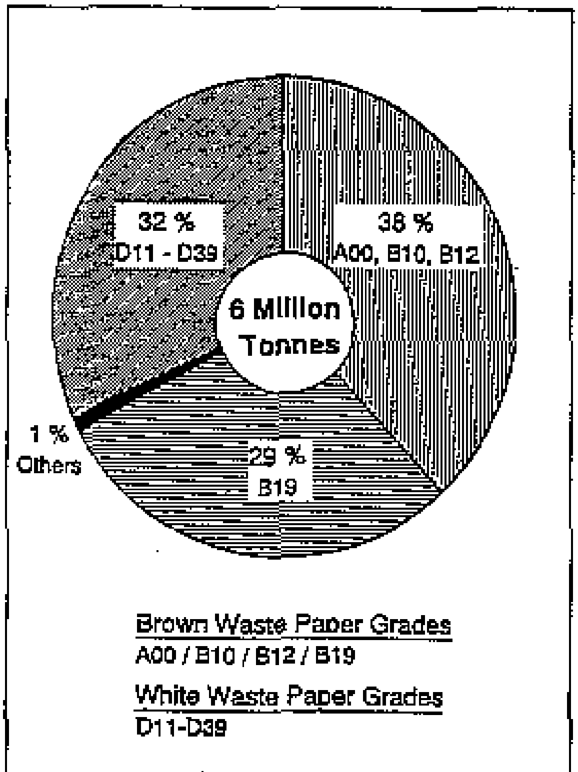
Fig. 1.2.-25 documents the total volume of utilized waste paper and its subdivision into ordinary grades on the one hand and the three other grades on the other hand.

Due to intensified recovery efforts the portion of the ordinary grades increased continuously in the nineties, compared with 1980. This indicates that the three other waste paper grades are almost totally recovered. They refer to pre-consumer waste in the first place and also to post-consumer waste with the exception of office waste. Significant waste paper volumes which will contribute to an increased volume of recovered paper are household waste belonging to the group of ordinary grades.



Source: Putz, H.-J., Darmstadt (1996)

Fig. 1.2.-25 Grade-specific Waste Paper Consumption in Germany IfP 1995



Source: Putz, H.-J., Darmstadt (1996)

Fig. 1.2.-26 Consumption of Ordinary Waste Paper Grades (1994) IfP 1995

1.2.5 Waste Paper Sorting

Sorting of waste paper aims partly at the removal of impurities (non-paper components) in the case of ordinary grades (B10, B12, B19) and partly at the separation of household waste into brown (packaging) and white (graphic) waste paper categories (D11-D39). Pre-consumer waste requires no sorting. Sorting takes place manually by distributing ordinary waste paper on a floor or on a belt. Mechanical sorting systems with on-line sensoring (image analysis) are under development.

Manual sorting of various waste paper grades is performed in a different manner according to the waste paper grades. Apart from unsorted mixed waste (A00), the dominating volume of mixed waste (B10, B12) is regarded as sorted grades which, however, means nothing else but non-selective removal of a certain portion of unwanted matter in terms of non-paper components and paper/board detrimental to paper production. If any sorting takes place, it is aiming at the selective elimination of higher value components such as corrugated containers. This is also the case with respect to supermarket waste (B19). Neither sorted mixed waste nor supermarket waste are manually separated into their main components such as packaging material and printed matter. The part of the paper industry which manufactures packaging paper (corrugating medium, testliner) and board (folding boxboard, grey board) is not interested in such a separation because they benefit from the portion of printed matter with its younger fiber generations and also from its mechanical pulp content which improves particularly bending stiffness (inner layer of folding box board and grey board).

An intensive manual sorting takes place in the case of waste paper for deinked pulp (DIP), which is mainly generated by joint household collection of packaging material and printed matter. The total volume of this jointly collected waste paper must be separated as perfectly as possible into brown and white paper components. This sorting is conducted either by waste paper dealers or by the paper industry applying belt systems. The advantage of this sorting procedure is the fact that, apart from the required separation into both fractions, elimination of unwanted matter (impurities) is performed. Despite this manual sorting, the white paper component, which consists of news, magazines, catalogues, brochures, inserts, and direct mail, a residual portion of brown components (approx. three percent to five percent board and pieces of corrugated containers) is still present in the white paper fraction. This residual portion of brown paper and board components affects optical properties

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Office waste, which is often shredded, is not sorted, although sorting would be a necessity taking into account that office waste increasingly becomes a blend of (white) woodfree and (grey) wood-containing writing and copy papers or computer printouts based on recycled graphic paper.

The volume of fairly well sorted waste paper totals 2.3 million tonnes in the case of wood-containing grades for DIP (D11 - D39). The volume of so-called sorted mixed waste totals approx. 4 million tonnes (B10, B12, B19).

1.3 Waste Paper Processing Technology

1.3.1 Physical and Chemical Characteristics of Waste Paper and Recycled Fibers

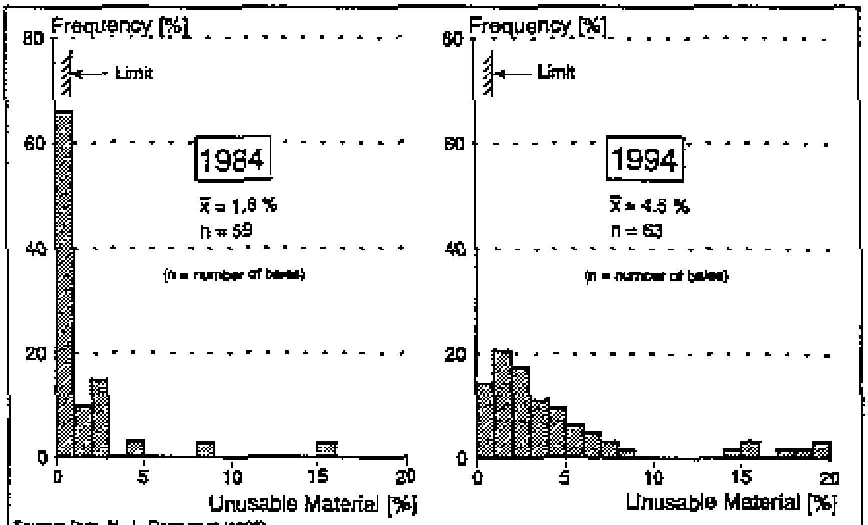
Unlike virgin pulps which are regularly analysed and evaluated with respect to their mechanical, optical and chemical properties by their manufacturers as well as by their users (paper mills), waste paper is not characterized by waste paper suppliers and only to a minor extent by paper mills, for example, as moisture or ash content. Considering this, only limited information is available on the characteristics of various waste paper grades. Therefore, in the eighties physical characteristics of waste paper were analysed for the first time in a statistically and systematically sound manner by the Department of Paper Science and Technology (IfP) in Darmstadt. In 1994 corresponding investigations were repeated and extended on waste paper for deinked pulp (DIP) from household collections. Various characteristics of such waste paper grades, which amount to almost 75 percent of the total waste paper volume processed, are presented in the following with reference to sorted mixed waste (B10, B12), supermarket waste (B19) and wood-containing waste paper (household waste) in terms of printed matter (news, magazines, brochures, catalogues, directories, inserts and direct mail etc.) for DIP (D21-D39).

1.3.1.1 Waste Paper Composition

Apart from mechanical, optical and chemical characteristics, further parameters are relevant in the case of waste paper, such as content of impurities (unusable material), moisture and ash content or composition in terms of the original paper and board grades present in waste paper grades, which are themselves based on multi-components, such as mixed waste, supermarket waste or household waste paper for DIP. The German Waste Paper List limits the proportion of unusable material of some waste paper grades. The specified amount of such matter is almost the only numerical reference in the case of waste paper. Unusable material comprises the following categories:

- Non-paper components: They consist of foreign matter, such as metal, glass, plastics, textile, wood, rubber or stones and sand.
- Paper and board detrimental to production: This category comprises treated paper and board which would render harmful fragments in production, such as waxed, bitumenised or wet-strength paper, carbon paper or vegetable parchment.

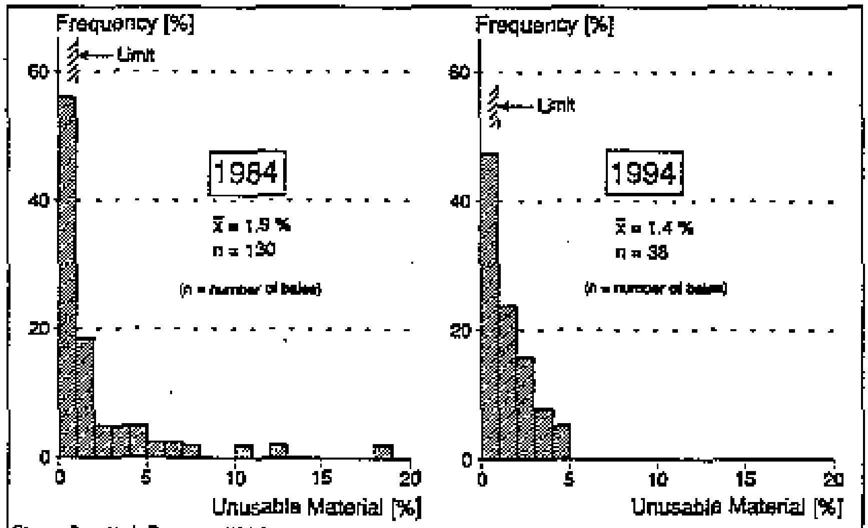
In sorted mixed waste paper (B10, B12) and supermarket waste (B19) the limit of such materials is - unrealistically - set at one percent. Fig. 1.3.-1 shows that for mixed waste paper (B12) the average amount of such impurities increased from 1.6 percent to 4.5 percent between 1984 and 1994 - as shown in the samples taken from a certain number of bales. This increase of the proportion of impurities results from the fact that the waste paper recovery systems have been significantly modified by the establishment of DSD in the early nineties. In collecting post-consumer waste by containers on public places and waste paper bins of private households - which was not common in 1984 - end-consumers are not sufficiently experienced and careful to keep unusable material out of the collection systems. The following manual sorting is not in a position to attain a level of cleanness which would be desirable from the point of view of the waste paper processing industry. As shown by the frequency diagram, in 1994 only 16 percent of the bales analysed fulfil the requirement in respect to unusable material - in contrast to 65 percent of the bales investigated in 1984. However, one must be aware that the content of unwanted matter is also affected by the balance between supply and demand of waste paper and furthermore by the management of individual waste paper suppliers (independent dealers or joint companies of dealers and paper firms).



Source: Putz, H.-J., Darmstadt (1996)

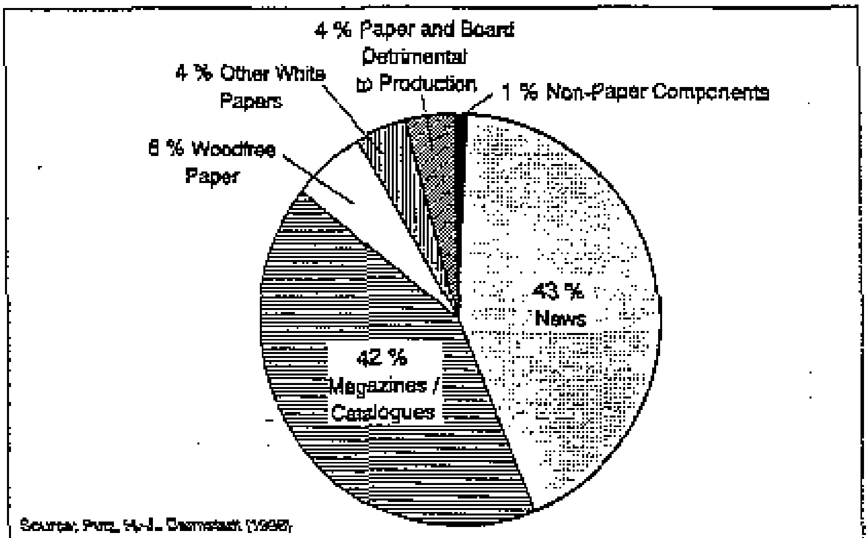
Fig. 1.3.-1	Unusable Material of Mixed Waste Paper (B12)	IfP 1996

In contrast to sorted mixed waste the average content of unusable material of supermarket waste (B19) slightly decreased from 1.9 percent to 1.4 percent during the previous ten years (Fig. 1.3.-2). However, the proportion of bales which fulfil the requirement decreased to a certain extent. This makes evident that intensified collection of waste paper from distribution centers (supermarkets and retailers) leads to an increasing volume of unusable material which is not sufficiently controlled by the following manual sorting - if waste paper dealers and other organizations really perform a treatment which can be regarded as sorting in terms of removal of impurities.



Source: Putz, H.-J., Darmstadt (1996)

Fig. 1.3.-2	Unusable Material of Supermarket Waste (B19)	IfP 1996



Source: Putz, H.-J., Darmstadt (1995)

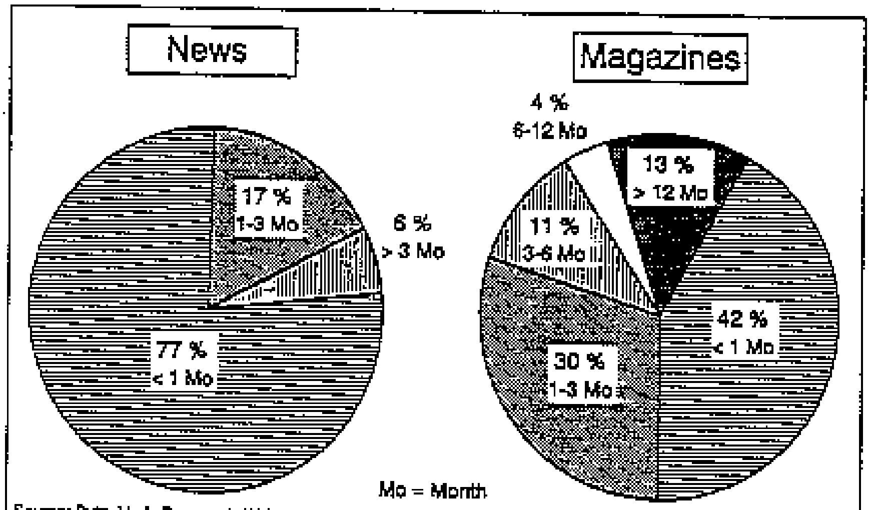
Fig. 1.3.-3 Composition of Waste Paper for DIP (1994)

HP 1995

In waste paper for deinked pulp, mainly received from private households and small commercial enterprises, the amount of non-paper components such as metal or glass is on average below the set limit of one percent (Fig. 1.3.-3). The waste paper material detrimental to production consists primarily of brown board grades such as folding boxboard or (pieces of) corrugated containers. The proportion of brown board and other packaging material totals three percent, whereas wet-strength papers (e.g. kitchen towels) and intensively dyed papers amount to one percent. This proportion of five percent unusable material is definitely too high.

Waste paper for deinking comprises primarily wood-containing paper grades. The composition of waste paper analysed at various locations in Germany was 43 percent news, 42 percent pamphlets, magazines and catalogues, six percent woodfree paper grades, four percent other white paper grades (e.g. recycled graphic paper such as copy paper) and five percent unusable material as described. This showed that the composition of waste paper for DIP does not fulfil the specification of the waste paper grades D31 and D39, which should contain at least 60 percent news.

Thanks to the high recovery and utilization rates of waste paper in Germany - including household waste - the average age of wood-containing waste paper for DIP is relatively low (Fig. 1.3.-4). The time interval between printing of news or magazines and waste paper supply to paper mills is identified as the age of waste paper. For example, 77 percent of news is not older than one month and only six percent is older than three months when entering the paper mills. Pamphlets and magazines are published at weekly or monthly intervals. Therefore, it is not surprising that they are generally older. However, 42 percent of pamphlets and magazines are less than one month old and 83 percent are younger than six months. For the benefit of a good deinkability, the waste paper for DIP is quite young particularly in the case of offset printed news because offset inks significantly affect the deinkability due to their natural ageing.



Source: Putz, H.-J., Darmstadt (1996)

Fig. 1.3.-4. Age Distribution of News and Magazines in Waste Paper for DIP (1994) IfP 1995

The proportion of graphic waste paper components of brown waste paper grades were determined, with on average:

- 75 % graphic paper in sorted original mixed waste (B10)
- 69 % graphic paper in sorted mixed waste (B12)
- 14 % graphic paper in supermarket waste (B19).

In the case of B10 no specification is given for the proportion of graphic papers according to the German Waste Paper List, whereas B12 should contain less than 40 percent graphic paper. In reality the proportion is almost twice the permissible level. B19 should contain at least 70 percent corrugated containers and no graphic paper products. Neither criterion is met by the waste paper grade B19. The share of corrugated containers is lower than specified and the proportion of graphic papers is 14 percent on average.

According to these findings it must be concluded, that the composition of the waste paper grades investigated does not correspond to the specifications of the Waste Paper Lists (German as well as European Waste Paper List) with respect to the permitted content of impurities and to the proportion of graphic papers in case of supermarket waste (B19) and sorted mixed waste (B12). Furthermore, waste paper for DIP does not contain at least 60 percent news as specified.

1.3.1.2 Moisture Content of Waste Paper

One of the often underestimated waste paper characteristics is the moisture content. According to the German Waste Paper List the moisture content of individual waste paper grades delivered must correspond to set target figures of agreements or contracts between waste paper suppliers and paper mills. Depending on the waste paper grade, the moisture content must be in a range between seven percent and twelve percent. Table 1.3.-1 shows the average moisture content of various waste paper grades, gravimetrically determined in 1984. The sampling procedure from waste paper bales was developed by IfP in Darmstadt based on cores taken out of bales by means of a motor-driven core drilling device.

Table 1.3.-1: Moisture Content of Different Waste Paper Grades (1984)

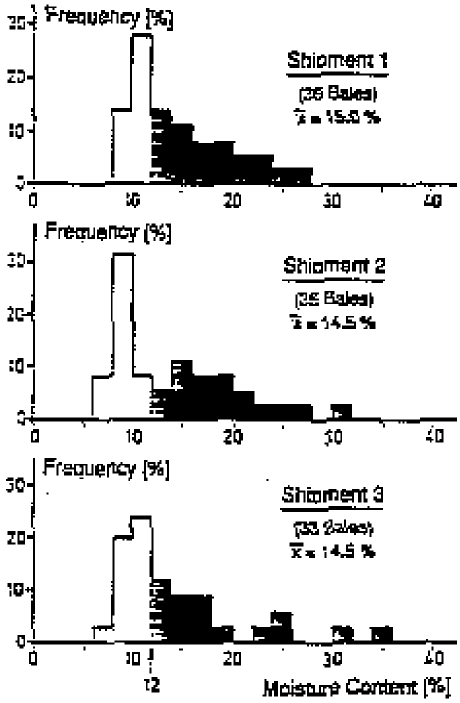
Waste Paper Grade	Average Moisture Content %
Mixed waste paper (B12)	11.5
Supermarket waste (B19)	12.5
Pamphlets and magazines (D21)	6.5
Over-issued news (E12)	8.5
Wood-containing white shavings (O14)	6.0
Woodfree white shavings, uncoated (R12)	6.5
Corrugated containers II (W52)	9.5
Corrugated containers I (W62)	11.0

Source: Institut für Papierfabrikation/Darmstadt (1995)

Investigations repeated in 1994 for the most important (by volume) waste paper grades resulted in the following moisture contents:

- Mixed waste paper (B10): 10.0 %
- Mixed waste paper (B12): 12.0 %
- Supermarket waste (B19): 10.5 %
- Waste paper for DIP: 9.5 %

Comparisons are only possible in the case of mixed waste (B12) and supermarket waste (B19). The moisture content did not alter significantly. The figures shown are representative for individual shipments, but not for total seasons with different weather conditions which can influence the moisture content of waste paper during collection as well as during outdoors storage. Compared with the small differences of the average moisture contents documented, the frequency based on individual figures, is more important. According to Fig. 1.3.-5 the moisture content is not normally distributed, as illustrated by three shipments of supermarket waste (B19). The moisture content of individual waste paper bales can differ significantly from the average of the total shipment. A moisture content of more than 20 percent was not uncommon in the case of single shipments of more than 30 bales (approx. 20 tonnes). These findings of 1984 were also confirmed by the investigation in 1994.



Source: Institut für Papierfabrikation, Darmstadt (1985)

Fig.1.3.-5 Frequency of Moisture Content of Supermarket Waste (B19)

IfP 1995

1.3.1.3 *Ash Content of Waste Paper*

The ash content was determined from homogenized slushed pulp samples at a combustion temperature of 975 °C according to DIN 54371 in the previous investigations and at 575 °C in 1994. The higher combustion temperature was then common for the determination of the ash content of paper. The figures so obtained do not reflect the reality in terms of the filler and pigment content due to calcium carbonate decomposition (44 percent loss by weight because of CO_2 released) at the high combustion temperature. To allow for the increasing content of calcium carbonate the lower temperature was chosen for the investigations in 1994. Averages of the ash contents are quoted in Table 1.3.-2.

The steadily increasing utilization of fillers and pigments in paper production is indicated by the increased ash content of mixed waste (B12) and supermarket waste (B19) compared to 1984. Original mixed waste paper (B10) has an even higher ash content than B12 also affected by its higher proportion of graphic papers.

Table 1.3.-2: **Ash Content of Different Waste Paper Grades**

Waste Paper Grade	Ash Content (1984: 975 °C) %	Ash Content (1994: 575 °C) %
Original mixed waste (B10)	-----	18.8
Mixed waste (B12)	14.0	17.3
Supermarket waste (B19)	9.5	10.6
Waste paper for DIP (D 31)	-----	19.8
Over-issued news (E12)	8.5	-----
Wood-containing white shavings (O14)	22.5	-----
Woodfree white shavings, uncoated (R12)	7.5	-----
Corrugated containers II (W52)	6.0	-----
Corrugated containers I (W62)	3.0	-----

Source: Institut für Papierfabrikation/Darmstadt (1985, 1994)

1.3.1.4 Physical Characteristics of Recycled Fibers

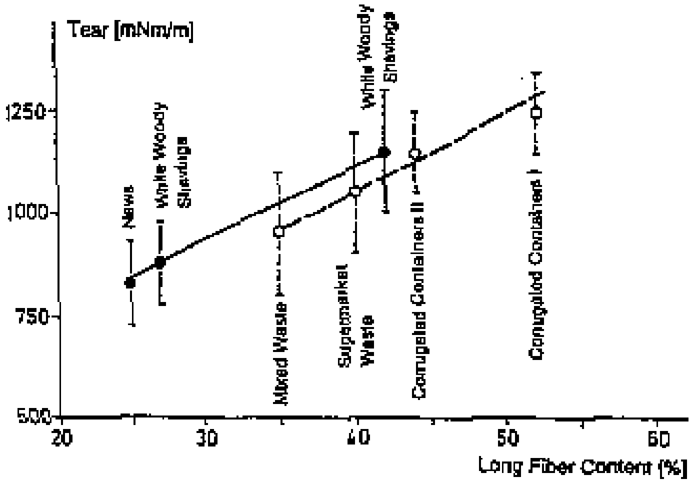
1.3.1.4.1 Pulp Characteristics

Pulp characteristics of recycled fibers provide - amongst others - information about the fiber-to-fiber bonding potential developed by the refining of secondary fiber stock. Pulp characteristics of recycled fibers, particularly in terms of freeness, are affected by slushing conditions as well as by the fines content of the white water used. The figures presented below are obtained in applying the same processing procedure (disintegration on labscale in clear water) to the waste paper samples investigated.

Differing procedures are employed, however, when sampling baled and unbaled waste paper. For the sampling of waste paper bales (all waste paper grades with the exception of waste paper for DIP) the IfP core drilling device was used. By means of this instrument waste paper cores are drilled out of bales having a weight between 300 g and 700 g each, depending on waste paper grade and density of the bale. After quantitative and selective manual removal of unusable material (particularly non-paper components) the waste paper samples were used for further processing. Each sample was homogenized in an Escher Wyss laboratory pulper for 30 seconds in a volume of 12 liters of taps water. Two to four slushed samples from each bale were then mixed. Final defibration of a part of the blended samples was subsequently performed in a laboratory disintegrator (volume: two liters) for 25 minutes at 1.2 percent consistency with tap water separating residual flakes into individual fibers. Optical measurements are based on filter pads whereas mechanical properties are determined by handsheets of a basis weight of 80 g/m².

Unbaled waste paper for DIP was treated in a different manner. For one sample 30 kg of waste paper was homogenized in a low consistency (LC) pilot plant pulper (1 m³) for ten minutes at four percent consistency. Final slushing of a sample of twelve liters was carried out in an Escher Wyss laboratory pulper at four percent consistency for 25 minutes.

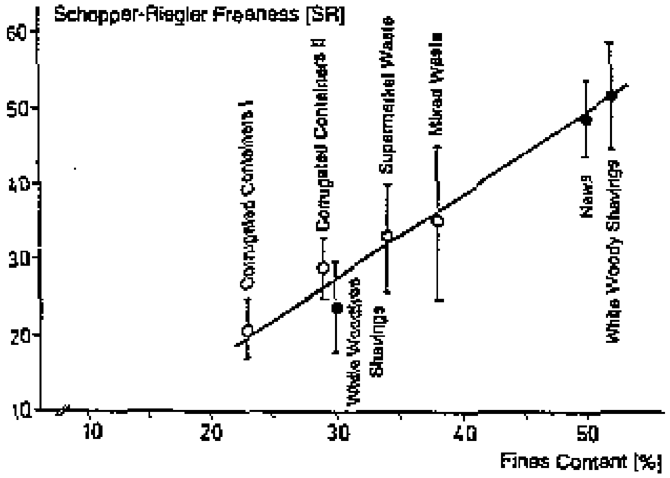
Correlations between strength properties and long fiber content had already been established for baled waste paper grades in the eighties. The higher the long fiber content the higher becomes tear (Fig. 1.3.-6). A further correlation refers to fines content versus Schopper-Riegler freeness (Fig. 1.3.-7). With increasing fines content Schopper-Riegler freeness increases and Canadian Standard Freeness decreases, respectively.



Source: Institut für Papierfabrikation, Darmstadt (1985)

Fig. 1.3.-6 Relationship between Tear and Long Fiber Content of Different Waste Paper Grades

IfP 1995



Source: Institut für Papierfabrikation, Darmstadt (1985)

Fig. 1.3.-7 Relationship between Schopper-Riegler Freeness and Fines Content of Different Waste Paper Grades

IfP 1995

Table 1.3.-3 compares the characteristics of mixed waste paper (B12) and supermarket waste (B19) identified in 1984 and 1994. Intensified recycling leads to a higher Schopper-Riegler freeness and fines content of mixed waste (B12). Because of raised brightness (1984: 38 % / 1994: 44 %) a higher proportion of graphic papers must be assumed in that year, which was at 69 percent in 1994, but not identified in 1984. In contrast, an insignificant decrease of Schopper-Riegler freeness and fines content was obtained for supermarket waste (B19). However, the pulp characteristics of supermarket waste are kept on the same level despite the fact that recovery and utilization rates increased during the decade concerned.

Table 1.3.-3: Pulp Characteristics of B12 and B19

Mixed Waste Paper (B12)		1984	1994
Schopper-Riegler freeness	SR	35	43
Long fiber content (Brecht-Holl)	%	35	33
Fines content (Brecht-Holl)	%	38	42
Supermarket Waste (B19)		**1984**	**1994**
Schopper-Riegler freeness	SR	33	31
Long fiber content (Brecht-Holl)	%	40	44
Fines content (Brecht-Holl)	%	34	31

Source: Institut für Papierfabrikation/Darmstadt (1985, 1994)

The present figures of the characteristics of waste paper for DIP cannot be compared with results of 1984 because this grade was insignificant in that time compared with other waste paper grades of a high volume. Characteristics of waste paper for deinking are shown in Table 1.3.-4.

Table 1.3.-4: Pulp Characteristics of Waste Paper for DIP

Waste Paper (from households) for DIP		1994
Schopper-Riegler freeness	SR	60
Long fiber content (R14 + R30)	%	26
Fines content (D200)	%	40

Source: Institut für Papierfabrikation/Darmstadt (1995)

1.3.1.4.2 Mechanical Characteristics

The results of the investigations carried out in 1984 are shown in Table 1.3.-5 for disintegrated but unbeaten recycled pulp. Almost identical mechanical properties were found for similar waste paper grades, for example mixed waste paper (B 12) and supermarket waste (B 19). Against this background, the individual waste paper grades presented can be classified into one of the following groups:

- Group 1 = Fair strength characteristics:
  corrugated containers I and II, woodfree shavings
- Group 2 = Medium strength characteristics:
  mixed waste paper, supermarket waste
  (because of woody graphic papers being present)

- Group 3 = Poor strength characteristics:
  news, wood-containing shavings
  (because of a high mechanical pulp content).

A differentiation of the strength characteristics depending on long fiber content can be seen when dividing the waste paper grades mentioned into their main utilization groups in the fields of graphic papers and packaging papers and board. Fig. 1.3.-6 documents this with reference to tear. Taking the standard deviation into account it is not surprising that results of neighbouring waste paper grades overlap, as, for example, supermarket waste and mixed waste. Similar trends of the results were confirmed by the investigation performed 1994.

Table 1.3-5: Characteristics of 80 g/m² Handsheets (1984)
(Unbeaten Recycled Fibers, Average and Standard Deviation)

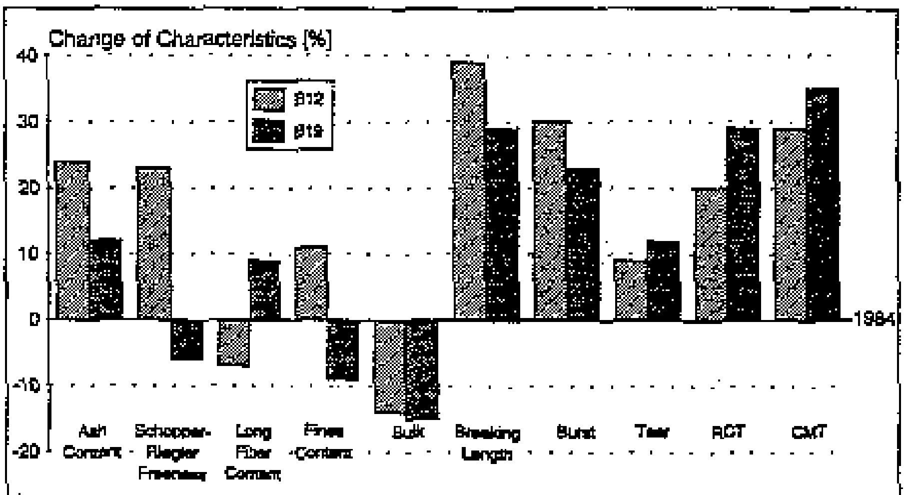
Waste Paper Grade	Breaking Length km	Burst kPa	Tear mNm/m	Bending Stiffness N*mm	Ply Bond Strength kN/m	ISO Brightness %
Mixed Waste Paper (B12)	2,4 ± 0,3	125 ±10	1000 ± 100	0,32	4.1 ± 0.2	42 ± 8
Supermarket Waste (B19)	2.5 ± 0.2	134 ± 12	1000 ± 70	0.35	3.6 ± 0.2	32 ± 5
Corrugated Containers I (W62)	2.8 ± 0.3	155 ± 15	1200 ± 50	0.37	3.8 ± 0.3	24 ± 1
Corrugated Containers II (W52)	3,0 ± 0.3	175 ± 19	1100 ± 60	0.34	3.8 ± 0.1	26 ± 2
News (E12)	2.2 ± 0.2	105 ± 9	800 ± 50	—	—	44 ± 1
White Woody Shavings (014)	2.4 ± 0.3	120 ± 18	900 ± 90	—	—	57 ± 3
White Woodfree Shavings (R12)	2.9 ± 0.2	165 ± 17	1100 ± 100	—	—	86 ± 1

Source: Institut für Papierfabrikation/Darmstadt (1985)

Fig. 1.3.-8 shows the differences (as percentage) of the results of several characteristics of the waste paper grades B12 and B19 between 1984 and 1994, taking 1984 as reference. With respect to strength properties almost all characteristics have been improved for both waste paper grades, by between 10 percent and 40 percent. The improvement of strength properties during the last decade is supposed to be affected by:

- Improved waste paper processing (in previous papermaking)
- Altered ratio between chemical and mechanical pulp content of wood-containing furnishes.

In the case of both waste paper grades, bulk has been reduced (by 15 percent) which impairs bending stiffness. The reduction of bulk is affected by increased ash content, reduced mechanical pulp content and intensified recycling with multiple mechanical treatment of the fibers during previous papermaking.



Source: Putz, H.-J., Darmstadt (1995).

Fig. 1.3.-8 Change of Characteristics of Waste Paper Grades B12 and B19 between 1984 and 1994 (1984 as Reference) IfP 1995

The most important strength characteristics of handsheets made of waste paper for DIP are as follows (1994):

- Breaking length: 3.5 km
- Tear: 1,150 mNm/m

These figures are almost identical with those of mechanical pulp despite the fact that the (undeinked) recycled fibers have an ash content of 22 percent. Breaking length and tear are superior to stone groundwood (SGW) and are in the range of pressurized groundwood (PGW) and thermomechanical pulp (TMP).

The reason for the impressive strength characteristics of these recycled fibers assessed (with an ash content of 22 percent) is that chemical pulp is a substantial part of the waste paper for DIP utilized in Germany. By microscopic analysis of newsprint made of 100 percent recycled fibers and by modelling of newsprint furnishes based on waste paper, the fiber composition of waste paper for DIP from private households was quantified. The fiber composition of newsprint manufactured in Germany (1994) from 108 percent waste paper was as follows:

- 55 % mechanical pulp
- 34 % softwood chemical pulp
- 11 % hardwood chemical pulp

The chemical pulp content of DIP for newsprint being as high as 45 percent contributes to good strength characteristics of DIP based paper. The range of the characteristics of recycled fibers commercially deinked by pre- and post-flotation is shown in Fig. 1.3.-9. Ash content and strength characteristics of handsheets made of commercially deinked pulp are in agreement with the corresponding results of laboratory analyses of undeinked samples confirming the quality of DIP.

Characteristics		Range
PULP PROPERTIES		
Schopper-Riegler	SR	54 - 61
R30 + R50	%	37 - 42
R100 + R200	%	21 - 25
D200	%	33 - 39
Ash Content (575 °C)	%	12 - 15
HANDSHEET PROPERTIES (60 g/m²)		
Ash Content (575 °C)	%	11 - 14
Density	g/cm³	0.54 - 0.57
Breaking Length	km	2.8 - 3.8
Tear	mJ/m	1050 - 1200
Burst	kPa	140 - 165
Porosity (Bendtsen)	ml/min	105 - 130
ISO Brightness	%	61 - 63
Luminance	-	67 - 70
Opacity	%	97 - 99
L*-Value	-	85 - 87
a*-Value	-	-1 - +1
b*-Value	-	5.0 - 7.5

DIP produced by double flotation from a waste paper mixture of about 50 % magazines and 50 % news

Fig. 1.3.-9 Characteristics of Commercial DIP (Samples taken at Machine Chest)

Source: Institut für Papierfabrikation, Darmstadt (1994)

IfP 1995

1.3.1.4.3 *Optical Characteristics*

Optical characteristics are highly relevant for such waste paper grades which are used for deinking and manufacturing of graphic papers as well as sanitary papers and further products (e.g. top layer of white lined board). For brown waste paper grades such as mixed waste (B12) and supermarket waste (B19) or old corrugated containers I and II (W52, W62) optical properties are almost irrelevant with the exception of appearance (e.g. freedom of specks) of packaging paper produced. This is a smaller problem than it is for graphic paper and sanitary paper, due to the darker background which lowers the visible contrast significantly. However, appearance of packaging paper and board is an increasingly significant marketing issue. Therefore, the pulp for top layers of testliner and board is commonly treated separately by dispersion to reduce the size of specks below the visible range.

On the other hand, excellent optical characteristics of DIP are essential. Besides brightness and luminance, opacity as well as colour shade are parameters which must fulfil stringent requirements. Fig. 1.3.-9 shows figures achieved from double flotated DIP based on household waste. ISO brightness of about 62 percent is common for this type of (wood-containing) DIP. By separate bleaching with hydrogen peroxide, sodium dithionite and formamidine sulfinic acid (FAS) brightness of about 68 percent can be attained for such wood-containing waste paper material. In the case of other waste paper grades (e.g. purely magazines) brightness can be further improved.

Additionally to brightness and colour shade, cleanliness of DIP is an important criterion, particularly in the case of high proportions of DIP in newsprint or by introducing DIP in high-quality graphic paper grades, such as SC- and LWC-paper. At present it is not worth discussing analysed speck figures because no standardized testing methods, testing procedures and size classification of residual ink and dirt particles are available and agreed, respectively, either nationally or internationally. So far, each DIP manufacturer characterizes specks, but the figures obtained are not comparable with corresponding findings of other manufacturers or research organizations.

1.3.1.5 Chemical Characteristics of Waste Paper

1.3.1.5.1 COD of Pulp Filtrates

With respect to chemical characteristics of waste paper even less information is available compared with physical characteristics. In the early eighties the COD of waste paper caused by dissolved matter released during slushing in tap water was evaluated with reference to the filtrate of the pulp slurry (Table 1.3.-6). More recent results are only available for mixed waste (B12) and supermarket waste (B19). Because of insignificant differences between the findings of 1984 and 1994 for B12 and B19, as far as averages are concerned and the large range of COD of all waste paper grades investigated, the previously attained ranking should be still valid. The highest COD (30 kg/tonne waste paper) is caused by woodfree shavings and corrugated containers II. This is not surprising, because the dominant paper grades present in these waste paper grades are usually treated with starch - by wet end or size press application. The second category contains waste paper grades with a COD of about 18 kg/tonne, with the exception of news (E12) where the lowest COD of 14 kg/tonne was determined. In principle, a COD load of 15 kg/tonne waste paper stands for a loss of approx. one percent organic carbon containing solids either related to fiber material or additives including starch.

Table 1.3.-6: COD of Different Waste Paper Grades

Waste Paper Grade	COD [kg/Tonne]		
	Range 1984	Average 1984	Average 1994
Mixed waste paper (B12)	12 - 24	18	15
Supermarket waste (B19)	16 - 22	19	22
Over-issued news (E12)	10 - 18	14	---
White wood-containing shavings (O14)	6 - 30	18	---
White woodfree shavings (Q14)	17 - 40	29	---
Corrugated containers II (W52)	23 - 37	30	---
Corrugated containers I (W62)	11 - 26	18	---

Source: Institut für Papierfabrikation/Darmstadt (1985, 1994)

1.3.1.5.2 Cations and Anions

Inorganic compounds in waste paper, such as heavy metals, alkaline earth metals or salts may originate from fibers, fillers and pigments or chemical additives used in preceding papermaking. Paper converting and printing, paper consumption and waste paper collection might be further sources of contamination. The concentration of inorganic substances are of special interest not only with respect to waste paper utilization in paper mills, but also with respect to waste paper used for other recycling purposes (e.g. particle board, moulded products) and for composting or energy recovery.

One of the first investigations on the content of heavy metals in wood, mechanical and chemical pulps, fillers and waste paper was performed in 1985 at the Department of Paper Science and Technology in Darmstadt. The findings of waste paper analyses are presented in Fig. 1.3.-10. The data obtained after a pressurized nitric acid decomposition of the total substrate matrix represent the total content of heavy metals in waste paper - regardless of the proportion fixed in a very stable manner to inorganic components (e.g. fillers, pigments). With respect to the averaged figures it becomes evident, that news has the lowest heavy metal content. The mercury concentration is close to the detection limit. The cadmium content is identical with that of mechanical pulp made of spruce. Lead and chromium are in the same range of about 5 mg/kg oven-dry pulp (5 ppm).

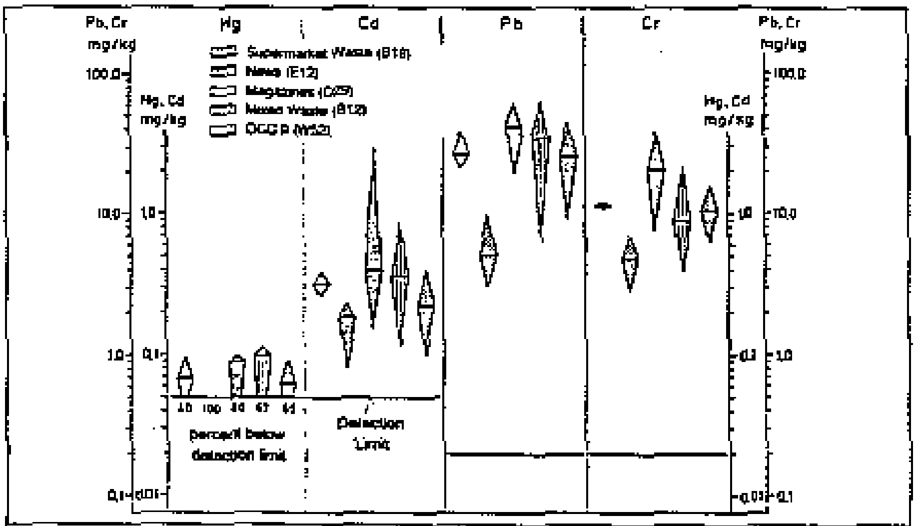


Fig. 1.3.-10 Heavy Metal Content of Different Waste Paper Grades (1985)
Source: Hamm, U.; Geller, A.; Göttsching, L., Darmstadt (1986)
IfP 1995

The highest content of lead and chromium is identified in magazines. Also in this waste paper grade the mercury concentration is partly below the detection limit. The average concentration of cadmium is 400 µg/kg (400 ppb). Lead is found on a level of 40 mg/kg and chromium at about 20 mg/kg. The ratio between lead and chromium does not correspond to a relationship which must be expected if lead chromate from printing ink pigments would be the main source for these heavy metals. Evaluations of unprinted and printed paper confirmed that the analysed heavy metals do not originate from printing inks in the first place.

The heavy metal contents of supermarket waste (B19), mixed waste (B12) and corrugated containers II (W52) are below that of magazines. Generally, waste paper has a higher level of heavy metals compared with virgin mechanical and chemical pulps where the concentration is in the range of wood. A dominant source of heavy metal contamination - particularly of lead and chromium - are fillers, pigments and inorganic chemicals used in previous papermaking. (Therefore, papermakers manufacturing paper from virgin components have a responsibility to ensure the purity of such materials.) The content of heavy metals in fillers and pigments depends on their geographic origin. Clays from Germany, for example, have a higher lead content than other clays, whereas the chromium content of North American carbonates is usually higher than that of carbonates from Europe. Due to the heavy metal content of fillers and pigments, a highly filled paper made of virgin fibers may have a higher heavy metal content than a paper based on recycled fibers with a lower content of fillers or pigments.

Heavy metals of fillers and pigments are strongly fixed in the crystal lattice and are therefore almost insoluble in water. Heavy metal concentrations in aqueous paper extracts are in the lower ppb-range (ppb = parts per billion). The limited migration to water has another positive effect: White water contamination by heavy metals is insignificant, even in waste paper processing paper mills. The heavy metal concentrations of effluents discharged are far below the concentration limits set by the **Federal Waste Water Act**. Generally, they are even below the limits set for drinking water in Germany.

A further comprehensive study on heavy metal concentrations of different waste paper grades was performed by Papiertechnische Stiftung (PTS), Munich, in 1993.

The composition of the analysed waste paper samples is presented in Table 1.3.-7.

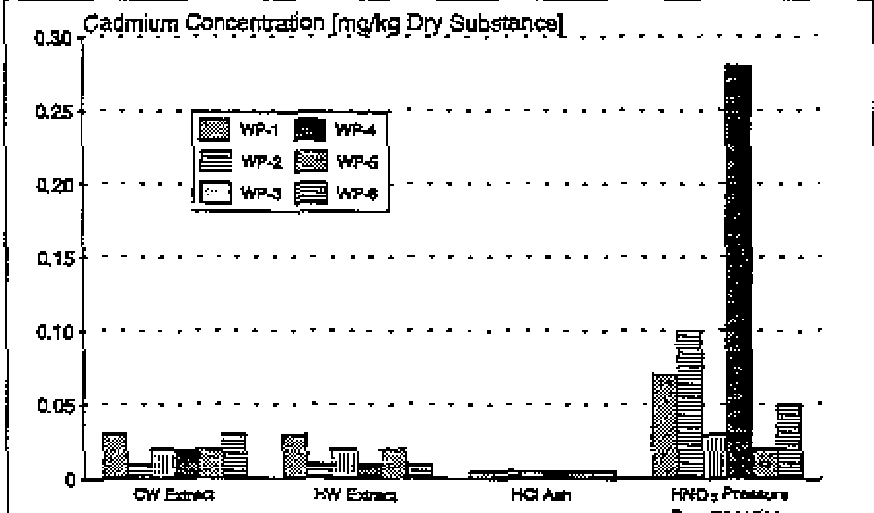
Table 1.3.-7: Composition of Waste Paper Samples

Sample	Composition of Waste Paper Samples
WP-1	News (DIP + Virgin Pulps)
WP-2	Packaging Paper, Paper Sacks, Corrugated Containers II
WP-3	Writing and Printing Paper, Office Waste
WP-4	Graphic Recycled Paper, Grey Board
WP-5	Composite Materials (incl. Liquid Board)
WP-6	Pamphlets, Magazines, Catalogues

The heavy metal concentration was determined

- in cold water extracts (CW Extract)
- in hot water extracts (HW Extract)
- in hydrochloric extracts of ash (HCl Ash)
- after pressurized nitric acid decomposition (HNO_3 pressure decomposition)

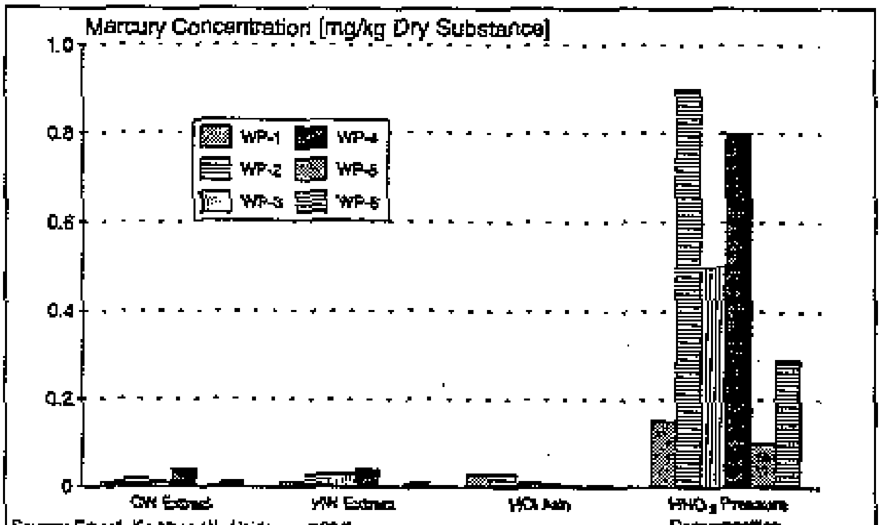
The results of heavy metal analyses are given in Fig. 1.3.-11 to Fig. 1.3.-17 as mg/kg oven-dry substance (waste paper). For all waste paper samples investigated the total concentration of cadmium and mercury are on a very low level. The highest total concentration of chromium, copper, nickel and lead are analysed in pamphlets, magazines and catalogues. It is obvious that the heavy metals in these papers originate mainly from fillers and pigments, which are present to a higher extent than in the other paper grades.



Source: Erhard, K.; Alber, W., Heidenau (1994)

Fig. 1.3.-11 Cadmium Concentration of Different Waste Paper Grades Affected by Sample Preparation (1993)

IfP 1995

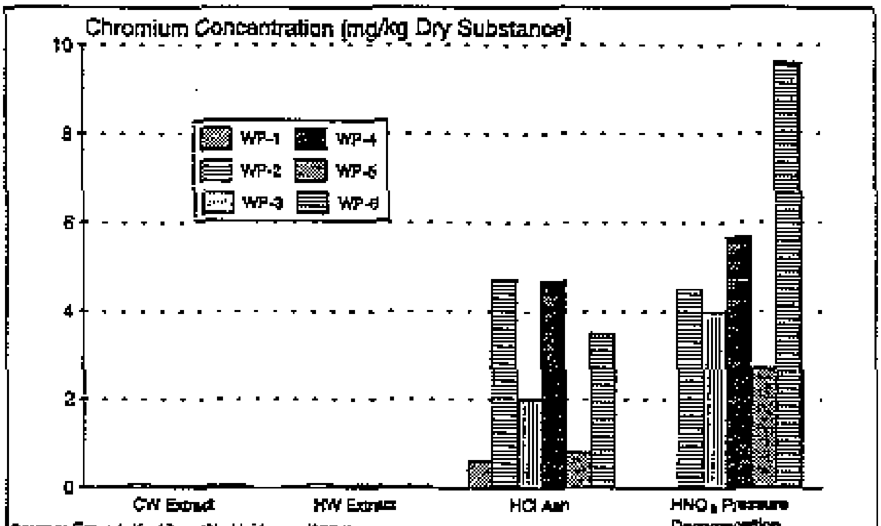


Source: Erhard, K.; Alber, W., Heidenau (1994)

Fig. 1.3.-12 Mercury Concentration of Different Waste Paper Grades Affected by Sample Preparation (1993)

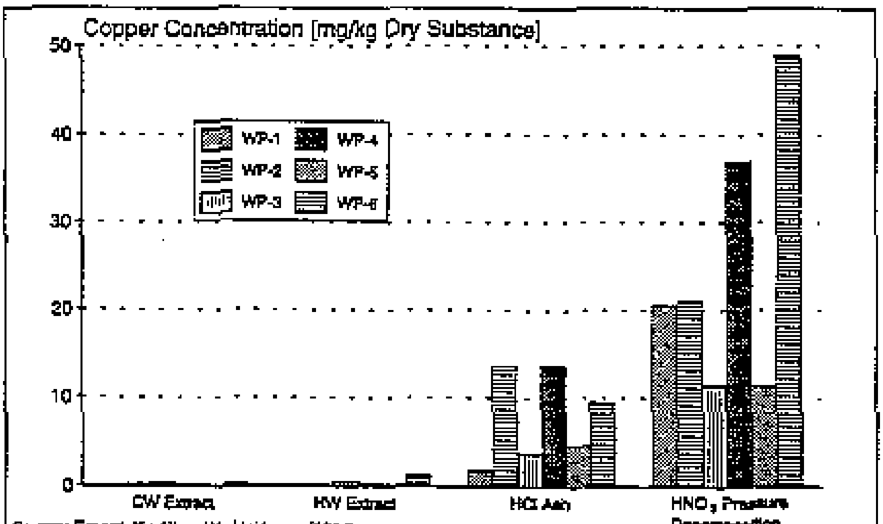
IfP 1995

In all cases the water-soluble portion of heavy metals is considerably lower than the total content only released by severe decomposition. There are insignificant differences between hot water and cold water extraction. This must be considered, when waste paper is disposed of by landfilling or when it is used as a co-substrate for composting.



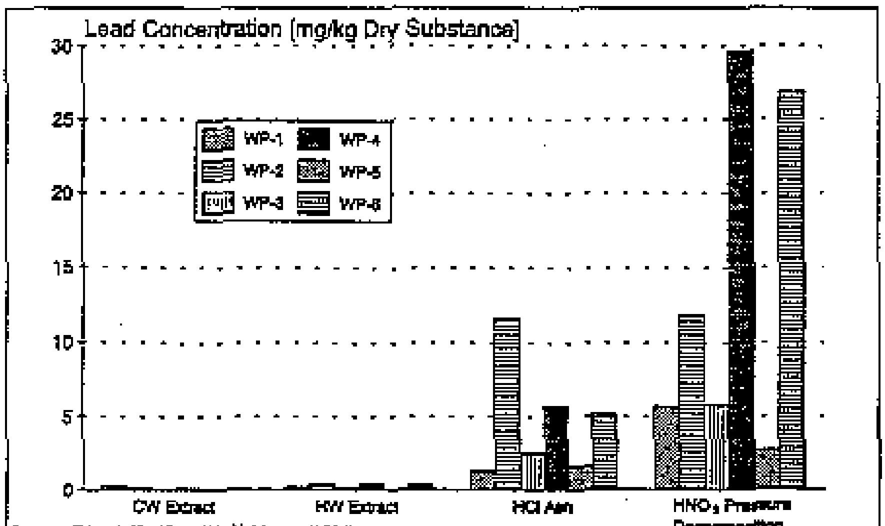
Source: Erhard, K.; Alber, W., Heidenau (1994)

Fig. 1.3.-13	Chromium Concentration of Different Waste Paper Grades Affected by Sample Preparation (1993)	IfP 1995



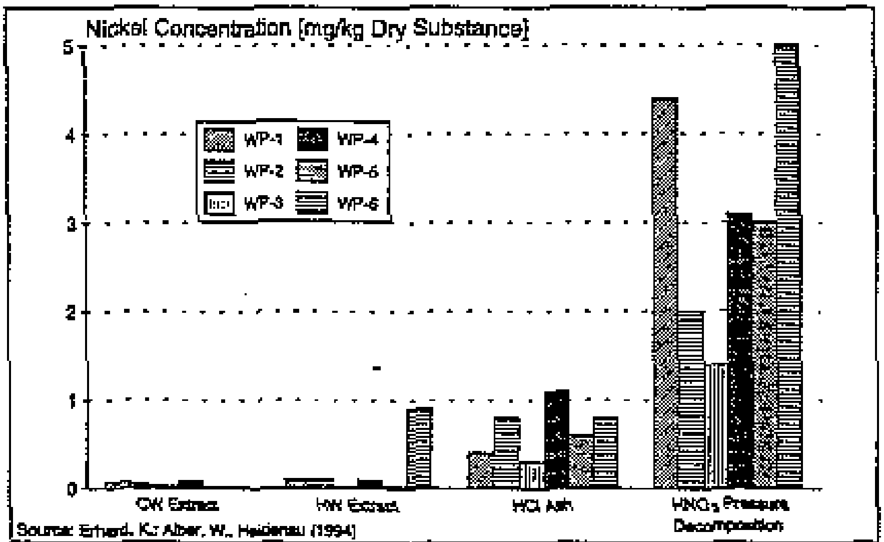
Source: Erhard, K.; Alber, W., Heidenau (1994)

Fig. 1.3.-14	Copper Concentration of Different Waste Paper Grades Affected by Sample Preparation (1993)	IfP 1995



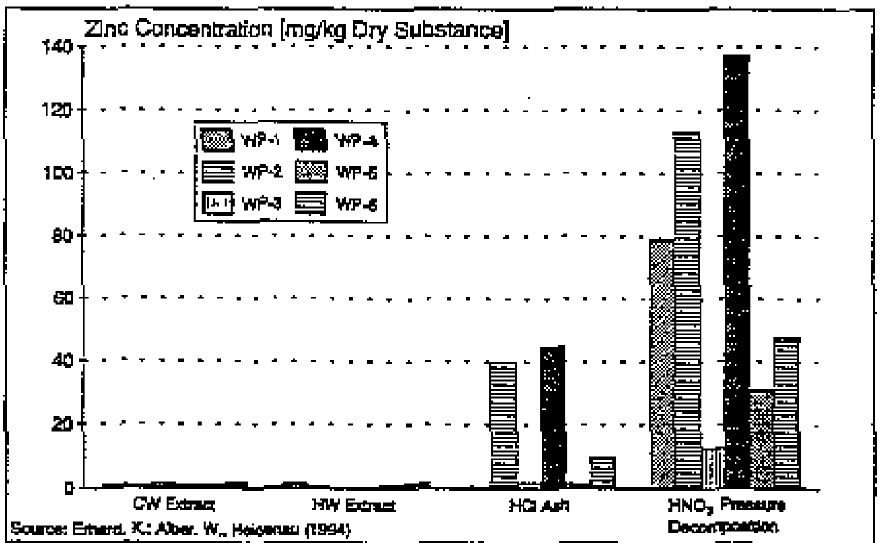
Source: Erhard, K.; Alber, W., Heidenau (1994)

Fig. 1.3.-15	Lead Concentration of Different Waste Paper Grades Affected by Sample Preparation (1993)	IfP 1995



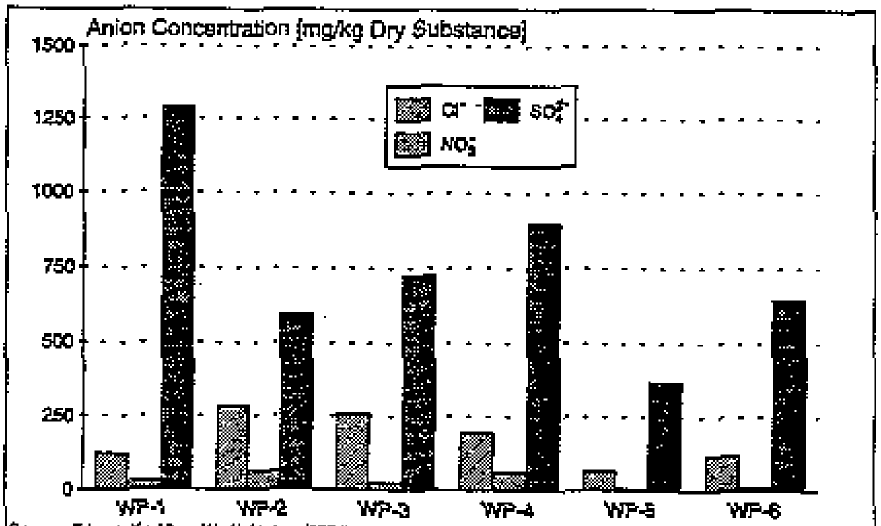
Source: Erhard, K.; Alber, W., Heidenau (1994)

Fig. 1.3.-16 Nickel Concentration of Different Waste Paper Grades Affected by Sample Preparation (1993) IfP 1995



Source: Erhard, K.; Alber, W., Heidenau (1994)

Fig. 1.3.-17 Zinc Concentration of Different Waste Paper Grades Affected by Sample Preparation (1993) IfP 1995



Source: Erhard, K.; Alber, W., Heidenau (1994)

Fig. 1.3.-18 Migration of Anions Into Water (Cold Water Extract) IfP 1995

The degree of migration of anions from waste paper into cold water is shown in Fig. 1.3.-18. The amount of water-soluble nitrate is very low (5 mg/kg to 65 mg/kg waste paper). The level of migrated chloride is between 65 mg/kg and 280 mg/kg waste paper. The highest concentration of water-soluble sulfate was measured in the cold water extract of news, caused by the application of aluminium sulfate in the production of this newsprint. Considering the migration of chloride and nitrate there is no significant difference between the different waste paper samples investigated.

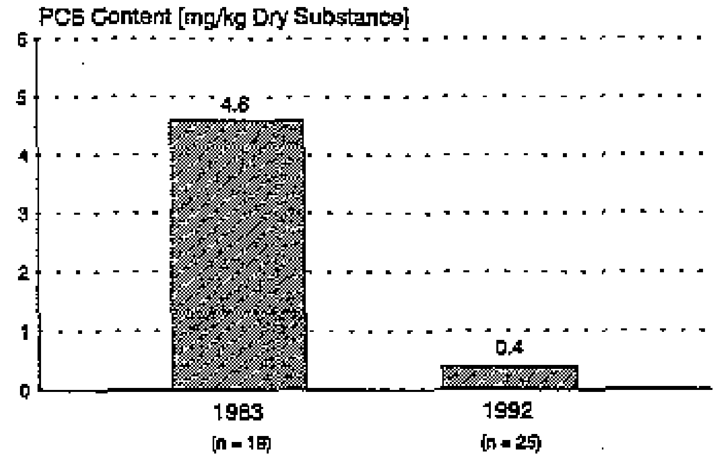
1.3.1.5.3 Chlorinated Organic Compounds

Investigations on the origin and the fate of chlorinated organic compounds in paper have shown that the main sources for these compounds are chlorine and/or chlorine dioxide bleached chemical pulps as well as wet-strength agents based on epichlorhydrine. The parameter AOX quantifies the total content of halogenated organic compounds in paper. The AOX content of recycled pulp ranges between 50 mg/kg and about 350 mg/kg oven-dry substance. Thus the concentration generally is on a higher level than the content of papers based on virgin pulp, but only in the case that the used chemical pulps are bleached with chlorine-free technologies. The results of AOX analyses, however, are not suitable for an assessment of the ecological toxicity.

It is well known that chemical pulps bleached with elemental chlorine may give rise to the formation of polychlorinated dioxins and furans if the chlorine charge exceeds a certain level. For chemical pulps delignified with oxygen and bleached with chlorine dioxide, polychlorinated organic compounds such as dioxins and furans are generally not present above background levels, provided that the raw materials used (wood, water, chemical additives etc.) are free from contamination.

The increasing use of TCF and ECF pulps in the German paper industry affects the dioxin/furan concentration of recycled fibers significantly. While in the early nineties the dioxin/furan content of recycled pulp was in the range of 10 ng I-TE/kg to 30 ng I-TE/kg oven-dry pulp, the concentration decreased later rapidly to a level of < 1 ng I-TE/kg to 6 ng I-TE/kg oven-dry pulp. The lower figures are measured in recycled graphic papers, the higher values in recycled packaging papers. Possible reasons for higher concentrations of recycled packaging papers is the use of pentachlorophenol (PCP) as slimicide in some European and overseas countries. The German paper industry had already renounced the utilization of pentachlorophenol in the beginning of the seventies. Today, nor production, sales neither utilization of PCP is permitted in Germany and some other European countries.

Further studies were performed on the content of polychlorinated biphenyls (PCB) of recycled fibers. PCB compounds were a major component in carbonless paper until the early seventies. PCB contamination originates from post-consumer waste paper mainly recovered in offices. As shown in Fig 1.3.-19 the PCB level of recycled fibers has been significantly reduced. In 1983 the average PCB content of different paper and board grades made of recycled fibers was 4.6 mg/kg oven-dry substance. In 1992 the level was 0.4 mg/kg oven-dry substance. Data of 1995 are in many cases below the detection limit of the test method (gas chromatography). Considering this, it can be confirmed , that the PCB content of waste paper used in Germany becomes irrelevant because it cannot be detected by sensitive test methods.



Source: Institut für Papierfabrikation, Darmstadt (1993)

Fig. 1.3.-19 Average PCB Content of Recycled Fiber Containing Paper and Board Made of Recycled Fibers IfP 1994

Guidelines and recommendations have been worked out in respect of the content of certain heavy metals and low molecular weight organic substances (e.g. polychlorinated biphenyls, pentachlorophenol, formaldehyde, glyoxal) in paper and board intented to come into contact with foodstuffs and for use in toys. EU legislation covering paper and board used in food contact applications will be developed in the near future, following **Recommendation XXXVI** (Empfehlung XXXVI) in force in Germany. Generally, products made of paper and board containing recycled fibers fulfil the set limits of this recommendation.

1.3.2 *Technology of Waste Paper Processing*

Each waste paper processing plant of a paper mill is a system of different units of operation. The layout of such systems is mainly governed by the waste paper grade(s) processed and the paper or board grade(s) produced. The system has to meet exacting requirements in terms of capacity, efficiency and economy, product quality and environmental issues related to energy consumption, white water loops, water-born emissions and solid waste generated. Waste paper processing is primarily based on mechanical stock treatment partly supported by chemicals (e.g. deinking) or totally performed by chemical regimes (e.g. bleaching). The basic stages in waste paper processing comprise slushing (disintegration/defibration), cleaning and screening, dewatering and thickening as well as white water treatment. Upgrading measures are increasingly established in order to improve pulp and paper characteristics depending on individual paper and board grades produced. The significance of upgrading technologies such as fractionation, dispersion, beating, deinking and bleaching is increasing mainly with reference to graphic and sanitary papers made of deinked pulp (DIP).

The functions of the different stages are as follows:

Slushing

aims at the separation of the fiber network of waste paper into single fibers and residual flakes. Therefore, fiber-to-fiber bonding must be weakened by means of water (and sometimes by chemicals) in combination with mechanical as well as hydraulic forces. The slushed pulp slurry contains fibers, fillers/pigments and additives, used in previous paper manufacturing and converting as well as impurities (unusable material). Nowadays a variety of equipment and procedures are available such as pulpers (operating at low or high consistencies) or partly perforated rotating drums.

Cleaning and screening

must be carefully performed in each waste paper processing plant in order to remove impurities from the pulp most selectively and quantitatively. With reference to the density of the fibers, impurities can be divided into three categories:

- Particles with high density such as stones, sand, metal, glass, ...
- Particles with low density such as cork, polystyrene, ...
- Particles with identical density such as wood, textiles, plastics, ...

Cleaning is conducted in centrifugal cleaners removing either particles with high densitiy (e.g. staples, sand, ...) or low density (e.g. stickies of low density). Screening serves the removal of impurities by size and shape. For that purpose pressure screens are commonly employed. In pre-screening aiming at the elimination of coarser particles, perforated baskets remove plastic foils and similar impurities. Fine screening by means of pressure screens is performed with slotted baskets removing shives and stickies in the first place.

Dewatering and thickening

are compulsory units of operation in order to control the consistency of the pulp in specifically required ranges depending on succeeding processes (e.g. high consistency for dispersion or peroxide bleaching). Dewatering and thickening are conducted with wire or belt presses, disc filters or screw presses. In waste paper processing plants the filtrates generated by thickening are reused - with or without special white water treatment.

White water treatment

becomes increasingly important, at least in advanced waste paper processing plants. So far, it is still regarded as an optional treatment stage. Due to permanent recirculation of white water in waste paper processing plants, the content of solid matter (fines and fillers) as well as of dissolved organic substances (quantified by COD) is increasing. To separate the water circuit(s) of the stock preparation plant and the paper machine, thickening or dewatering stages are required. The recovered white water is reused for slushing and/or other dilution purposes within the waste paper processing plant. Before its reutilization the white water can be treated either by sedimentation (clarification) or by micro-flotation applying flocculation agents.

Upgrading processes

are of a different nature depending on paper or board grades to be produced. The most traditional unit of operation is **beating**, similar to beating of chemical pulp. In beating of recycled pulp a compromise must be aimed at: maximization of fiber swelling (development of internal and external surface area) and minimized fiber cutting avoiding a significant change of freeness which affects drainage on the paper machine.

By means of **fractionation** the pulp slurry is divided into a long fiber and a short fiber component which can then be upgraded separately according to its composition. The long fiber fraction contains a higher proportion of impurities which must be treated, e.g. by dispersion. Dispersion of a part of the pulp results in a reduced power demand related to the total pulp. This procedure is supposed to contribute to energy saving.

Dispersion is carried out in order to reduce the size of certain impurities such as wax, bitumen or ink particles below their visibility limit of approx. 50 micron. Size reduction of bitumen or printing ink particles improves the appearance of the paper sheet produced. Unfortunately, dispersion causes a brightness reduction - in the case of white recycled fibers - due to the increased specific surface of the invisible ink and dirt particles.

Deinking is a purification process based on mechanical, hydraulic and chemical forces predominantly aimed at the removal of printing ink particles. Additionally deinking removes certain types of stickies and speck generating impurities. Two different processes of deinking are state-of-the-art: **flotation** and **washing**. In flotation differing surface characteristics of fibers (being hydrophylic) and ink particles (being hydrophobic) guarantee the removal of ink, whereas size and shape differences between fibers and ink particles are more significant for the removal of ink particles as well as fillers and pigments by washing.

Bleaching is a pure chemical reaction which takes place in further treatment of deinked pulp (DIP). In waste paper processing, bleaching must not contribute to delignification which will result in a high loss of yield in the case of wood-containing DIP. Most common chemicals are hydrogen peroxide, sodium dithionite and formamidin sulfinic acid (FAS). Chlorinated compounds should not be used for environmental reasons. Oxygen or ozone are supposed to be inadequate bleaching agents in sequences with the above mentioned chemicals.

1.3.2.1 Features of Basic Unit Operations

1.3.2.1.1 Slushing

Waste paper is mainly delivered in form of bales kept together by metal wires. Less than 30 percent of waste paper volume processed in Germany is delivered unbaled (Fig. 1.3.-20). Particularly waste paper for DIP, processed in large deinking plants, is predominantly unbaled (75 %). To operate large volumes of unbaled waste paper, discharge stations and special storages are compulsory. On the other hand no equipment for wire cutting and removal is required. The delivery of baled waste paper is common for all other waste paper processing plants.

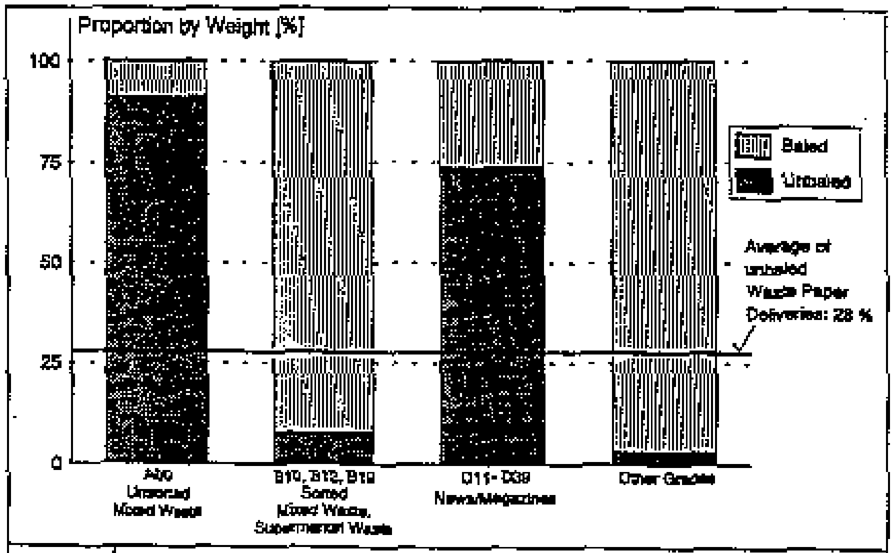


Fig. 1.3.-20 Delivery of Ordinary Waste Paper Grades in Germany (1994)
Source: Putz, H.-J., Darmstadt (1995)
IfP 1995

The target of a pulping system is the transformation of waste paper into a suspended pulp slurry which can be pumped at a low energy demand. In principle, the same equipment as for chemical pulp can be used. Opened bales or unbaled waste paper are conveyed by a flat rubber belt or a lamella conveyor to a pulper or a drum system. Drums are commonly operating in deinking plants.

Pulpers are available in various designs. They operate batchwise or continuously at low consistency (3 % - 7 %) or at high consistency (15 % - 20 %). Low consistency (LC) pulpers are predominantly of the continuous type and used for slushing of brown and mixed waste paper grades. High consistency (HC) pulpers run either batchwise or continuously and predominantly in deinking plants. For graphic waste paper continuously operating HC drums are also employed. Drum pulping guarantees a gentle disintegration of waste paper with the effect that contaminants are kept at larger size and can therefore be more easily removed in the following screening stages.

In general, LC and HC pulpers are of circular tub design with a rotor (the rotor axis is usually vertically mounted) and baffles for slushing. Rotors are rotating with revolutions between 150 min^{-1} and 500 min^{-1}. Pulpers are available with different rotor designs depending on the waste paper to be treated and the consistency range applied. LC pulper rotors have a low profile, whereas an HC pulper has a rather large central rotor with helical flights. In LC pulpers shear forces are dominating whereas in HC pulpers, due to lower rotor speed, shear forces decrease and friction becomes more important for an effective slushing action. To remove coarse impurities a perforated extraction plate is placed at the bottom of the pulper with hole diameters between 10 mm and 30 mm. Continuous LC pulpers are usually equipped with a junk trap system, in which contaminants such as plastics - not passing the holes of the extraction plate - are accumulated. The junk trap is normally emptied intermittently by a double-valve discharge arrangement. Separate screening systems outside the pulper such as secondary pulpers or post-screening drums are sometimes connected to the pulpers. They are used:

- of necessity if there is no perforated extraction plate inside the pulper to protect the following equipment and the pumps from damage by coarse contaminants,
- if a batchwise HC pulping system with extraction plate is used to recover fibers from coarse contaminants,
- in continuous LC pulping systems to increase capacity by transporting a part of the stock through the system and by recirculating the accept.

Additionally, in LC pulpers, large circulating impurities (bale wires, plastic foils, strings, textiles, etc.) are removed by a ragger. The device slowly winds up a rope, which is spun from these contaminants thanks to the rotary motion in the pulper.

Drum pulpers are slightly inclined. The waste paper is fed into their upper end. The drum is divided into two sections:

- the pulping zone with a consistency between 15 percent and 20 percent
- the perforated screening zone where water is added for dilution decreasing consistency to six percent or even less.

In the pulping section the waste paper is lifted by baffles through the rotation to the top of the drum (2.5 m - 4.0 m diameter) and falls down to the bottom. In this machine the mechanical forces are very gentle but sufficient to turn the waste paper for deinking into a pulp slurry.

Continuous pulping systems guarantee a more homogeneous pulp, but the feeding equipment has to be more sophisticated for an automated process. With batch pulper systems the defibration can be easily adapted to the requirements of changing waste paper quality by varying the pulping time. LC pulping systems dominate in traditional waste paper processing plants. HC operation is common in deinking plants. The main advantages of HC pulping are:

- an efficient detachment of ink from the fibers by higher friction forces
- an effective chemical action due to higher consistency (e.g. bleaching chemicals)

- a gentle slushing by reduced shear forces which avoid severe disintegration of contaminants (e.g. adhesives, book backs).

Drum pulping systems are bigger in size, require larger space and are more costly than HC pulpers at the same capacity. Investment cost comparisons should take into account that the cost difference for the total pulping system is much smaller than the initial difference because of additional equipment for reject treatment and a more sophisticated control system for HC pulpers. On the other hand lower energy consumption, lower maintenance costs and a more gentle mode of operation are advantages of drum pulping systems.

1.3.2.1.2 Cleaning

Contaminants of waste paper have a great variety in terms of composition and size. Large or high-density contaminants can be relatively easily removed. Provided that large contaminants are not too far disintegrated during pulping, they will be already removed to a great extent in the pulper. Smaller contaminants such as staples, paper clips or sand as well as fragments of disintegrated larger contaminants will leave the pulper with the accept and must be removed in the following stages of processing. This is also the case with other important contaminants such as:

- Stickies and other light-weight contraries
- Ink particles
- Colloidal and dissolved impurities.

In order to protect the following equipment from damage or excessive wear smaller heavy-weight contaminants (e.g. staples) must be removed, first of all. The hydrocyclones applied are characterized by conical design and tangential pulp inlet. Cyclones make use of centrifugal forces to remove contaminants above a density of about 1.05 g/cm^3. The efficiency of contaminant removal is generally improved with lower consistency of the pulp feed and with smaller diameters of the cyclones.

Immediately after pulping, high-density hydrocyclones are installed. They are specially designed for high consistencies between four percent and six percent. By application of a rotor at the top of the cyclone the rotational flow is strengthened and the pressure loss is lower. Due to centrifugal forces, high-density particles move inside the cyclone to its wall. Because of the conical cyclone design these particles rotate helically downwards to the reject outlet. High-density hydrocyclones are equipped with a reject box where a recovery of fibers by flush water and a pneumatic valve system is provided. Illumination and a glass window at the separation zone are helpful to control the cleaning effect by adjusting the flush water volume. The cleaned accept is usually removed at the top of the hydrocyclone.

Conventional hydrocyclone cleaners are then used to eliminate smaller high-density particles at lower consistencies (0.7 % - 1.5 %). There the centrifugal flow is not created by a rotor but by the tangential feed and the transfer of inlet pressure into flow speed. The pressure drop between inlet and outlet is in the range of 1.5 bar to 3.5. bar. Because of the continuous reject flow some fibers are also removed together with the reject. This is the reason that cleaners are installed in different stages. The accepts of the second, third and following stages are fed back to serve fiber recovery. The reject from the last stage is sent to waste.

Hydrocyclones separate fiber components and impurities by means of density. During this process there is not only an enrichment of high-density particles at the periphery and the lower end of the cone but also of particles in the center of the cyclones which are lighter than the suspension. This effect was first employed to remove air and small polystyrene particles in the production of testliner and corrugating medium by introducing a concentric pipe in the upper part of the cyclone. The obtained de-aeration might be sufficient for packaging paper and board grades but it is not sufficient for printing and writing grades. The concept of removing low-density contaminants (e.g. stickies) was developed further and is applied in deinking plants.

Instead of the de-aeration flows for the removal of low-density contraries reverse centricleaning is performed. Reverse centricleaning refers to a situation where the flow, which constitutes the accept in conventional systems, is representing the reject and vice versa. High reject rates and pressure drops are the drawback of such systems. To avoid these problems other types of cleaners for the removal of low-density impurities have been designed. These so-called through-flow cleaners have an tangential pulp feed at the top of the cleaner. Accept as well as reject are removed at the upper part of the cleaner. For low-density contaminant removal with high efficiency further equipment has also been developed, e.g. cleaners with motor-driven high speed rotating conical rotors or cylinders. By the high centrifugal acceleration of the pulp inside of this horizontal cleaner type the low-density contaminants are concentrated and removed from the center of the cleaner. High investment costs and energy demand are the bottlenecks of such cleaner types.

1.3.2.1.3 Screening

The removal of impurities or flakes whose density is similar that of the fibers is performed by screens. Today pressurized screens are widely used. Pressureless screens such as vibrating screens are not suitable for high capacities and are used only in final stages of a screening cascade. Pressurized screens separate contaminants from the pulp slurry according to their shape and size. The pulp flow passes continuously perforated screening baskets with holes or slots. Hole sizes are in the range of one millimeter to three millimeter and slot widths between 0.10 mm and 0.8 mm. These openings are widened towards the accept side. The reject which is restrained by the screen must be removed continuously to avoid plugging. Due to the simultaneous removal of a substantial amount of fibers with the reject, pressurized screens are connected in cascades. The consistency used for the smallest holes and slots is below one percent and the process is named fine screening. In deinking plants fine screening is performed very often after flotation whereas for the production of packaging paper and board, a pressurized screen operating at low consistency is established first in the approach flow system. Higher consistencies up to four percent can also be applied in screening, but not in the case of very small holes or slots. Very often this pre-screening stage is placed ahead of flotation and after a first cleaning stage.

The design of pressure screens does not only include the openings of the basket but also the geometry of the screen plate which can be plain or contoured. Compared to standard baskets with the same opening dimensions, profiled baskets can be operated with double the consistency (= double capacity) and half the specific energy demand. At the same capacity or energy demand, smaller basket openings can be chosen for profiled baskets, resulting in an improved screening efficiency.

Additionally, the geometry of the screening rotor and foils and the clearance between them and the basket are important to produce pressure pulses for keeping the openings free from fibers and contaminants. Four basic types of cylindrically shaped pressure screens are available, characterized by the flow direction and the arrangement of the foils:

- Inward flow, foils at inlet side
- Outward flow, foils at inlet side
- Inward flow, foils at accept side
- Outward and inward flow, foils at inlet side (double basket design).

For screening in the higher consistency range, two configurations have proved to be advantageous. One is the rotor arrangement inside the screen basket and flow through the basket from inside to outside. Due to the fact that the rotor is located in the stock inlet zone impurities can be forced between the foils and the screen basket surface. Therefore the gap between rotor, attached hydrofoil and screen basket should be kept as large as possible and the rotor speed as low as possible. These conditions guarantee the formation of an auxiliary fiber layer inside the screen basket for the benefit of screening efficiency - even at larger openings (generally above 2.5 mm diameter).

The screening system with operation of the screening rotor in the accept area and a pulp flow from outside to inside has also proven effective. This arrangement allows smaller gaps between foils and basket surface. In this manner, an intensive cleaning efficiency of the screen basket openings is achieved as a result of the hydrofoil shaping and the high circumferential speed. These are essential conditions for the use of small screen basket openings (1.5 mm to 2.5 mm holes and slot widths between 0.2 mm and 0.6 mm) in the high consistency range. In general, slotted screens have the drawback of lower capacity compared with holed screens.

The efficiency of a screening configuration does not only depend on the size of the openings. The combination of various pressure screens with different hole sizes and slot widths as well as the following reject treatment of each screen by a traditional cascade or by forward-fed accepts influences significantly the over-all screening efficiency. For single pressure screens, the screening efficiency is improved with increasing reject rates. At the same reject rate, the velocity of the flow passing the screen openings is the dominant factor for screening efficiency. At high flow velocities, screening efficiency can be reduced significantly, especially for stickies which are usually elastic and can be pushed through the openings at high velocities.

1.3.2.1.4 Fractionation

Fractionation machines are similar to pressurized screens. Instead of a reject and an accept stream two accepts are generated. On the "reject side" of the fractionator a long fiber enriched fraction is obtained, whereas the "accept" fraction is enriched by shorter fibers. The baskets of fractionators are plain and perforated with holes between 1.0 to 1.6 mm diameter depending on the waste paper grade. Fractionation consistency is in a range of three percent. The "reject" rate varies between 40 percent and 60 percent (approx. 50 percent is very common).

Fractionation is mainly carried out in stock preparation plants for corrugating medium, testliner and folding boxboard. The long fiber fraction ("reject") with its lower Schopper-Riegler freeness (compared with the total pulp and the short fiber fraction) is dispersed or beaten improving strength and optical performance without effecting the freeness too significantly.

In DIP production, fractionation is not yet applied, although some benefits might be expected. Ink particles would be enriched in the short fiber fraction and the demand for deinking capacity for this fraction could be smaller (approx. 50 percent). The long fiber fraction will be quite bright and could be bleached separately to higher brightness compared with the total pulp. The long fiber fraction would be almost free of ash. The ash content of the short fiber fraction could be separately controlled by washing. Dispersion for the detachment of residual inks would be only necessary for the long fiber fraction. Long and short fiber fractions could be bleached separately making use of the most effective bleaching chemicals. So far, only one commercial application in manufacturing DIP is running in Europe. In this case the short fiber and long fiber fractions are used on different paper machines for the production of various paper grades.

1.3.2.1.5 Beating

Beating of recycled fibers contributes to the recovery of strength characteristics. It is almost exclusively performed in the treatment of (brown) mixed waste paper grades, whereas deinked pulp is usually not yet post-refined. For beating the typical refiners which are also used in chemical pulp beating (disc as well as conical refiners) are employed. Due to the high Schopper-Riegler wetness of mixed waste, refining must be performed very gently by using low specific edge loads to avoid an excess of fines production causing drainage problems on the paper machine. In combination with fractionation, refining is only performed with the long fiber fraction.

1.3.2.1.6 Dispersion

The objectives of dispersion are different depending on the paper and board grades produced. In the production of board, dispersion aims at an increase of bulk, beneficial for improved bending stiffness. In manufacturing corrugated medium and testliner dispersion is mainly carried out in order to reduce the size of residual impurities such as wax, stickies, ink specks etc. below the visibility limit (< 50 microns). Dispersion treatment of DIP is performed not only for the reduction of speck size but also to detach ink particles and contaminants from the fiber surface. After dispersion DIP is treated very often in a subsequent flotation (for newsprint production) or washing (for production of sanitary paper) stage in order to remove the detached ink particles improving brightness and cleanliness. Dispersion of DIP becomes increasingly important with higher proportions of recycled fibers in pulp furnishes for paper production. Due to the fact that dispersers are also effective mixers for bleaching chemicals they are applied ahead of bleaching stages.

For effective dispersion the pulp must be dewatered to consistencies of at least 25 percent (up to 35 percent). Dewatering of the pulp is a prerequisite to separate the white water loops in a paper mill. Usually the thickened stock is preheatinged by saturated steam to temperatures between 80 °C and 120 °C. Two dispersion systems are available:

- Kneaders
- Disc dispersers

Kneaders are available as single- or two-shafted machines on the market. They are characterized by low rotational speed (< 300 min^{-1}) and a relatively wide gap between the bars, resulting in a gentle friction action. Strength characteristics are negatively affected with increasing consistencies, energy input and temperature. On the other hand bulk and porosity of the paper sheet are improved. This is the reason that these machines are mostly applied for board production.

Disc dispersers are similar to disc refiners. Pressureless systems (< 100 °C) are dominating. The thickened pulp is fed by a screw conveyor into the disperser. The shear forces are considerably higher than in a kneader due to the high rotation speeds of 1,000 min^{-1} to 3,000 min^{-1} and small disc clearance below one millimeter. This results in an effective dispersion of inks and impurities. In DIP production, only disc dispersers are applied in Germany. In contrast to kneaders, increasing energy input leads to improved strength characteristics (breaking length, burst, CMT) but to decreased bulk and porosity.

The energy input for dispersion in the production of corrugating medium, testliner and board ranges from 30 kWh/tonne to 50 kWh/tonne. For sufficient ink dispersion and detachment of residual ink particles in DIP production, the energy demand is on a higher level between 50 kWh/tonne and 60 kWh/tonne.

1.3.2.1.7 Flotation Deinking

Deinking is targeting at the removal of ink from printed (white) waste paper grades. The development of deinking capacities (with reference to flotation) during the previous decades underlines the importance which this technology has achieved (Fig. 1.3.-21). Deinking chemistry is very complex and the chemical reactions are not completely understood. The chemicals applied have to fulfil the following functions:

- Separation of ink particles from fiber surface (detachment)
- Break down or agglomerating of ink particles to adequate size
- Removal of ink particles from the pulp slurry
- Improvement of optical properties by bleaching
- Controlled removal of fillers/pigments
- (de-ashing, mainly by wash deinking)

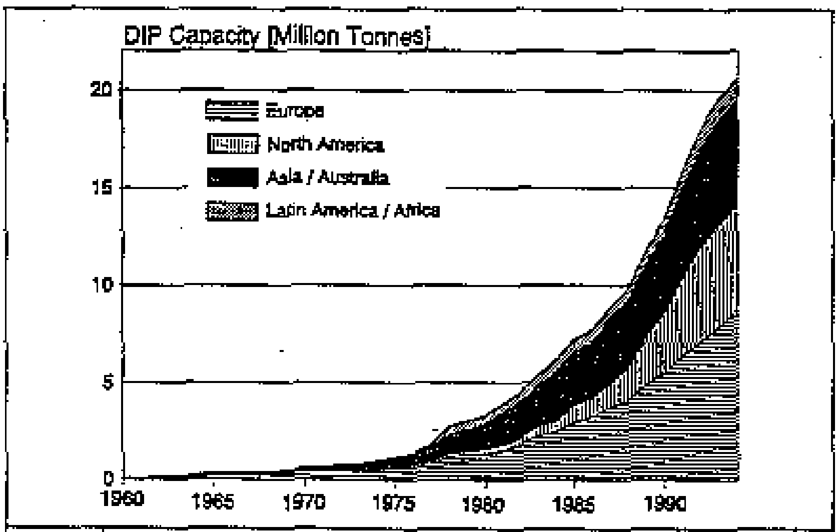
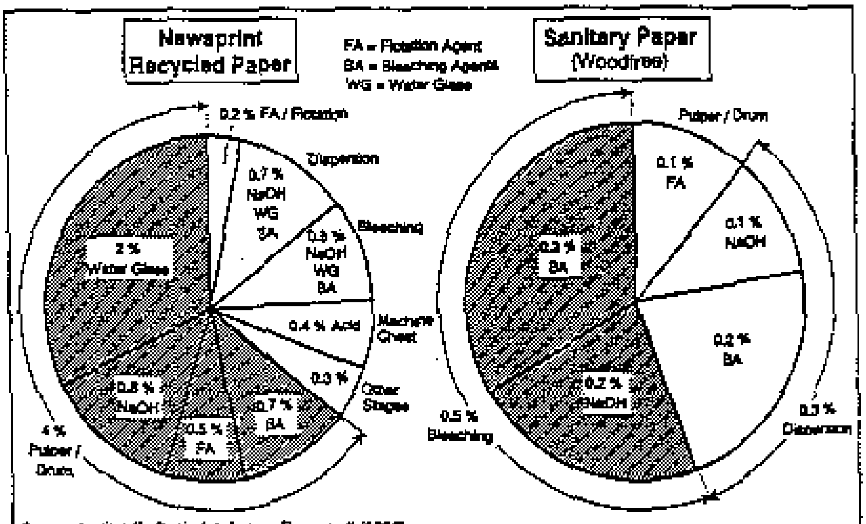


Fig. 1.3.-21 Global DIP Capacities (Flotation)
Source: PPI, Annual Reviews (1975-1995)
IfP 1995

The chemicals are mainly added into the pulper or the drum with the exception of bleaching agents which are partly applied separately in the post-bleaching stage. In Fig. 1.3.-22 the places of addition of chemicals and their types are shown for the treatment of wood-containing waste paper for newsprint and recycled graphic paper as well as for the treatment of woodfree waste paper for the production of sanitary paper. The range of the dosage of the applied chemicals are listed in Table 1.3.-8.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 1.3.-22 Addition of Chemicals for Deinking and Bleaching of Waste Paper for Newsprint and Sanitary Papers IfP 1995

Table 1.3.-8: Dosage of Deinking and Bleaching Agents

DIP for Newsprint and Recycled Paper				
Addition to	NaOH	Sodium Silicate	Flotation Agent	Bleaching Agent
Pulper/Drum	0.20 - 2.10	0.75 - 3.00	0.15 - 0.65	0.12 - 1.80
Flotation	--	--	0.20 - 0.60	--
Dispersion	0.20 - 0.70	0.40 - 1.00	--	0.50 - 1.45
Post-Bleaching	0.50 - 0.70	0.40 - 1.00	--	0.25 - 1.75

DIP for Sanitary Paper (Woodfree)			
Addition to	NaOH	Flotation Agent	Bleaching Agent
Pulper/Drum	--	0 - 0.30	--
Dispersion	0 - 0.18	--	0.35 - 0.40
Post-Bleaching	0 - 0.60	--	0 - 0.75

Figures as percentage related to oven-dry pulp

Source: Institut für Papierfabrikation/Darmstadt (1996)

The detachment of ink particles from the fibers is the primary function of the pulping and dispersion stages. The separation of the detached ink particles can be performed by two different processes, which are sometimes employed in combination in the case of sanitary paper. The processes are flotation and washing.

In flotation deinking, physico-chemical effects (hydrophobicity) contribute to the aggregation of ink particles and the attachment to air bubbles. The buoyancy of the air bubbles shift the ink particles to the suspension surface where ink-enriched foam is removed from the pulp slurry.

In a flotation process the fiber suspension is diluted to a consistency of about one percent. Air is introduced either by self-sucking injectors, turbines or compressors. The mixing of air with the pulp slurry is performed by turbulence caused by injectors, so-called mixing chambers. For high flotation efficiency the ink particles should be in a range of 10 microns to 120 microns.

Flotation cells available are differing according to:

- Shape (round, elliptic, rectangular)
- Stock feed (central, tangential, at bottom, below pulp slurry surface)
- Foam removal (free overflow, suction, paddle)
- Atmospheric or pressurized action.

With the exception of one design, all flotation lines include several flotation cells organised in one or two stages. Generally, the froth from the multiple flotation cells of the first stage is collected and flotated a second time in so-called secondary flotation cells, identical with the cells of the primary stage. The advantage of a two-stage system is a reduction of losses, which are in a range of five percent to ten percent depending on the waste paper grade and its ash content.

1.3.2.1.8 Wash Deinking

The alternative to flotation is the removal of ink by washing. Washing is based on the principle of replacing the "ink laden" water phase, in which the ink particles are dispersed, with clean water. In Germany, washing is only employed for the production of sanitary papers and, in Europe, by some mills manufacturing newsprint or LWC paper. However, flotation is the dominating deinking process in Europe and Asia. Preference to washing is given in North America. Nowadays there is also a trend towards flotation deinking taking its technological benefits into account.

For acceptable washing efficiency, the detached ink particles must be as small as possible, in a range below 10 microns, to provide the passing of ink particles through the filter media (e.g. a wire) and the fiber mat generated by dewatering. Together with the ink, also fillers and fines are removed by washing. This is the reason that the yield of washing is in a range of 25 percent to 30 percent for waste paper grades used for sanitary papers in Germany. In traditional washing machines (e.g. deckers or sidehill screens) the washing process is performed by a stepwise counter-current displacement of the water phase containing the ink particles. Each stage comprises dewatering followed by dilution with the filtrate from the succeeding stage. Clean water is only used in the last stage.

Dewatering action in washing devices can be based on hydrostatic forces (e.g. sidehill screens, deckers), on a combination of hydrostatic and mechanical effects (e.g. wire presses) or mainly performed by mechanical forces (inclined screens, extractors or screw presses). In most modern washing devices dynamic (centrifugal) forces are additionally applied (high speed washers) in order to improve washing efficiency. The last mentioned machine is often applied in only one or in two stages.

Efficiency of ink removal in a washing machine can be calculated by the consistency differences of the pulp between inlet and outlet of a washer, assuming simply that the ink is removed in the proportion as water:

$$\eta_{\text{theor}} = \frac{100\left(c_o - c_i\right)}{\left(c_o - c_F\right)\cdot\left(100 - c_i\right)} \cdot 100 \; [\%]$$

with c_O = outlet consistency of pulp [%]
c_i = inlet consistency of pulp [%]
c_F = consistency of filtrate [%]

However, the real ink removal rates are significantly lower than the theoretical ones, due to interactions between ink particles and fibers and because the particles are not soluble and will be retained more effectively with the thickening fiber network during dewatering. Because the amount of ink is difficult to determine on the one hand, but ash contents are easy to measure on the other hand, ash removal rates for typical washing machines are given in Table 1.3.-9. If the ink particles are well dispersed they should behave very similar to filler and pigment particles during washing.

The filtrate from the wash deinking stage contains a high quantity of ink particles, ash and fines. To overcome the high water consumption of the washing process it is absolutely necessary to clean the white water (at least after the first washing stage) and to reuse the purified water for dilution in the last stage at the end of the process line. Water cleaning is mainly performed by DAF (Dissolved Air Flotation) which guarantees removal of more than 95 percent of the incoming solids. The re-use of the froth from DAF in papermaking is not yet realized. This is the reason for the low yield of not more than 70 percent.

Table 1.3.-9: Operating Ranges and Ash Removal Rates of Washing Machines

Type	Operating Range		Ash Removal Rate	
	Inlet Cons. [%]	Outlet Cons. [%]	Theoretical [%]	Practical [%]
Sidehill Screen	0.8	3.0	74	60
Decker	0.8	3.0	85	55
Inclined Screw	3.0	10.0	72	45
Horizontal Press	4.0	28.0	89	35
Dynamic High Speed Washer	0.8	10.0	93	80

Source: Großmann et al. (1994)

1.3.2.1.9 Alternative Deinking Processes

For deinking other processes were proposed more recently:

- Ultrasonic deinking
- Deinking by electrical fields
- Ink agglomeration by chemicals and removal by centrifugal forces
- Flotation in centrifugal fields by gas sparged cyclones
- Solvent deinking

These proposed methods for ink removal from waste paper stock have not yet reached an accepted commercial application, partly they are still under development on lab or pilot scale.

1.3.2.1.10 Bleaching

Bleaching is only performed on DIP. The bleaching chemicals applied are free from chlorine or chlorine compounds. The target of DIP bleaching is the improvement of brightness and the adjustment of the colour shade. Bleaching is usually carried out at the end of the stock preparation process or during dispersion between two deinking stages. Nevertheless, peroxide is applied during slushing in most cases of wood-containing waste paper treatment in order to avoid alkaline yellowing of the mechanical pulp fibers. Bleaching chemicals utilized are either oxidative (hydrogen peroxide) or reductive (sodium hydrosulphite, FAS) acting agents. The most favourable bleaching conditions are:

Peroxide:	20 percent to 30 percent consistency, 60 °C to 80 °C, 1 h to 2 h, alkaline environment (pH 9 to pH 11)
Sodium hydrosulphite:	4 percent to 6 percent or 10 percent to 15 percent with medium consistency (MC) pumps, 50 °C to 70 °C, 20 min to 1 h, slightly acid environment (pH 6.0 to pH 6.5)
FAS:	10 percent to 15 percent consistency, 50 °C to 70 °C, 1 h, alkaline environment (pH 8 to pH 10)

The brightness gains obtained with DIP are always smaller compared with virgin mechanical pulp at the same bleaching conditions. In bleaching of wood-containing DIP, brightness increase of three points to six points in one stage is a fairly good result. Brightness gains up to ten points are obtained in the case of a two-stage bleaching sequence. Higher brightness increase is only achieveable in colour stripping of dyed woodfree DIP - as far as the suitable dyestuffs were utilized in previous papermaking.

1.3.2.1.11 Dewatering/Thickening

Thickening is a compulsory stage between various waste paper treatment processes in order to adjust the consistency of the pulp to suit the operating conditions of the different machines. Due to the fact that each thickening device causes investment and operation costs, the number of installations must be reduced to a minimum. Simple stock preparation systems such as for corrugating medium do not need any thickening. But in the case of a disperser system, dewatering is indispensible to obtain high consistencies above 20 percent. For this purpose belt thickeners or screw presses are available.

In deinking plants, thickening is also necessary after flotation where the pulp has only about one percent consistency. For the first thickening stage (up to storage consistencies), deckers are employed in older plants, whereas disc filters are common for new installations. When bleaching or dispersion must be performed a second thickening stage is required with screw presses in new processing plants or belt presses in older plants. For new installations, disc filters and screw presses are common because different white water qualities can be obtained by a disc filter, which can then be used for different purposes. Screw presses guarantee higher consistencies compared with belt presses, resulting in an improved dispersion and peroxide bleaching efficiency or both.

In the context of white water treatment, intensive dewatering is advantageous for the separation of water loops in stock preparation plants. This enables, for example, the first loop to run under strong alkaline conditions for the benefit of ink detachment and a second loop neutrally for the benefit of reductive bleaching. By diluting a deinked pulp of low moisture content with paper machine white water the carry-over of colloidal material on to the paper machine is minimized.

1.3.2.1.12 White Water Treatment

With the permanent reduction of fresh water consumption and effluent volume, multiple usage of white water is a necessity before it is finally released to the waste water treatment plant. Fresh water is usually only used at the paper machine. The white water in the stock preparation becomes increasingly loaded with inorganic and organic dissolved matter. In order to control the concentration of white water, its internal treatment becomes increasingly common in waste paper processing plants.

In paper mills producing corrugating medium, testliner or board with a relatively open water circuit, the white water is often treated in old fashioned clarifiers by sedimentation, sometimes also by flotation. Recently a project started on a commercial scale to evaluate the possibilities and advantages of anaerobic and aerobic white water treatment in a totally closed paper mill.

Paper mills with deinking plants are not yet effluent free. The fresh water consumption of newsprint mills ranges at approx. 7 m³/tonne to 10 m³/tonne. In deinking plants, the white water is successfully treated by dissolved air flotation (DAF). The only difference between various mills refers to the position and number of DAF units employed. In one mill, each separate water loop has its own DAF unit. In combination with flocculation chemicals, it is possible to remove a large quantity of anionic and non-ionic trash (potential stickies) by DAF for the benefit of paper machine runability and paper quality.

1.3.2.2 Equipment/Process Combinations for Different Paper Grades

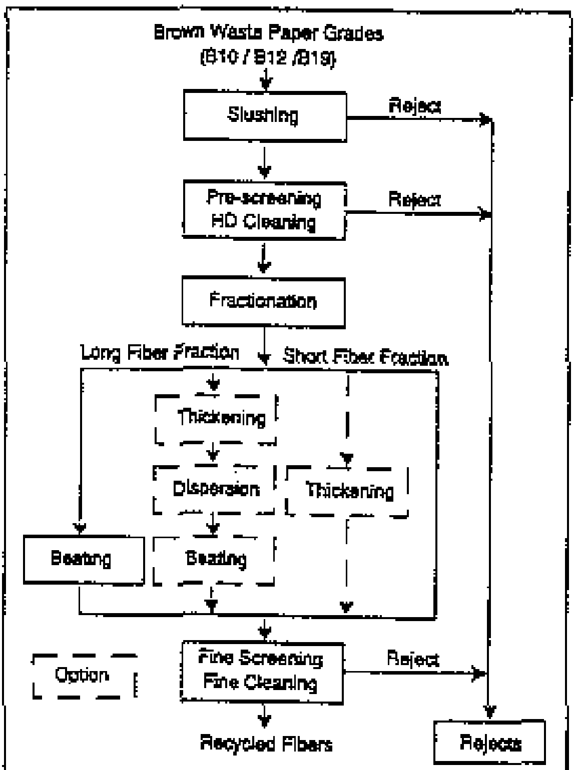
The basic stages of waste paper processing are described earlier. Simplified flow sheets of waste paper processing systems for the production of different paper grades are discussed in the following sections. In general, waste paper processing plants have individual designs in terms of their layout and equipment, even if the same paper grade is produced.

1.3.2.2.1 Corrugating Medium and Testliner

The total German production of medium and liner is made of waste paper such as mixed waste paper (B10, B12) and supermarket waste (B19) partly upgraded by a small proportion of corrugated containers I/II. The production of medium and liner amounts to 2.9 million tonnes and the waste paper utilization rate is 107 percent. This production requires 3.1 million tonnes of waste paper which corresponds to 50 percent of the volume of ordinary waste paper grades.

The layout of a waste paper processing plant for manufacturing corrugating medium and testliner is rather simple. In principle, only the following process stages are compulsory: slushing, pre-cleaning/pre-screening and fine cleaning/fine screening. The fine cleaning and fine screening stages can be integrated in the approach flow system of the paper machine.

The stock preparation system in Fig. 1.3.-23 is more advanced than present state-of-the-art. After LC slushing, pre-cleaning and pre-screening are performed at about four percent consistency followed by pulp fractionation. By separating short and long fiber fractions, the following treatment of the long fiber fraction serves economy (energy saving) and quality (by dispersion and/or beating). While the short fiber fraction is not further treated, with the exception of a possible dewatering, the long fiber fraction is dispersed, beaten or both. Beating improves strength properties, while dispersion affects appearance in terms of cleanliness. Depending on the structure of the paper machine, long and short fiber fractions are either blended or used in separate plies of the paper produced. In the latter case, the top layer is made of the long fiber fraction because this pulp contributes to a better performance and printability. The rejects generated by slushing, pre-cleaning and pre-screening, fine cleaning and fine screening totals about seven percent which equals 220,000 tonnes in 1994.



Source: Institut für Papierfabrikation, Darmstadt (1995)

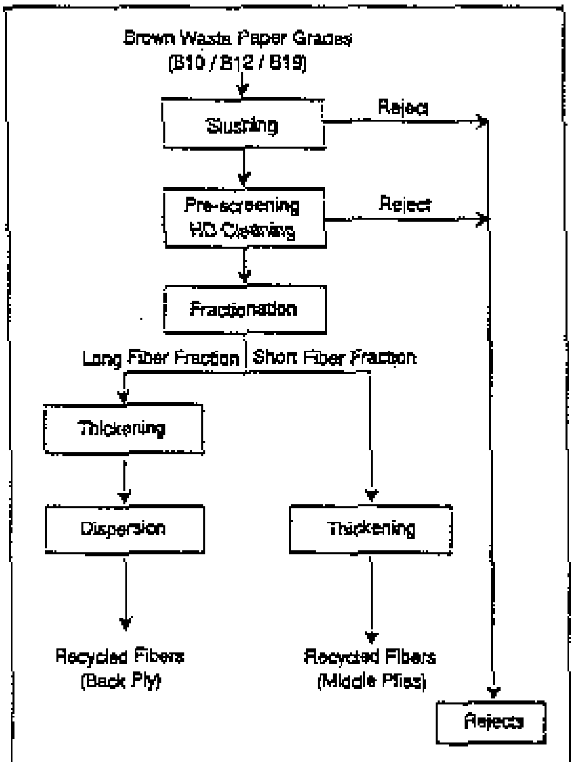
Fig. 1.3.-23 Simplified Scheme of Waste Paper Processing for Corrugating Medium and Testliner IfP 1995

1.3.2.2.2 *Folding Boxboard*

The production of folding boxboard and other board grades (e.g. lined and unlined grey board) totals 2.0 million tonnes based on 80 percent waste paper such as mixed waste (B10, B12) and supermarket waste (B19) for inner layers, news for the back layer and woodfree or wood-containing waste paper for the top layer. The waste paper volume used amounts to 1.6 million tonnes. The dominant proportion consists of ordinary waste paper grades, whereas smaller volumes comprise medium grades (back layer), superior grades (top layer) and kraft-containing grades (top and/or back layers).

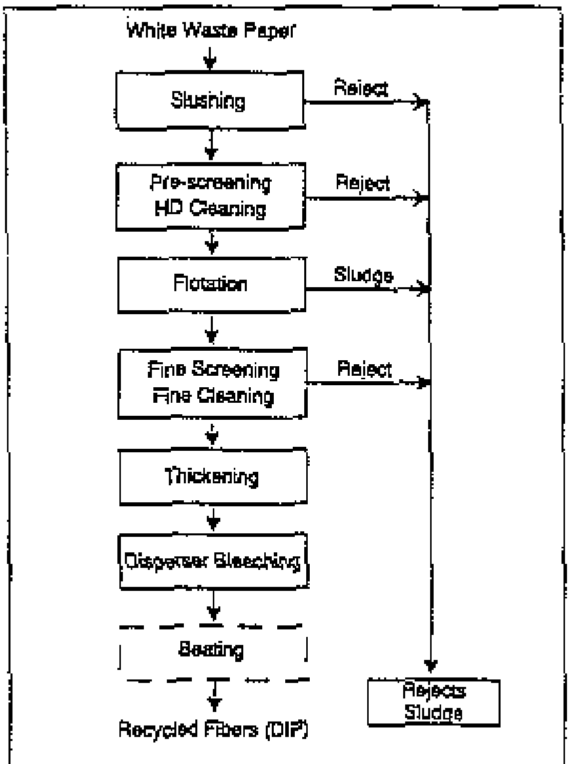
Fig 1.3.-24 shows the layout of a stock preparation plant for the production of the back and middle layers of folding boxboard. Considering that folding boxboard exists of various plies, fractionation is very common. But in contrast to the production of corrugating medium and testliner, short and long fiber fractions are used separately in different layers of the board.

The utilization of waste paper for the top layer of folding boxboard requires a flotation process in order to fulfil optical requirements (Fig. 1.3.-25). Before flotation, slushing and pre-cleaning/pre-screening are performed. After flotation fine screening and fine cleaning stages are established before the DIP is dewatered, followed by storage or post-bleaching in combination with dispersion. Due to the fact that for these purposes often woodfree waste paper grades (office waste) are used which are non-impact printed (toner of laser prints), dispersion is consequently required in order to obtain optical homogenity and cleanliness.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 1.3.-24 Simplified Scheme of Waste Paper Processing for Folding Boxboard (Back and Middle Plies) IfP 1995



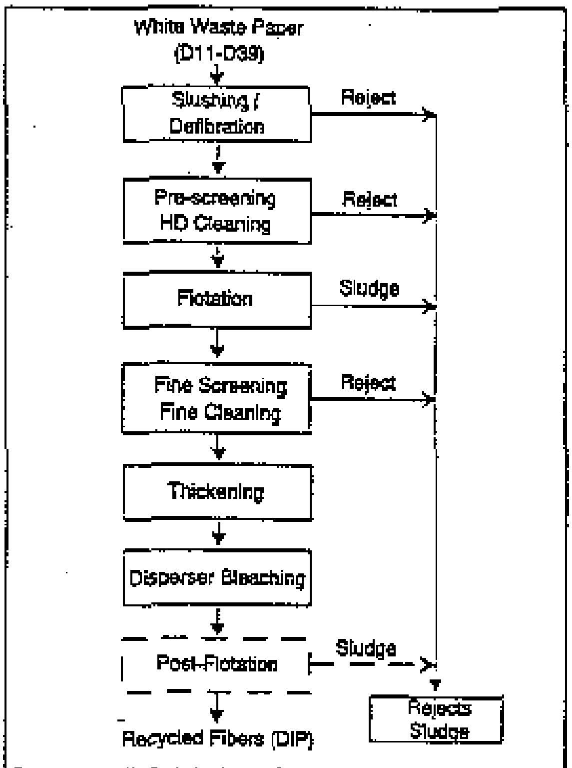
Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 1.3.-25 Simplified Scheme of Waste Paper Processing for Folding Boxboard (Top Ply) IfP 1995

1.3.2.2.3 Graphic Papers

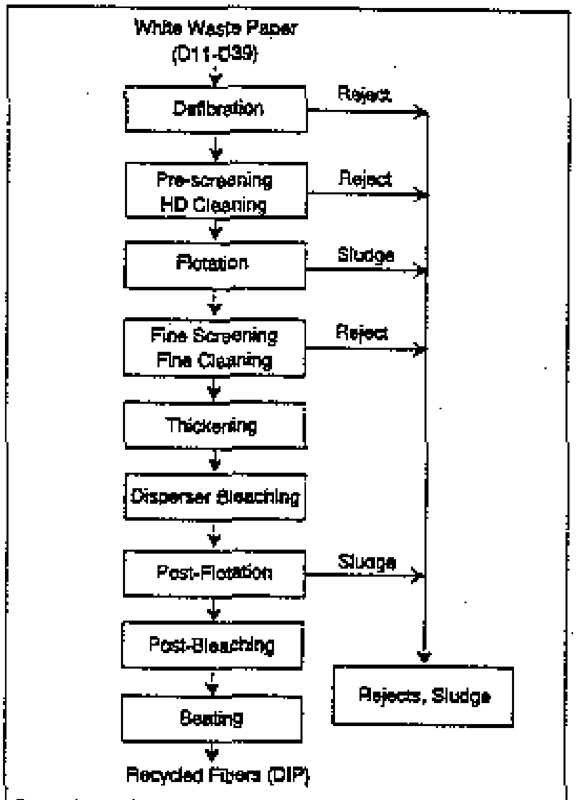
The traditional layout of a stock preparation for manufacturing graphic papers such as news (1.5 million tonnes) and recycled graphic paper (0.3 million tonnes) from wood-containing waste paper is shown in Fig. 1.3.-26. In such stock preparation plants HC slushing is common. After pre-cleaning and pre-screening, flotation is performed followed by multi-stage fine cleaning and fine screening in order to control the stickies content. After dewatering, disperser bleaching is state-of-the-art.

Upgrading treatment of wood-containing DIP for SC- or LWC-papers is identical with a stock preparation plant for news up to the disperser bleaching stage (Fig. 1.3.-27). Additional treatments then comprise post-flotation, post-bleaching and gentle beating to adjust the fiber properties to the requirements of such papers with their higher quality profile in terms of cleanliness and printability.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 1.3.-26 Simplified Scheme of Waste Paper Processing for Graphic Papers (Newsprint, Recycled Paper) IfP 1995



Source: Institut für Papierfabrikation, Darmstadt (1995)

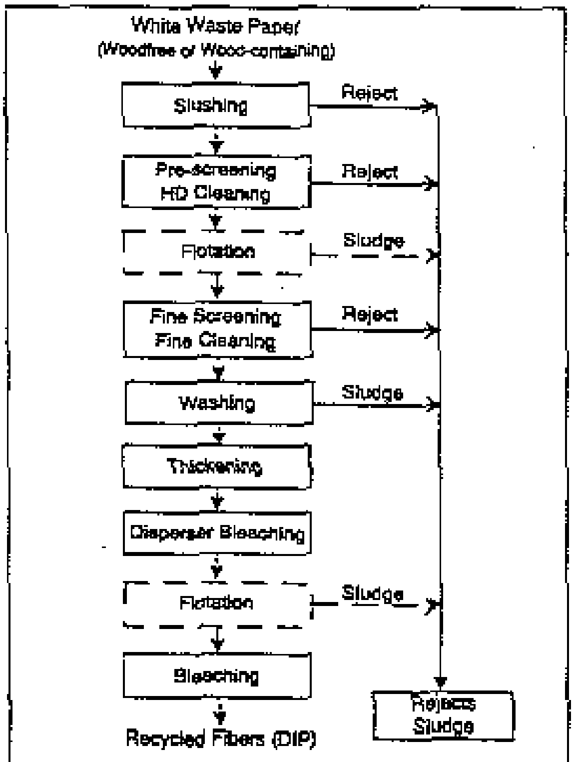
Fig. 1.3.-27 Simplified Scheme of Waste Paper Processing for High-Grade Graphic Paper (SC/LWC-Paper) IfP 1995

A well operating waste paper processing plant is characterized by many technological details such as the combination of the accept and reject flows within the screening and cleaning cascades, the white water treatment and reuse of residues and the reject management system. In this context, the design of the white water system with its loops, which are not shown in the flow sheets presented, is very important. For example, in manufacturing DIP for news, there exist stock preparation plants with anything from none up to three dissolved air flotation systems for white water treatment.

1.3.2.2.4 Sanitary Papers

Sanitary papers produced total 0.9 million tonnes based on 69 percent waste paper which corresponds to 0.6 million tonnes of waste paper partly in terms of wood-containing ordinary grades (e.g. news and magazines) and partly as medium grades. Because of limited waste paper availability and economy, woodfree waste paper (superior grades) are of minor importance.

According to Fig. 1.3.-28 the waste paper processing plant is relatively costly because of multi-stage deinking based on flotation and washing which results in a large volume of sludge for further processing or disposal. Besides ink removal deinking of waste paper for manufacturing of soft sanitary paper must aim at a most effective de-ashing. The furnish based on recycled fibers must contain not more than a few percent of residual fillers and pigments which had been applied in previous papermaking and coating.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 1.3.-28 Simplified Scheme of Waste Paper Processing for Sanitary Paper

HP 1995

The ash content of the furnish and the paper produced affect most of the important properties of sanitary paper such as softness and water absorbency. Besides ash, fines must be also removed. The removal of printing ink, fillers/pigments and fines results in a volume of sludge in the range of 25 percent to 30 percent whereas screening and cleaning contribute to a further reduction of the yield. Finally about 30 percent to 35 percent of the waste paper processed must be regarded as waste (rejects and sludge) which is increasingly used by the cement industry.

1.3.3 Waste from Waste Paper Processing Paper Mills

1.3.3.1 Composition and Volume

Industrial manufacturing activities are unavoidably linked with the generation of solid waste, because it is impossible to operate any process at 100 percent efficiency or yield. In the first place, waste management at paper mills must aim at the avoidance of waste by following measures:

- Reduction of waste volume leaving the manufacturing processes by application of internal measures which improve retention in papermaking (e. g. by means of retention aids, save-alls, closure of white water loops).
- In-mill reuse of waste in terms of fibers recovered from waste water clarifier sludge or by energy recovery (e. g. bark, sludge, rejects).

Waste volume reduction must be regarded as the primary option, followed by external waste utilization in other industries, energy recovery by the paper industry and other forms of reuse of waste. Waste reduction at source eases the control of problems associated with the downstream handling of waste.

In general, intensified waste paper utilization leads to an increase of the volume of waste, particularly as rejects and deinking sludge. Of course, one of the advantages of waste paper processing is an overall reduction of the volume of municipal waste. But then the volume of industrial waste has to increase due to rejects of cleaning and screening and deinking sludge generated by sophisticated upgrading measures in waste paper processing and because of efficient multi-stage waste water treatment to comply with tight discharge standards.

Table 1.3-10: Waste of the Paper Industry

Wood Residues	Stock Preparation Rejects	Sludges	Incineration Waste	Others
Bark	Ragger Tail	Deinking Sludge	Ash	Chemicals
Sawdust	Drum Reject	Clarifier Sludge	Cinders	Waste Oil
etc.	Screening Rejects	Biological Sludge	Flue Ash	Wires
	Reject of Cleaners		Gypsum	Felts

Source: Institut für Papierfabrikation/Darmstadt (1995)

Table 1.3.-10 classifies the main components of paper mill waste such as bark (from mechanical pulping), rejects, sludges, incineration waste and miscellaneous. The management of these components requires measures appropriate to their composition, ash content, dry content and the possibility of pollution by eventually harmful substances. The weight-related subdivision of different waste components in various production groups of the German paper industry is shown in Table 1.3.-11. The volumes presented refer to wet matter with different dry contents. They reflect the differing inputs of raw materials into the mills in various production groups.

The composition of paper mill waste varies considerably depending on the type of raw materials used at different mills and the number and types of cleaning and screening stages applied. In the case of trace components such as heavy metals or organochlorinated compounds, possible contaminations by virgin furnish components used in preceding papermaking (e. g. chemical pulp, additives) must be taken into account. Sludge and rejects of deinking plants and of non-deinking waste paper mills can contain trace components of chemicals, additives and printing inks used in previous papermaking, paper converting and printing. Some of these materials are still loaded with heavy metals or with organochlorinated compounds.

Physical and chemical characteristics of waste of German paper mills are shown in Table 1.3.-12. In view of set limits of governmental regulations, paper mill waste is not considered to be hazardous. This is also valid for deinking sludge which was sometimes regarded as contaminated with heavy metals.

Table 1.3.-11: Waste of Different Production Groups of the German Paper Industry (1994) (Figures in tonnes of wet state)

	Woodfree Paper and Board	Coated Paper	Wood-containing Paper	Sanitary Paper				Paper and Board from Recycled Fiber					Specialty Paper	Total
				Virgin Fiber	Recycled Fiber without Deinking	Recycled Fiber with Deinking	Total	Graphic Paper with Deinking	Board without Deinking	Board with Deinking	Others without Deinking	Total		
Bark	0	186,468	36,116	0	0	0	0	7,734	570	0	0	8,304	407	231,295
Rejects VF	0	38,108	8,212	0	0	5,000	5,000	4,480	281	0	0	4,761	458	56,539
Rejects RF	0	1,720	0	0	506	6,200	6,706	20,820	231,786	5,426	36,726	294,758	181	303,165
Sludge	27,972	211,636	9,758	50	2,120	147,500	149,670	567,098	65,108	12,880	22,756	667,842	76,505	1,465,184
• Clarifier	8,852	43,583	12	0	0	2,120	2,120	21,827	2,275	0	7,000	31,102	46,259	131,928
• Biological Sludge	19,120	190,053	9,746	50	0	50	50	32,609	62,833	12,880	3,848	112,179	30,247	361,386
• Deinking Sludge	0	0	0	0	0	30,000	30,000	318,780	0	0	0	318,780	0	348,780
• Mixed Sludge	0	0	0	0	0	117,500	117,500	193,882	0	0	0	193,882	0	311,382
Incineration Waste	1	53,361	2,108	0	0	0	0	78,368	13,267	0	5,343	96,978	26,842	179,282
• Fly Ash	1	44,652	2,100	0	0	0	0	76,971	12,907	0	4,933	94,811	26,671	168,235
• Gypsum	0	8,709	0	0	0	0	0	1,397	300	0	410	2,167	171	11,047
Others	1,788	25,373	1,390	161	999	803	1,963	1,304	319	0	250	1,873	57,550	89,937
• Paper Waste	1,709	11,905	746	90	650	0	740	0	70	0	250	320	46,816	63,136
• Others	79	13,468	644	71	349	803	1,223	1,304	249	0	0	1,553	10,734	27,700
Total Waste	29,761	538,666	57,576	211	3,625	159,503	163,339	679,804	311,331	18,306	53,167	1,062,608	161,944	2,013,894

VF: Virgin Fibers
RF: Recycled Fibers

Source: Chryssos, G. et al. (1995)

Table 1.3-12: Physical and Chemical Characteristics of Waste of German Paper Mills*

		Sludge				Bark	Rejects	Incineration Waste
		Biological	Clarification	Deinking	Mixed			
Dry Content	%	6.4 - 32.1	29.4 - 52.7	38.1 - 62.1	24.7 - 58.5	19.9 - 73.5	9.2 - 75.1	35.6 - 100
Ash Content	%	14.5 - 65.0	23.9 - 74.5	36.4 - 67.3	16.7 - 53.3	71.0 - 97.0	2.7 - 93.4	59.3 - 99.8
Heating Value	kJ/kg (wet)	215 - 2,315	40 - 5,751	1,236 - 4,321	1,140 - 3,020	820 - 11,427	70 - 25,650	--
	kJ/kg (dry)	8,800 - 26,430	1,990 - 13,590	4,750 - 8,600	2,500 - 13,490	15,140 - 19,620	7,810 - 36,740	--
pH		5.9 - 8.6	6.8 - 8.5	6.8 - 8.3	6.6 - 7.7	3.9 - 5.3	5.6 - 8.9	9.2 - 12.8
S	%	0.3 - 1.3	< 0.1 - 0.20	0.06 - 0.12	0.05 - 0.24	< 0.05 - 0.08	< 0.05 - 0.18	--
F	%	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	--
Cl	%	0.02 - 0.11	0.01 - 0.08	0.001 - 0.11	0.01 - 0.07	0.01 - 0.02	0.01 - 6.1	--
Br	%	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05	--
I	%	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	< 0.10	--
C	%	17.3 - 43.4	13.2 - 37.2	19.1 - 35.8	24.5 - 41.7	47.4 - 50.3	--	0.45 - 3.5
N	%	0.91 - 8.10	0.20 - 0.92	0.16 - 0.51	0.34 - 1.88	0.48 - 0.79	--	< 0.1 - 0.6
H	%	2.6 - 6.00	1.8 - 5.3	2.6 - 4.7	3.3 - 5.2	5.7 - 6.0	--	0.07 - 1.3
NH_4 - N	mg/kg	250 - 3,000	< 150 - 210	< 150	< 150 - 980	< 150	--	< 150
P	mg/kg	1,820 - 16,180	90 - 7,280	300 - 500	530 - 3,060	340 - 600	--	410 - 6,980
K	%	0.17 - 0.80	0.01 - 1.3	0.08 - 0.30	0.07 - 0.28	0.08 - 0.24	--	0.20 - 5.5
Ca	%	1.2 - 9.6	0.39 - 21.1	1.54 - 14.9	0.42 - 16	0.66 - 1.6	--	3.4 - 25.9
Mg	%	0.15 - 1.0	0.15 - 1.7	0.16 - 0.79	0.17 - 0.62	0.06 - 0.81	--	0.26 - 1.64
Pb	mg/kg	10.8 - 394	10 - 210	9.5 - 79.4	14.0 - 93	2.0 - 14.6	< 10 - 91	125 - 166
Cd	mg/kg	0.15 - 9.1	0.01 - 0.98	0.02 - 1.5	0.08 - 1.1	0.39 - 2.9	0.02 - 15.4	< 0.3 - 4.4
Cr	mg/kg	5.8 - 116	8.8 - 903	4.8 - 96.6	12.9 - 311	0.70 - 11.9	< 10 - 69	52 - 71
Cu	mg/kg	33.6 - 494	19.9 - 195	64.2 - 345	18 - 206	3.0 - 54.3	12.2 - 270	57 - 289
Ni	mg/kg	< 10 - 247	< 10 - 63.5	< 10 - 31.3	< 10 - 17	< 5	< 30	20 - 42
Hg	mg/kg	0.16 - 3.3	0.10 - 1.1	0.1 - 0.89	0.11 - 0.25	0.07 - 0.23	0.07 - 15.9	< 0.1 - 1.1
Zn	mg/kg	89.7 - 2,350	6.4 - 460	34.2 - 1,320	84.6 - 320	74 - 173	10.5 - 2,330	264 - 808
PCB	mg/kg	< 0.30	< 0.30	< 0.30	< 0.30	--	--	--
AOX	mg/kg	35 - 320	< 30 - 650	160 - 1,200	45 - 510	< 30 - 36	--	< 30 - 690
PCDD/PCDF	ng I-TE/kg **	2.0 - 4.3	0.53 - 5.7	26.5 - 58.3	--	--	--	--

* According to Standard Test Methods of the German Organization for Standardization (DIN)

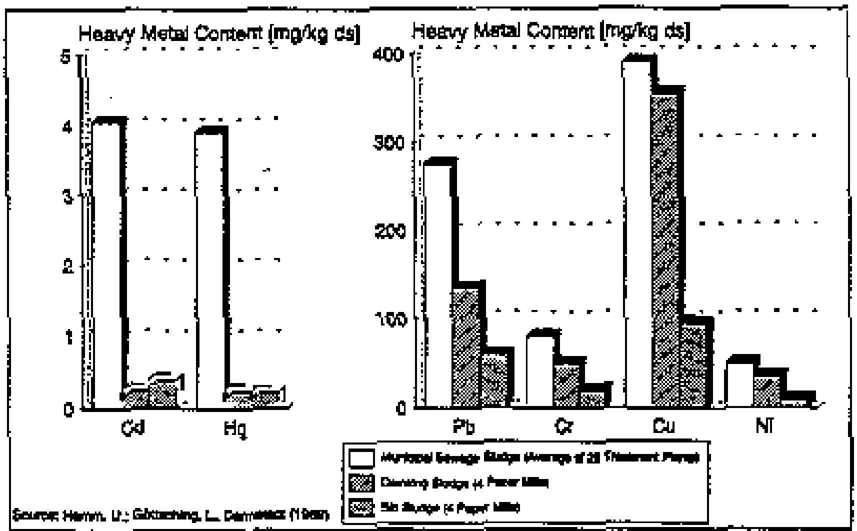
** I-TE = International Toxicity Equivalent according to NATO/CCMS

Source: Chryssos, G. et al. (1995)

Deinking sludge is characterized by a high ash content, which varies in a broad range affected by the grade(s) of recovered paper, the number and types of processes (e. g. flotation and wash stages) applied and the quality requirements of the paper manufactured. Ash of deinking sludge consists mainly of clay constituents (aluminium silicate), calcium carbonate and negligible amounts of titanium dioxide or other fillers and pigments. The ash content is in a range between 45 percent and 70 percent, with sludge of paper mills manufacturing sanitary paper and using deinked pulp falling at the higher end of this range. The heating value of dry sludge varies with the ash content (5 MJ/kg to 10 MJ/kg oven-dry sludge).

Nitrogen and phosphorus contents of deinking sludge are negligibly compared with biological sludge. This must be considered, when deinking sludge is used in composting and agricultural application because it requires the addition of further components containing sufficiently high contents of nitrogen and phosphorus.

The level of heavy metals of sludge of waste paper processing paper mills is generally low. In Fig. 1.3.-29 the concentration of heavy metals of deinking sludge is compared with the content of heavy metal of bio sludge of waste water treatment plants of paper mills and of municipal sewage sludge. These data make evident that sludge of deinking plants is less contaminated than those of municipal waste water treatment. Particularly the concentration of cadmium and mercury is insignificant, sometimes even below the detection limit of the test method applied (atomic absorption spectrometry). Only the concentration of copper is of the same order of magnitude as that of municipal sewage sludge. The copper content of deinking sludge is mainly caused by blue pigments of printing inks based on phthalocyano compounds.



Source: Hamm, U.; Göttsching, L. [illegible] (1995)

Fig. 1.3.-29	Heavy Metal Content of Deinking Sludge, Bio Sludge and Municipal Sewage Sludge	IfP 1995

Traces of halogenated organic compounds such as polychlorinated biphenyls (PCBs) and polychlorinated dibenzodioxins (PCDDs) as well as polychlorinated dibenzofurans (PCDFs) have to be taken into account, too. PCBs were used in manufacturing of carbonless copy paper not later than in the early seventies. PCB discharges from waste paper processing mills may be caused by old post-consumer waste paper. The PCB level of deinking sludge has certainly decreased significantly since then. Recent data obtained from several deinking plants confirm that PCB concentration is below the detection limit of 0.3 mg/kg dry solids (0.3 ppm = 0.3 parts per million).

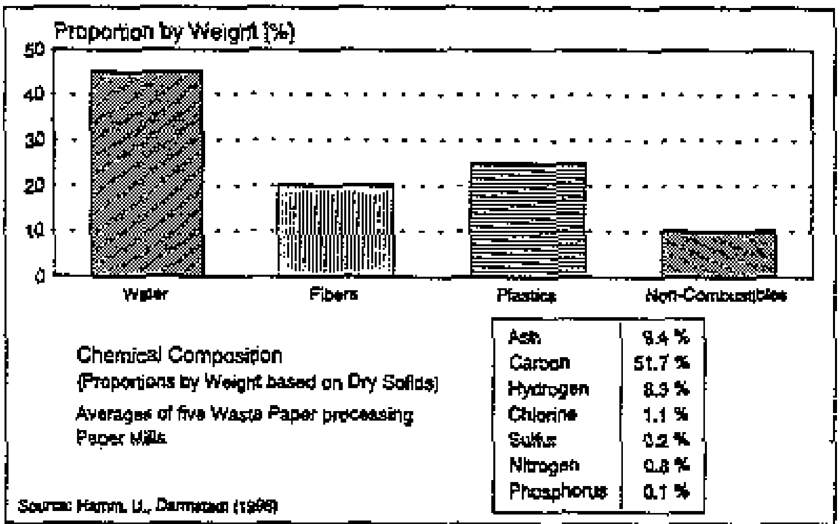
PCDD/PCDF concentrations of waste of waste paper processing paper mills show a similar pattern of decline. Due to the ongoing change from elementally chlorine bleaching to chlorine dioxide and to totally chlorine free pulp bleaching; the PCDD/PCDF contents of solid waste of German paper mills decreased significantly. Today, PCDD/PCDF concentrations of deinking sludge ranges between of 25 ng I-TE/kg and 60 ng I-TE/kg dry solids (I-TE = International Toxicity Equivalent). These figures are not significantly higher than the average contents of PCDD/PCDF of municipal sewage sludge. As a result of modifications of the bleaching sequences of virgin chemical pulps dioxin formation is declining in most pulp producing countries. Consequently, dioxin discharges from waste paper processing paper mills, which are already low, will gradually decrease further.

The parameter AOX (adsorbable organic halogen-containing compounds) plays an essential role in German regulations. For example, the direct application of sewage sludge on agricultural soil is regulated with respect to heavy metal concentration, PCB and dioxin concentrations as well as AOX. In many cases the AOX of deinking sludge is above the set limit of 500 mg/kg dry solids. Investigations at the Department of Paper Science and Technology, Darmstadt, made evident that up to 80 percent of AOX of deinking sludge is caused by (chlorinated) yellow pigments being a component of printing inks. However, these pigments are water-insoluble and non-biodegradable. Nevertheless, the analytical procedure for the determination of AOX of solid waste includes these compounds, which will not be released in nature (aqueous phase) by microbiological forces. Therefore, no bio accumulation of this type of AOX generating printing ink pigment must be expected, not even in the long-term.

Rejects of waste paper processing mills are composed of various materials such as plastic bags, plastic bottles, toys, wooden pieces, metals, glass, sand, stickies etc. Rejects are generated in all waste paper processing mills, including deinking plants.

Sources of rejects are slushing in pulpers and drums, high-density cleaning, pre-screening, fine screening and light-density reject removal. Due to the heterogeneous composition of the rejects analytical data shown in Table 1.3.-12 and Table 1.3.-13 vary in a wide range.

Fig. 1.3.-30 shows the composition and chemical characteristics of screening rejects of waste paper processing mills manufacturing corrugating medium totally based on recycled fibers. The rejects contain a high proportion of plastic material. This is the reason for a high chlorine content of this kind of reject. PVC compounds such as foils, adhesive tapes, carrying straps of packaging must be regarded as chlorine sources. Impregnated wood and PVDC-coated paper are further chlorine sources. The chlorine content of screening rejects can reach six percent (dry matter).



Source: Hamm, U., Darmstadt (19[illegible])

Fig.1.3.-30: Composition of Screening Rejects of Corrugating Medium Production based on Waste Paper

IfP 1995

Table 1.3.-13 presents the water-soluble proportion of various chemical compounds of paper mill waste. The analysed figures are compared with the legal standards for landfilling of municipal waste according to the Municipal Waste Management Provision. The obtained data for paper mill waste are in many cases below the analytical detection limits. The maximum values of paper mill waste do not usually exceed the set standards. The standards for the parameters extractable lipophilic matter and TOC will not be enforced till the year 2005. As far as the water-soluble proportion of heavy metals is concerned, the levels of paper mill waste are very low. The analysed concentrations of water extracts are generally in the lower ppb-range, far below legal limits (ppb = parts per billion). According to these findings, waste of waste paper processing can be disposed of by landfilling on dumps for municipal waste.

Table 1.3-13: Chemical Characteristics of Aqueous Extracts of Waste of German Paper Mills*

Parameter		Sludges				Bark	Rejects	Incineration Waste	Legal Standards**
		Biological	Clarification	Deinking	Mixed				
pH		6.9 - 8.2	7.2 - 8.3	7.1 - 7.9	6.7 - 7.6	4.4 - 7.0	6.0 - 8.6	9.8 - 12.9	5.5 - 13.0
Conductivity	µS/cm	1,176 - 2,600	213 - 1,690	590 - 1,180	601 - 2,310	297 - 911	120 - 1,361	238 - 7,910	≤ 50,000
Water-soluble Proportion	mg/l	958 - 2,220	410 - 2,048	480 - 1,380	606 - 3,063	577 - 2,290	291 - 1,337	360 - 1,967	--
Ash Content	mg/l	--	--	--	--	157 - 453	139 - 653	122 - 1,219	--
Extractable Lipophilic Matter	mg/l	< 0.1 - 1.9	< 0.1 - 19.5	< 0.1 - 4	< 0.1 - 8.8	< 0.1 - 1.9	< 0.1 - 16.1	< 0.1 - 8.3	≤ 0.8
BOD$_5$	mg/l	--	--	--	--	192 - 3,030	53 - 280	--	--
COD	mg/l	--	--	--	--	840 - 7,910	192 - 1,071	--	--
TOC	mg/l	223 - 930	15 - 618	85 - 439	63 - 1,010	112 - 2,791	60 - 302	< 10	≤ 100
AOX	mg/l	0.01 - 0.62	< 0.05 - 0.38	< 0.1 - 0.72	0.07 - 0.26	< 10	42 - 425	< 10 - 32	≤ 1.5
Fluoride	mg/l	< 5	< 5	< 5	< 5	< 5 - 28.5	< 5	< 5	≤ 25
Sulfate	mg/l	< 40 - 161	< 40 - 228	43.5 - 168	82 - 300	< 100	< 20 - 250	< 100	--
Chloride	mg/l	5.4 - 47.7	< 5 - 93	2.1 - 28	< 5 - 20.5	< 10 - 22	4.5 - 38	< 10 - 36	--
Cyanides	mg/l	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 5	< 0.01	≤ 0.05
Nitrite	mg/l	< 0.05 - 0.46	< 0.05 - 0.11	< 0.05 - 0.09	< 0.05 - 0.06	< 1	< 0.05 - 0.15	< 0.05 - 0.81	--
Phenols	mg/l	0.02 - 0.20	0.01 - 0.16	< 0.01	< 0.01 - 0.48	< 0.01 - 3	< 0.01 - 0.11	< 0.01 - 0.05	≤ 50
Ammonium	mg/l	98 - 250	< 1 - 19	< 1	< 1 - 128	< 1 - 4.6		< 1 - 18.4	≤ 200
As	µg/l	< 5 - 30	< 10 - 10	< 10	< 10 - 11	< 10 - 13.8	< 10	< 10	≤ 500
Pb	µg/l	< 100	< 100	< 100	< 100	< 10 - 22	< 10 - 59	< 10 - 30	≤ 1,000
Cd	µg/l	< 1	< 1 - 2.8	< 1	< 1 - 1.4	< 1 - 4.2	< 1 - 1.5	< 1	≤ 100
Cr	µg/l	< 100	< 100	< 100	< 100	< 100	< 100	< 100	--
Cu	µg/l	< 25 - 36	< 25 - 160	< 25 - 38	< 5 - 25	< 25	< 25 - 394	< 25	≤ 5,000
Ni	µg/l	< 100	< 100	< 100	< 100	< 100	< 100	< 100	≤ 1,000
Hg	µg/l	< 1 - 7.3	< 1 - 2	< 1 - 3	< 1	< 1 - 1.1	< 1	< 1	≤ 20
Zn	µg/l	53 - 270	56 - 620	98 - 4,450	42 - 240	180 - 1,650	55 - 2,600	< 25 - 95	≤ 5,000

* Aqueous Extracts were performed according to the German Standard Test Method DIN 38 414 Part 4: Determination of the Leachability by Water

** Legal Standards according to the Municipal Waste Management Provision (1993)

Source: Chryssos, G. et al. (1995)

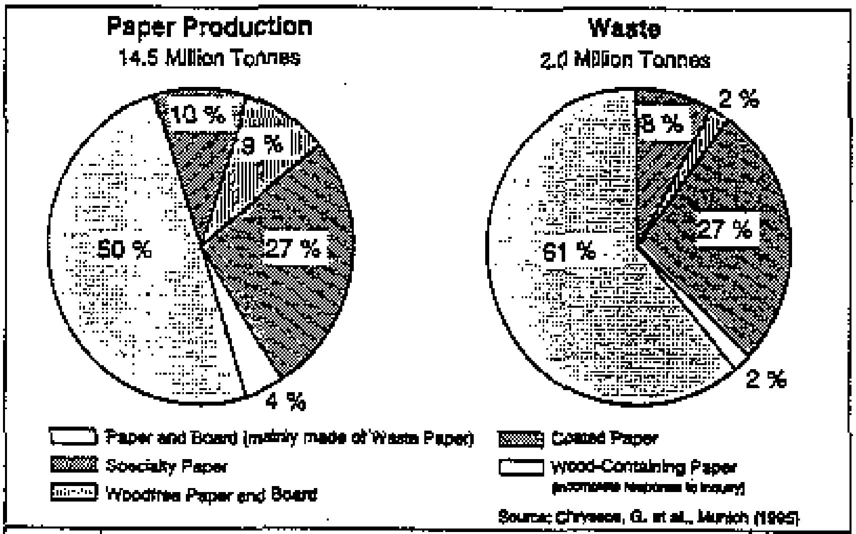
In 1994 the German paper industry generated 2.0 million tonnes of waste (in wet state). Sludges accounted for 57 percent, rejects for 18 percent, bark for eleven percent, incineration waste for nine percent and others for five percent (Table 1.3.-14).

Paper and board mainly based on recycled fibers amounted to 50 percent of the total German paper production. The volume of waste generated by this production group, however, was about 60 percent of the total waste (Fig. 1.3.-31). The types of waste of waste paper processing paper mills are shown in Fig. 1.3.-32. Sludge accounted for 66 percent and rejects for 25 percent. About 80 percent of the sludge was generated by deinking plants and as a mixture of deinking sludge and sludge of biological effluent treatment plants (bio sludge).

Table 1.3.-14: Solid Waste from all German Paper Mills (1994)
(Tonnes refer to wet state)

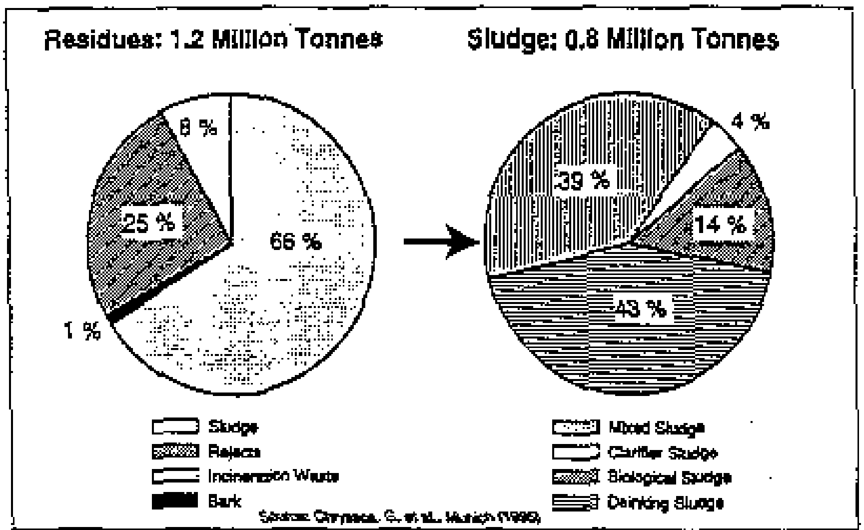
Waste	Tonne/a	%
Bark	231,000	11.4
Rejects	360,000	17.8
Sludges	1,165,000	57.5
Incineration Waste	179,000	8.8
Others	90,000	4.5
Total	2,025,000	100.0

Source: Chryssos, G. et al./Munich (1995)



Source: Chryssos, G. et al., Munich (1995)

Fig. 1.3.-31 Production of Different Paper Grades and Waste Generation in the German Paper Industry (1994) IfP 1995



Source: [illegible] G. et al., Munich (1995)

Fig. 1.3-32 Residues and Sludges generated only in Waste Paper Processing Paper Mills in Germany (1994) IfP 1996

1.3.3.2 Treatment, Recovery and Final Disposal

Solid waste of paper mills mainly consists of various sludges, e. g. deinking sludge, sludge of white water clarification and sludge of effluent treatment plants. Other components of solid material such as rejects are generated by slushing in pulpers or drums and screening or cleaning. The total volume of such sludges occurs in a wet state from various processes with solid contents of one percent to five percent. Unless sludge can be used by the production process (only realized in some waste paper processing mills manufacturing corrugating medium, testliner and board) the sludge must be mechanically dewatered to an optimum dry content for adequate downstream handling. Sludge going to incineration must be as dry as possible for the benefit of energy recovery.

Most commonly, dewatering is performed by belt and screw presses. Screw presses can achieve the highest dry solid content (50 percent to 60 percent), depending on sludge characteristics and sludge mixtures. Generally, in a paper mill the optimum overall dewatering result will be achieved if sludges with sufficient (fiber sludge) and with poor (biological sludge, deinking sludge) dewatering behaviour are blended. Simple gravity thickening of sludge is not widely practised.

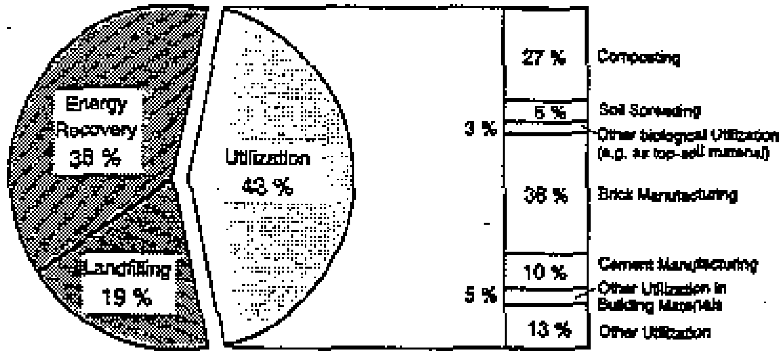
Pre-treatment aiming at the improvement of sludge drainage is common practise in dewatering of biological sludge. Organic polymers are applied similar to those used as retention aids in papermaking.

Further water removal from dewatered sludge cakes can be accomplished by drying. Drying is normally carried out in the case of energy recovery in external incineration plants. In this case, drying is accompanied by pelletizing the dried sludge to facilitate boiler operation and to control particulate emissions. Nevertheless, sludge drying opens up a wider range of waste management options producing a more stable material for temporary storage. However, drying is relatively expensive and seems to make sense only in the case that a high value-added material for utilization can be generated. Drying is performed by steam heated contact dryers, hot air flash dryers or superheated steam flash dryers.

As shown in Fig. 1.3.-33 72 percent of the total waste volume of the German paper mills was utilized including energy recovery. About 28 percent of the waste including ash of sludge incineration was disposed of by landfilling.

Today, incineration is increasingly applied for energy recovery of sludge. The organic proportion of sludge represents in many cases a significant heating value. Paper mill sludges have a heating value of 6 MJ/kg to 20 MJ/kg dry solids. The options for sludge incineration are as follows:

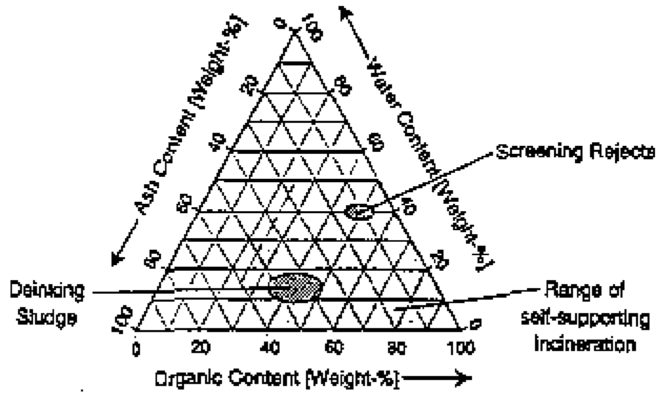
- Incineration in combination with bark in bark boilers
- Incineration in boilers in combination with coal
- Separate sludge incineration.



Source: Chryssos, G. et al., Munich (1995)

Fig. 1.3.-33 Utilization and Disposal of Paper Mill Waste in Germany (1994)

IfP 1995



Source: Hamm, U., Darmstadt (1996)

Fig. 1.3.-34 Fuel Triangle of Waste of the Paper Industry IfP 1995

For separate sludge incineration the German paper mills employ various types of grate. multi-hearth and fluidized bed boilers. For deinking sludge, fluidized bed boilers seem to be superior and are at present the predominant type of new installations. Fluidized bed boilers can be fed with 100 percent sludge, although the use of support fuel (e. g. coal, oil or gas) is common is some cases. The need for support fuel depends on the dry and ash contents of the sludge. A dry content of at least 45 percent to 60 percent is required for self-combustion of sludge. Fig. 1.3.-34 shows the so-called fuel triangle, which illustrates the connection between the combustible proportion as organic content, ash content and moisture content of fuels. The range of self-combustion is marked. In this range, sludge can be burnt without any additional fuel. In the fuel triangle the position of highly dewatered deinking sludge (50 percent to 65 percent dry solids) and rejects (45 percent to 55 percent dry solids) shows that both materials are combustible without any support fuel.

Due to their high plastic content, rejects of waste paper processing have high calorific values (> 20 MJ/kg dry solids) and should be suitable for energy recovery. But so far only a few paper mills use their rejects as fuel in combustion plants. Others are afraid that they cannot fulfil the set limits for dioxins and furans (0.1 ng I-TE/m^3) of the purified flue gas. Therefore, in 1994 about 85 percent of the rejects of waste paper processing mills were disposed of by landfilling.

Atmospheric emissions of incineration plants are characterized by several potential pollutants. The most important are sulphur dioxide (SO_2), nitrogen oxides (NO_x), hydrogen chloride (HCl) and hydrogen fluoride (HF), different heavy metals and trace organic compounds, such as dioxins and furans. The key emission discussed in previous years refers to dioxins and furans due to their notoriety with respect to waste incineration and the high toxicity of some of these compounds. Emissions of carbon dioxide and its effect as a greenhouse gas are widely discussed but are of minor importance when burning sludge of waste paper processing mills. Since the organic proportion of sludge must be regarded as biomass, its combustion does not contribute to the greenhouse effect. Released carbon dioxide will be reabsorbed by trees, which is the original source of the most part of this waste.

Table. 1.3.-15: Emissions of In-Mill Incineration Plants in Germany, burning Waste of Waste Paper Processing compared with Legal Standards (17th Regulation of the Federal Emission Control Act)

Parameter		Unit	Plant A	Plant B	Plant C	Legal Standards
Particles		mg/m^3	8.2	6.0	6.4	10
Carbon monoxide	CO	mg/m^3	< 5.0	8.0	8.5	50
Total Carbon	C	mg/m^3	< 1.0	0.3	0.9	10
Hydrogen chloride	HCl	mg/m^3	1,7	0.5	2.8	10
Hydrogen fluoride	HF	mg/m^3	0.03	0.1	< 0.1	1.0
Sulfur dioxide	SO_2	mg/m^3	8.0	15	6.1	50
Nitrogen oxides	NO_x	mg/m^3	190	185	220*	200
Cadmium + Thallium	Cd + Tl	mg/m^3	< 0.0002	0.002	0.01	0.05
Mercury	Hg		< 0.010	0.02	0.02	0.05
Other heavy metals	As, Co, Ni, Sb, Pb, Cr, Cu, Mn, V, Sn	mg/m^3	0.022	0.06	0.01	0.5
Dioxins/Furans	PCDD/PCDF	ng I-TE/m^3	0.002	0.03	0.01	0.1

*at present installation of an equipment to remove NO_x

Plant A: Travelling Grate Furnace
Plant B: Stationary Fluidized Bed Furnace
Plant C: Stationary Fluidized Bed Furnace

Source: Institut für Papierfabrikation/Darmstadt (1995)

Table 1.3.-15 presents atmospheric emissions of three incineration plants, established in previous years in the German paper industry. In plant A a mixture of sludge of waste paper processing (without deinking) and bio sludge is burnt. The fuels of plants B and C are deinking sludge and a minor part of bio sludge. Whereas plant A runs a travelling grate furnace, plants B and C are stationary fluidized bed boilers. These plants are equipped with different flue gas purification systems. The flue gas purification system of plant A consists of a bag filter for particle removal and wet scrubbers in two stages. In plant B particle removal is performed with an

electrostatic precipitator, whilst acid gases are retained by wet scrubbers. Plant C applies bag filters for particle removal and the injection of a lime mixture into the gas stream in order to neutralize acid compounds. The flue gas purification equipments of the three plants include no additional measures such as activated carbon injection or filters to control dioxin/furan emissions because further control of dioxins and furans is irrelevant.

The flue gas emissions of the plants discussed are compared with the standards of the 17th Regulation of the Federal Emission Control Act, valid for plants which incinerate waste and similar matter. Concerning sludge incineration in waste paper processing paper mills, the following conclusions can be drawn:

- Emissions of particles, sulphur dioxide, hydrogen chloride, hydrogen fluoride, carbon monoxide are low compared with the standards. Due to the high ash content of deinking sludge which is rich in calcium carbonate, this sludge is not expected to release all sulphur as sulphur dioxide. Flue gas purification of the state-of-the-art guarantees that no significant environmental impact arise.
- The emission of heavy metals is very low compared with the standards, particularly the emission of cadmium and mercury.
- The emission standard of nitrogen oxides can generally be met by improved combustion control (temperature, oxygen level). In some cases the application of specific measures to remove NO_x could be necessary.
- The stringent emission standard of dioxins and furans (0.1 ng I-TE/m^3) can be satisfied without any additional measures in flue gas purification.

The latter reference is of special interest with respect to plant B. In its fluidized bed boiler shredded rejects of waste paper processing were used as additional fuel. The high plastic content of this material appears to increase dioxin/furan emissions but not above the set limits.

Bottom ash of plant A is used for manufacturing construction materials, the fly ash serves as raw material in the cement industry. Although fly ash of fluidized bed boilers is, in some cases, considered as hazardous waste, the fly ash of plants B and C does not cause environmental concern with respect to reuse. This fly ash is used by the cement industry as well as in manufacturing of construction material. Considering this, it can be concluded that burning of sludge of waste paper processing paper mills does not cause any significant environmental pollution thanks to modern incineration plants and ash disposal. The application of modern combustion as well as flue gas purification technologies makes it possible to burn sludge without exceeding emission standards and without any health hazards.

External utilization of waste can be performed without any environmental pollution. In 1994 about 35 percent of the reused paper mill waste was composted, spread on agricultural soil or used as top-soil material, e. g. for final covering of closed landfills. Composting of paper mill sludges, including deinking sludge, for the production of humus requires blending with other materials, such as bark, municipal sludge, biowaste of households or of other sources, in order to decrease their high carbon/nitrogen ratio (nitrogen content is too low in this case). Composting requires companies which are experienced technically and in marketing. Therefore, paper mills usually composte their waste in cooperation with such companies, which are also responsible for the supply of further waste with a high nitrogen content.

There should be a potential for an extended application of composting, provided there is a market within reasonable transport distances for the compost produced. Composting of sludge and waste paper in combination with biowaste and agricultural waste is currently a research project at the Department of Paper Science and Technology (IfP). The findings indicate, that compost made of different proportions of these materials does not only fulfil stringent requirements, such as degree of maturity or suitability for plant growth, but it also controls parameters, such as salt content and the proportion of organic substances or process-related leachable emissions.

Soil application of mill sludge can improve water retention of soil and increase microbial activity. Due to the high carbon/nitrogen ratio of most of these sludges the nitrogen of soil can be temporary immobilized. In this case additional fertilizer must be added. The benefits of soil application depend to a high extent on the nature of the soil concerned. Independent of the benefits on crop yield, a lasting advantage is an improvement of the structure of soil.

In contrast to North America, where soil application seems to be attractive to many paper mills, in Germany the direct agricultural use of paper mill sludge is controversially discussed, particularly the use of sludge of waste paper processing paper mills. Some Federal States of Germany prohibited soil application of deinking sludge in previous years. Although this sludge fulfils in many cases the standards of the German Sewage Sludge Regulation (Klärschlammverordnung), the authorities argue that there is a lack of knowledge about harmful substances caused by additives which are used in preceding paper converting and printing and which might be adsorbed by deinking sludge.

In Germany about 35 percent of the utilized paper mill waste is used in brick works. By the addition of sludge - mostly deinking sludge - to the raw material of bricks two benefits are achievable. Firstly, the inorganic components (fillers, pigments) of the sludge is added to the brick material. Secondly, the organic components (fines, printing inks), when being burnt, improve the porosity of bricks, which contributes to reduced heating transfer of the bricks.

In 1994 only ten percent of the reused paper mill waste was converted by the cement industry. It is supposed that the cement industry is in a position to make use of a higher volume of rejects, sludge and ash. In Germany, the annual production of cement is about 33 million tonnes manufactured in 65 cement works with about 100 rotary kilns. Ash of burnt deinking sludge with its content of CaO, Al_2O_3 and SiO_2 can be used as a secondary raw material. An attractive option is the direct introduction of sludge into the cement manufacturing process. By introducing sludge into the cement rotary kiln, which is generally oil-fired, the organic fraction of the sludge is burnt. Simultaneously the heating value serves as a secondary fuel. The inorganic fraction is incorporated as a part of the cement. Processes of this type have been put into operation within the last five years. The utilization of rejects as a secondary fuel has been intensified within the last two years.

Further methods for the utilization of ash, deinking sludge and other sludge which have been used to a limited extent, but which may be applied in special cases are as follows:

- Production of light weight aggregates (LWA)

  LWA refers to a group of materials which is used in various construction materials such as concrete blocks and decorative stone. They contribute to a reduction of the final density while maintaining acceptable strength properties. LWA is traditionally used in applications such as bridge decks, high-rise building construction, roofing tiles, wall panels and concrete blocks. It is also finding more application in sea wall and roadway construction.

- Production of particle board
- Production of cat litter
- Mine reclamation.

1.3.3.3 Summary

Unlike the waste of virgin pulp processing paper mills, the waste of waste paper processing mills contains substances which result from previous papermaking, from paper conversion (incl. printing), from the use of paper products and from the collection of waste paper. The removal of these substances (e. g. fillers and pigments or printings inks and adhesives) in waste paper processing generates a higher volume of waste (as percentage related to the stock processed) compared with paper manufacturing based on virgin pulps, if bark of pulping and spent liquor of pulp digesting is not taken into account.

The contamination of rejects and deinking sludge from waste paper processing is on a rather low concentration level, with the exception of the content of chlorine present in rejects caused by a high plastic proportion. Over the years, the content of organochlorinated compounds of deinking sludge has decreased significantly, for example in terms of polychlorinated biphenyls (PCB). The reduction of organochlorinated compounds was partly affected by modifications in pulp bleaching (either elemental chlorine free (ECF) or totally chlorine free (TCF) bleaching) and partly by the substitution of organochlorinated substances used as additives in papermaking and paper conversion.

Contamination of deinking sludge by heavy metals is less than that of sewage sludge of municipal effluent treatment. Today, printing inks play a minor role as a source of heavy metals, with the exception of copper which is present in blue pigments. A major source of heavy metals are fillers and pigments which are partly removed by deinking in waste paper processing followed by incineration or disposal of deinking sludge.

Waste of waste paper processing can be utilized or disposed of in an environmentally sound manner. So far, 80 percent of the waste volume of the total German paper mills is either used as a material for different purposes or as fuel for energy recovery. Not more than 20 percent of the waste volume is still dumped by landfilling. Energy recovery by deinking sludge can be performed without any environmental concern employing combustion plants with flue gas purification according to the present state-of-the-art.

The paper industry aims at further external utilization of its waste materials, for example, in the cement industry with its capacity to make use of rejects, deinking sludge and ash of incineration plants of the paper industry. On the other hand, it is not supposed that increasing volumes of waste might be used by agriculture or compost facilities because of a severe competition with other organic material, e. g. biowaste of households, municipal sewage sludge or waste of agriculture (liquid manure, manure or straw).

1.4 Disposal of Non-recycled used Paper Products

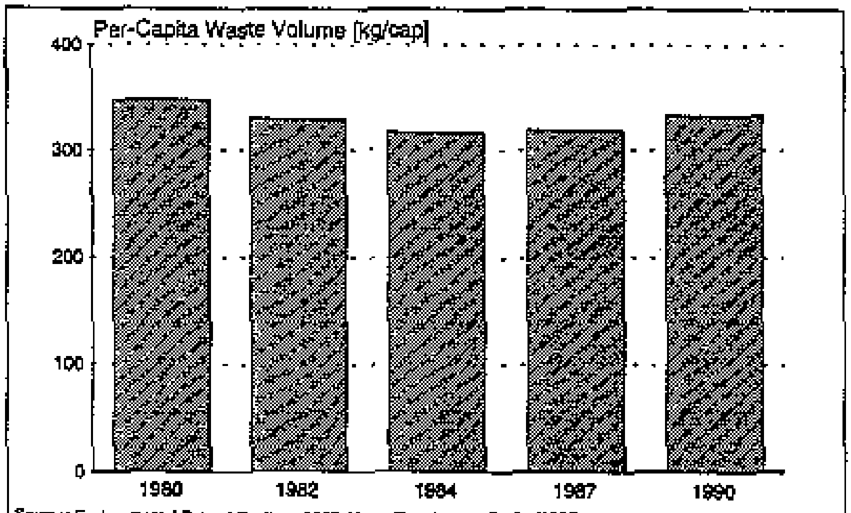
1.4.1 Classification and Volume of Waste

According to the German Federal Bureau of Statistics the total volume of waste which was disposed of amounted to 292 million tonnes (1985). This total volume of waste is divided into categories such as:

- Municipal waste
- Industrial waste
- Sewage sludge
- Construction and demolition waste
- Excavation waste.

The volume of recycled waste is not included in this statistic.

The volume of municipal waste from private households totalled 30.5 million tonnes which corresponds to a proportion of approx. ten percent. The volume of industrial waste was more than 122 million tonnes (42 percent of the total waste), whereas the waste mainly associated with the construction and building industries accounted for 120 million tonnes of the total waste.



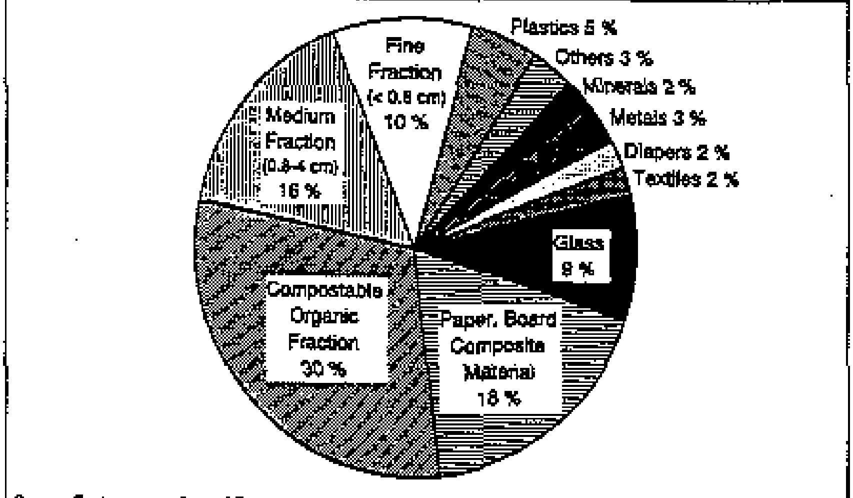
Source: Environmental Data of Germany 1995, Umweltbundesamt, Berlin (1996)

Fig. 1.4-1 Volume of Household Waste per-Capita in Germany IfP 1995

In 1990 the per-capita volume of household waste was 333 kg. According to Fig. 1.4.-1 this indicates only a slight decrease compared with 1980. Since private consumption had significantly increased during this period of time, this was considered as a first success of legal measures giving priority to avoidance and recycling of waste.

1.4.2 Composition of Waste

The last country-wide analysis of the composition of household waste was carried out in 1985. The results are shown in Fig. 1.4.-2. The biggest proportion of the total volume of household waste was the compostible organic fraction called biowaste (e. g. residues of vegetables, garden waste, domestic garbage). For this fraction the Municipal Waste Management Provision foresees a reduction of at least one third realized by separate collecting and biological treatment with anaerobic and aerobic technologies.



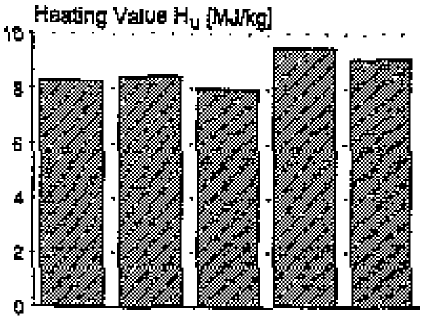
Source: Environmental Data of Germany 1995, Umweltbundesamt, Berlin (1995)

Fig. 1.4.-2 Composition of Household Waste in Germany (1985) IfP 1995

The proportion of paper, board and composite material was about 18 percent in 1990. The volume of these components has been significantly decreased within the last three years due to the Packaging Ordinance. Similar effects must be considered for glass, metals and plastics.

Other fractions of municipal waste are influenced to a smaller extent by avoidance and recycling strategies. The fine (< 0.8 cm) and medium (0.8 cm - 4 cm) fractions of household waste accounted about 25 percent, textiles two percent and diapers two percent. Minerals and hazardous waste are other components of household waste.

Avoidance and recycling will significantly affect the heating value of the residual waste. Nowadays, the heating value of municipal waste is 30 percent to 40 percent higher than the heating value required for self-combustion in waste incineration plants (about 6 MJ/kg to 7 MJ/kg). Fig. 1.4.-3 refers to the influence of different separate collection systems and recycling rates on the heating value of residual household waste. Those figures indicate that in the case of high recycling rates of biowaste the heating value of residual waste will increase, even if paper and plastics will be recycled to a high extent. Therefore, residual waste should remain self-burning in the future.



	No Utilization	Green Bin (Paper, Glass)	Green Bin (4 Groups of Materials)	Bio Bin + Container (Paper, Glass)	Bio Bin + Green Bin (4 Groups of Materials)
Utilization Rate of Paper	0 %	75 %	75 %	50 %	75 %
Utilization Rate of Glass	0 %	80 %	80 %	50 %	80 %
Utilization Rate of Metals	0 %	0 %	50 %	0 %	50 %
Utilization Rate of Plastics/Textiles	0 %	0 %	40 %	0 %	40 %
Utilization Rate of Biowaste	0 %	0 %	0 %	94 %	94 %
Total Utilization Rate	0 %	20 %	25 %	50 %	60 %
Heating Value H_u MJ/kg	8.3	8.6	8.0	9.5	9.1
Change of Heating Value	0 %	- 2 %	- 4 %	+ 14 %	+ 10 %

Utilization Rates based on Household Waste Composition in Germany (1985)
Source: Bilitewski, B.; [illegible], Berlin (1994)

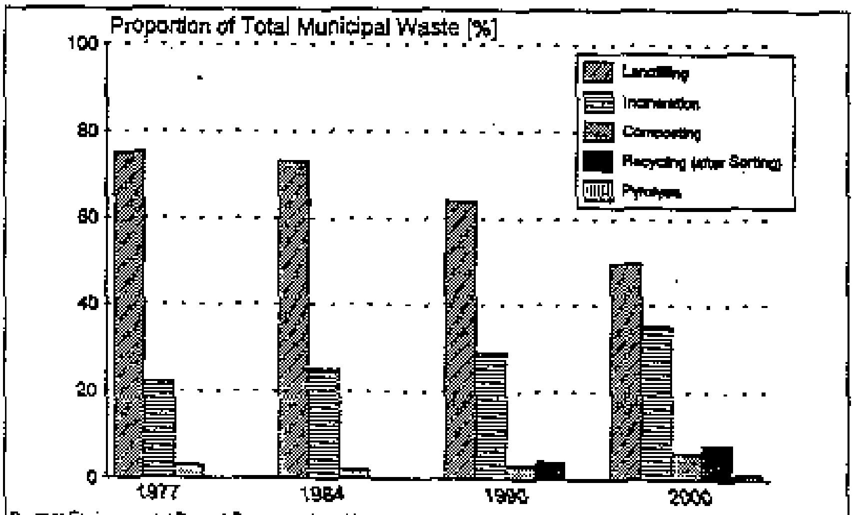
Fig. 1.4.-3 Heating Value of Residual Household Waste depending on Different Utilization Rates IfP 1995

1.4.3 *Alternatives of Waste Treatment*

Fig. 1.4.-4 shows data of the waste treatment strategies in Germany from 1977 to 1990. The proportion of waste going to landfilling slightly decreased from 75 percent in 1977 to 64 percent in 1990. In 1990 incineration accounted for 29 percent, which is only seven percent higher than in 1977. The proportion for composting remained constant during this period of time - on a level of two percent. Sorting prior to recycling of waste (e. g. glass bottles, aluminium and steel cans,

waste paper, textiles) amounted to four percent. A breakdown in respect to the types of waste going to recycling is not achievable.

In Fig. 1.4.-4 a forecast of waste experts is presented. This indicates a further decline of the waste proportion for landfilling and an increase of treatment such as incineration and composting.



Source: Environmental Data of Germany 1995, Umweltbundesamt, Berlin (1995)

Fig. 1.4.-4 Municipal Waste Treatment in Germany

IfP 1995

With regard to the Municipal Waste Management Provision and its main target that at latest by the year 2005 no solid material that contains more than five percent organic matter can be landfilled. the situation will be changed more significantly. There should be an increased demand for incineration facilities. The necessary number of additional incineration plants, however, depends on various conditions concerning the future waste volume and the further development of biological treatment facilities and their capacities. The suppliers of incineration plants foresee an additional demand for 25 to 50 plants within the following ten years, each with an annual capacity of about 100.000 tonnes.

Table 1.4.-1 presents the number of waste treatment plants in former West Germany in 1990 and 1995 compared with 1984. In this period of time the number of incineration plants did not increase significantly. Between 1990 and 1995 not more than four additional incineration plants have been established. Dumps for landfilling decreased from 372 to 295, while sorting plants for recycling increased tremendously. Only 18 composting plants were in operation in 1990. This situation has changed significantly within the last five years. At the end of 1995 about 170 composting plants came on stream (see chapter 1.4.6).

Tab. 1.4.-1: Number of Treatment Plants for Municipal Waste in Germany

Waste Treatment Technology	**Number of Plants**		
	1984	**1990**	**1995**
Incineration	46	48	52
Composting	27	18	= 170
Pyrolysis	1	1	steady state
Sorting prior to Recycling	3	45	increasing
Landfilling	372	295	declining

Source: Environmental Data 1992/93
Umweltbundesamt, Berlin, 1994

1.4.4 Incineration

1.4.4.1 Current Situation

As already presented in Fig. 1.4.-4 about 29 percent of municipal waste was burnt in 48 incineration plants by the end of 1990. The capacity of these plants varies between 30,000 tonnes to 500,000 tonnes per year. Almost all plants generate electrical power. Waste heating of these plants is also used as a heating source for local heating systems. Nevertheless, the contribution of waste incineration plants to the total energy generation in Germany is insignificant. Related to a total energy generation of 14,140 Petajoule (as primary energy) in 1993 the contribution of municipal waste incineration plants for electrical power generation was only about 70 Petajoule (0.5 percent).

Most of the incineration plants are equipped with grate-firing using roller grates, reciprocating grates (reverse and forward action), rocking grates and travelling grates. In contrast to Japan, where already 40 fluidized bed combustion plants have been established in 1987, the first fluidized bed plant in Germany started only in 1993 with a capacity of 65,000 tonnes per year.

1.4.4.2 Future Trends

Today other thermal technologies are discussed such as:

- Thermoselect Technology
- SIEMENS Thermal Waste Recycling Technology (Schwel-Brenn-Technology)
- NOELL Conversion Technology (Flugstrom-Vergasung)

These processes combine fundamental technologies of thermal waste treatment:

- Incineration
- Pyrolysis
- Gasification

In Table 1.4.-2 the above mentioned technologies for waste treatment are compared with traditional waste incineration based on grate-firing.

Thermoselect Technology

The Thermoselect process is based on a combination of pyrolysis and high temperature gasification. First the volume of waste is reduced by a scrap press to about ten percent of its original level. The highly compacted waste packages are transferred to a pressure resistant pyrolysis chamber, where they form a gas tight plug. The chamber is heated externally so that the waste is roasted at a temperature of up to 600 °C. Organic waste is thereby pyrolysed and converted to carbon which forms briquets with inorganic mineral and metallic residues. After two hours new compressed material is fed into the pyrolysis chamber thus pushing the briquets into a high temperature gasification chamber, where they burst due to the residual internal pressure from pyrolysis. With the controlled addition of pure oxygen all solid materials, such as metals, minerals and glass, melt completely at a temperature of 2000 °C. Some of the heavy metals and other pollutants are trapped at this stage and carbon containing materials are pyrolysed. In a second reactor the carbon residues are burnt and, at a temperature of 1600 °C, the metallic and mineral melts are separated.

Tab. 1.4.-2 Thermal Waste Treatment Technologies (1995)

Principle	**Grate Incineration**	**Thermal Waste Recycling Technology**	**Thermoselect Technology**	**Conversion Technology**
Supplier	ABB, Babcock, Noell, Von Roll, Martin, Steinmüller etc.	Siemens	Thermoselect	Noell
Investment Costs	300,000 - 400,000 t.p.a.: ≈ 300 - 400 Million DEM	100,000 t.p.a.: 215 Million DEM 150,000 t.p.a.: 300 Million DEM	150,000 t.p.a.: 210 - 255 Million DEM 300,000 t.p.a.: ≈ 300 Million DEM	100,000 t.p.a: 250 Million DEM
Treatment Costs (DEM/tonne Waste)	= 400	≈ 350	300 - 400	≈ 415
Plant Availability (8800 hr/a = 100 %)	85 % - 90 %	85 %	85 %	≥ 85 %
Sold Energy	up to = 550 kWh_{el}/tonne Waste	≈ 460 kWh_{el}/tonne Waste	= 350 kWh_{el}/tonne Waste	≈ 300 kWh_{el}/tonne Waste ≈ 1,600 kWh_{th}/tonne Waste
Proceeds from Value-Added Products	*low:* Salt or HCl Gypsum Sintered Slag	*high:* Iron Other Metals Granulate	*medium:* high by Granulate low by Salts and Metals	*high:* Iron Other Metals Sulfur
State of Development	State-of-the-art Technology worldwide	Long-term Experience on Pilot Plant Scale First Plant under Construction	Pilot Plant (≤ 4,2 tonnes/hr) First Plant under Construction	Combination of commercially approved Components First Plant under Construction
Application	≈ 500 Plants	Two Pilot Plants	One Pilot Plant	No Plant

Source: EntsorgungsPraxis 13 (1995) Nr. 11, 88 - 89

The gas which is produced in the pyrolysis chamber - mainly steam (H_2O), carbon monoxide (CO), carbon dioxide (CO_2), hydrogen (H_2) and methane (CH_4) - also flows into the high temperature reactor where it reaches a temperature of more than 1200 °C after four seconds. At the high temperature the entire organic compounds are decomposed and converted to low molecular species. In order to prevent the formation of dioxins and furans at a later stage, the synthesis gas is shock cooled with injected water to about 90 °C. Traces of heavy metals which have been carried over, hydrogen chloride and hydrogen fluoride are separated and condensed in further stages. After these first purification stages the remaining synthesis gas passes an acid and then a basic scrubber to remove pollutants as hydrochloric acid, hydrofluoric acid and sulfur compounds. After further cooling to 5 °C in order to reduce the water content the gas is finally led through two activated charcoal filters. At the end of the process 600 kg of synthesis gas per tonne of waste are recovered with a composition of 35 percent H_2, 40 percent CO, 20 percent CO_2, traces of CH_4 and nitrogen (N_2).

About 265 kg residual materials per tonne of waste must be disposed of, namely 2.7 kg dust, 12.5 kg sodium salts from the purification of waste water of flue gas treatment, 23 kg metals, 4.8 kg calcium sulfate and 222 kg of glassy material from the melts which must go into landfilling or could be used for other purposes (e. g. road construction, building material industry).

The Thermoselect technology was developed in a pilot plant (4.2 tonnes/hour) in Fondotoce, Italy. So far, no commercial plant is installed in Germany. In 1997 the first plant will start in Karlsruhe, Germany, with an annual waste capacity of about 100.000 tonnes.

Thermal Waste Recycling Technology (Schwel-Brenn-Technology)

The SIEMENS Thermal Waste Recycling Technology combines pyrolysis and high temperature incineration. The crushed household waste is transferred to a conversion drum, where it is heated in the absence of oxygen at a temperature of about 450 °C within a period of one hour. The pyrolysis gas is fed directly into a high temperature boiler. The remaining solids are going to a screening stage, where they are separated into a fraction > 5 mm (mainly consisting of glass, ceramics, minerals, metals) and a fraction < 5 mm. More than 99 percent of the residual carbon is in the latter fraction. This material is crushed and fed to the high temperature boiler for incineration together with the pyrolysis gas at a temperature of about 1300 °C. This temperature is approx. 150 °C higher than the ash melting point of the fine fraction. Fly ash of the electrostatic filter is fed back to the high temperature boiler and incorperated into the ash melt, which is quenched in a water bath. The resulting cinder being a glassy material can be used in road construction or for manufacturing building material. Flue gas emissions are controlled by electrostatic filter, spray dryer, filter bag, scrubbers and additional equipment in order to remove NO_x.

The SIEMENS technology has attracted attention also in Japan. In 1991 Mitsui Engineering and Shipbuilding Co. Ltd. acquired the licence for the installation of such plants in the Far East. In 1994 a demonstration plant was set in operation in Japan. In Germany the first plant will start at the end of 1996 in Fürth/Nürnberg. At present three further installations starting during the following two years have been ordered.

Conversion Technology

Another new technology for thermal waste treatment is the conversion process. This multi-stage technology combines well-known steps of pyrolysis and fly stream gasification (Flugstromvergasung). The objective of pyrolysis is to dry and to embrittle the waste to be treated. At a temperature of about 500 °C pyrolysis gas and carbon residues are generated. The carbon residues (pyrolysis coke) are discharged and granulated below a particle size of five millimeter.

The granulated pyrolysis coke is fed to the gasifier together with the pyrolysis gas and a slurry of oil, water and dust. The gasifier works at pressures of 20 bar to 30 bar and at temperatures between 1500 °C and 2000 °C. Industrial oxygen is used for gasification. The yielded synthesis gas is rich in carbon monoxide and hydrogen. The mineral compounds of the waste melts completely. The molten slag runs down on the cooled walls of the gasifier and is quenched with water to a temperature of about 200 °C. The slag solidifies to a glassy material which can be used in manufacturing construction material. The synthesis gas is also quenched to a temperature of about 200 °C avoiding the De-Novo synthesis of dioxins and furans. After additional purification the synthesis gas is used for electric power generation. About 20 percent to 25 percent of the purified synthesis gas is used for heating the pyrolysis drum.

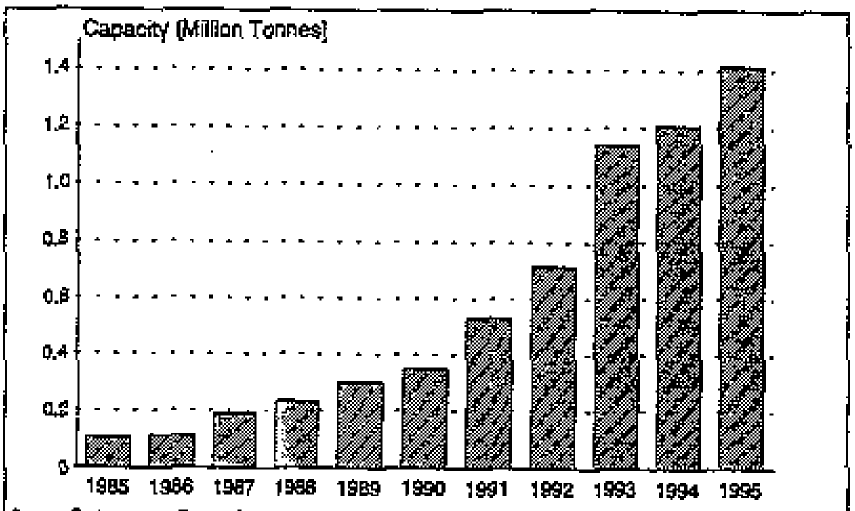
Despite the fact that there does not exist any pilot plant, the company NOELL received an order for the installation of the first commercial plant with an annual waste capacity of 100,000 tonnes for the end of 1996.

1.4.5 Biological Treatment

1.4.5.1 Current Situation

Separate collection of solid organic residues from households, garden and park areas is today the common procedure in Germany. The former technology of composting of unseparated household waste has not been proved to be successful with respect to the quality of the final compost. Today, this traditional municipal waste composting is no longer permitted.

Biological treatment of biowaste has become significantly important, mainly within the last four years. Fig. 1.4.-5 presents the capacities of biological treatment plants established in Germany since 1985. In 1995 about 1.4 million tonnes of organic waste from private households were collected separately and composted under aerobic or digested under anaerobic conditions. In spite of the current predominance of aerobic treatment systems, increasing capacitiy of anaerobic technologies (fermentation) is expected. Nowadays, only 120,000 tonnes of biowaste (about ten percent) is treated by anaerobic technologies.



Source: Environmental Data of Germany 1995, Umweltbundesamt, Berlin (1995)

Fig. 1.4.-5 Capacity of Biological Treatment Plants for Biowaste in Germany

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Composting is an aerobic process characterized by a microbial oxidation of different kinds of organic molecules transformed into carbon dioxide, water and partially humified organic matter (compost). Oxygen is the most important factor which controls the process. Oxygen consumption by microbial aerobic respiration generates heat. As a consequence, the temperature of the substrate increases because heat is generated at a rate exceeding its loss to the surroundings. Oxygen also contributes to preventing odour formation during the process. Most of the odour is based on reduced molecules containing nitrogen, sulfur and phosphorus. By their oxidation, bad smelling gases are transformed into odourless liquids. The availability of sufficient volume of oxygen in composting is the main factor that can be influenced by technology. Even the feed-back control of the process is based on oxygen or temperature monitoring of the substrate. Finally, only an oxidized and aerobically stabilized compost without any residual phytotoxic effect will be compatible with agricultural demands.

In Germany, there are about 30 suppliers of biowaste composting systems on the market place. The processes may be classified in one of the six following categories:

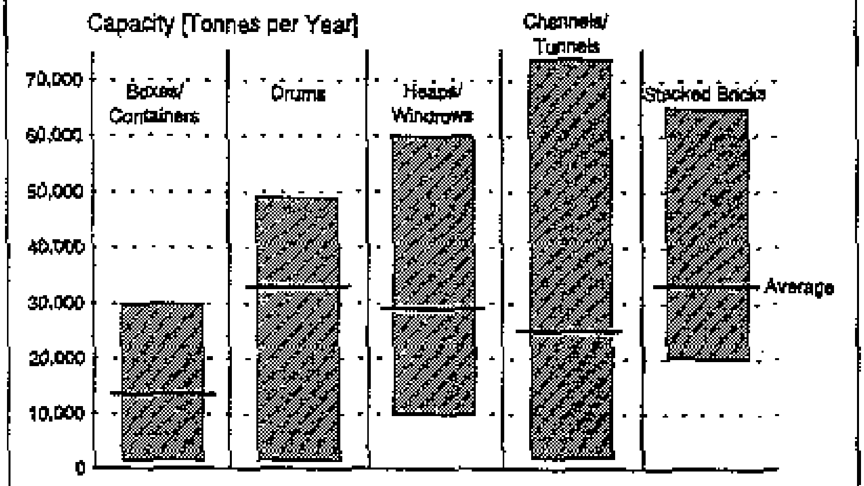
- Drum composting
- Box or container composting
- Heap or windrow composting
- Channel or tunnel composting
- Stacked bricks composting
- Silo composting.

These composting technologies vary with regard to time of intensive decomposition, level of decomposition and applied process control mechanisms (aeration, turning, watering). Currently, there is a trend towards bigger production capacities and improved quality standards.

In 1994 box or container composting had a proportion of about 45 percent of the composting facilities established. The proportion of drum composting plants was about 15 percent. Heap or windrow composting totalled 25 percent. Other systems amounted to 15 percent.

In 1994 the average capacity of the composting plants was about 13.000 tonnes of biowaste per year. In 1995 this capacity increased to about 20.000 tonnes per year. Capacity ranges of the different composting systems are presented in Fig. 1.4.-6.

At the same time as composting activities increased significantly the German **Federal Compost Quality Assurance Organization** (FCQAO) defined a general quality standard (RAL compost quality label GZ 251) and established a country-wide system for external monitoring of composting plants and composted material. In 1995 approx. 150 compost plants participate in the quality assurance of FCQAO.



Source: Kern, M.; Wiemer, K., Kassel (1995)

Fig. 1.4.-6 Capacities of Different Composting Systems in Germany (1995) IfP 1996

The quality assurance program refers to definition and continuation of quality requirements, organization and enforcement of quality monitoring and labelling of the quality standard. Type, extent and frequency of these evaluations depend on the capacity of the composting plants. In order to guarantee an identical standard, FCQAO established a central office where all results are evaluated originating from external monitoring.

Table 1.4.-3: **Approximate Values of RAL Compost Quality Label GZ 251 for Heavy Metal Contents of Composts**

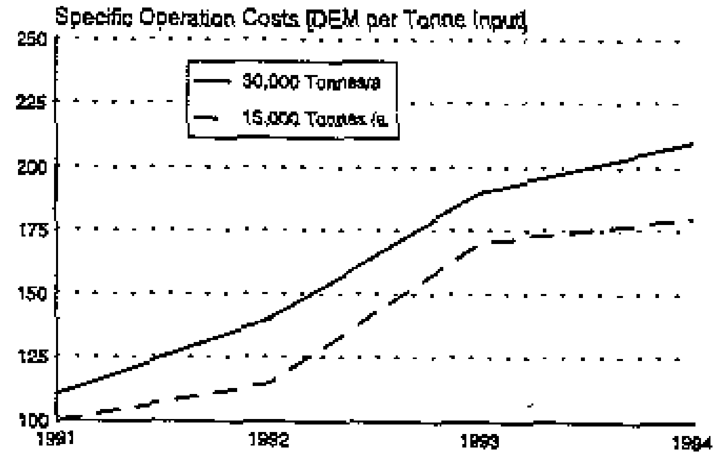
Heavy Metal		**Approx. Value (mg/kg ds)***
Cadmium	Cd	1.5
Chromium	Cr	100
Copper	Cu	100
Lead	Pb	150
Mercury	Hg	1
Nickel	Ni	50
Zinc	Zn	400

* ds = dry substance
Figures refer to 30 percent organic substance
Source: Gütegemeinschaft Kompost e. V./Bonn (1995)

Besides hygienic requirements, the content of undesirable materials and contaminants as well as approximate values for heavy metal concentration of compost are defined by the quality standard. Table 1.4.-3 presents the limits of heavy metals. The heavy metal content of composts produced must be converted to a standardized compost based on 30 percent organic substance. This means that a compost having, for example, a measured concentration of 250 mg Zn/kg dry substance and a content of organic substance of 65 percent is rated in such a way that it contains 500 mg Zn/kg dry substance. This compost would not meet the requirement of the RAL quality with a set limit of 400 mg/kg dry substance.

The capital investment costs for composting plants in 1994 ranged between 850 DEM/tonne and 1,400 DEM/tonne raw material at an annual capacity between 15.000 tonnes and 20,000 tonnesin terms on raw material input. In the case of an annual raw material input of 30,000 tonnes to 40,000 tonnes the investment costs decreased to a level between 700 DEM/tonne and 1,250 DEM/tonne.

Operation costs, including salaries, maintenance, insurance premiums, costs for energy and disposal of waste water and waste, as well as depreciations on plant equipment, depend on capacity. Fig. 1.4.-7 shows the development of operation costs for two different capacities. Nowadays, operation costs of approx. 200 DEM/tonne to 240 DEM/tonne are regarded as realistic. The operation costs for anaerobic treatment of biowaste are estimated to be about 150 DEM/tonne to 180 DEM/tonne for capacities of 10,000 tonnes per year.



Source: Kern, M.; Wiemer, K., Kassel (1995)

Fig. 1.4.-7 Specific Operation Costs of Composting Plants with Different Capacities

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In Germany, waste paper is not regarded as an important composting material. Only a few composting plants use waste paper as a co-substrate in order to control moisture content and the carbon/nitrogen ratio of the initial biowaste feedstock or as bulking material. The volume of separately collected waste paper which is used in composting plants is estimated at about 30,000 tonnes per year. The proportion of waste paper which is going to biological treatment plants via biowaste is unknown. In summer time this proportion is supposed to be higher, because waste paper is often used as packaging material for kitchen waste to prevent the generation of odour in biowaste bins. Taking into account a waste paper proportion of collected biowaste of about five percent, the composted waste paper volume is approx. 70,000 tonnes per year. In summary a total volume of about 100,000 tonnes waste paper per year is biologically treated either in composting plants or by fermentation. This means a marginal proportion of two percent of non-recovered waste paper which is converted to compost.

1.4.5.2 Future Trends

With separate collection of biowaste from private households a per-capita volume between 40 kg and 170 kg of biowaste is expected, depending on the social structure of the collection areas. Whilst the volume of organic kitchen waste remains almost constant, the volume of garden waste changes seasonally. On average, the per-capita volume of biowaste is estimated at 110 kg to 130 kg.

Taking into account the population of Germany (80 million) this would result in a total potential of biowaste of about 8.8 million tonnes to 10.4 million tonnes per year. Due to microbial oxidation about 50 percent of the biowaste is degraded. The volume of final compost would be therefore 4.4. million tonnes to 5.2 million tonnes. Taking a specific weight of about 650 kg/m^3 of the compost produced this results in 6.8 million m^3 to 8.0 million m^3 compost per year. This volume would significantly increase, if other composting materials such as agricultural waste or organic waste from industrial processes including bark are utilized to a larger extent.

The future compost potential could be more than 10 million cubic meter per year. This volume is about the same as the present peat demand in Germany.

By 2000, about 300 biological treatment plants with a total capacity of five million tonnes biowaste input are forecast. Assuming investment costs of one million DEM per 1,000 tonnes capacity this corresponds to total investment costs of about 5,000 million DEM.

It is doubtful whether this forecast is realistic. One must bear in mind, that already at present, the volume of produced compost seems to have reached a saturation level on the market place. A further increase of biowaste composting will significantly depend on new applications of biocomposts, e. g. in agriculture or forestry.

As far as the forecast for the year 2000 is concerned, the estimated volume of collected biowaste of about five million tonnes could be composted with a maximum volume of waste paper of about 0.8 to 1.0 million tonnes. A higher proportion of waste paper would shift the carbon/nitrogen ratio of biowaste to an unacceptable level.

1.4.6 Landfilling

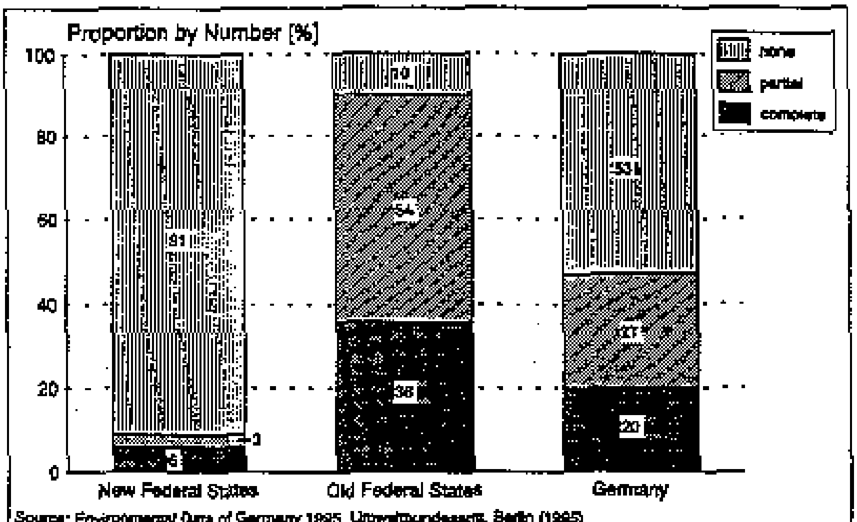
1.4.6.1 Current Situation

For many centuries landfilling was the only waste management strategy. Only in the previous few decades landfilling has advanced from uncontrolled dumping to an engineered waste disposal technology, which is increasingly equipped with environmental protection measures. Landfill gas and leachate emissions represent the key environmental concerns associated with landfilling options.

Landfill gas (a mixture of carbon dioxide and methane) can cause damage to vegetation in the landfilling surrounding. It also contributes to the greenhouse effect. Since methane has a more significant impact on greenhouse effect than carbon dioxide (at the same unit of weight), landfilling of waste is assumed to have a much higher impact than waste incineration. Leachate arises from water present in the dumped waste and from rain water infiltration of landfill sites. The emission of leachate can generate serious implications on ground water, particularly when this water is used as drinking water.

In Germany, the number of landfill facilities for municipal waste has decreased significantly within the last two decades. While in Western Germany about 4,400 landfill sites were in use in 1975, the number was only 263 in 1993.

Fig. 1.4.-8 shows the proportion of landfills, which are equipped with an impermeable sealing layer to prevent leaching. In West Germany about 90 percent of landfills are lined with such an impermeable layer. So far, this layer mostly consists of minerals. Modern landfills and new sections of existing landfills respectively are sealed with a combination of minerals and plastics. The mineral sealing is installed and compacted in several layers on the levelled subsoil. The layers have usually a thickness of 20 cm to 25 cm. The number of layers depends on

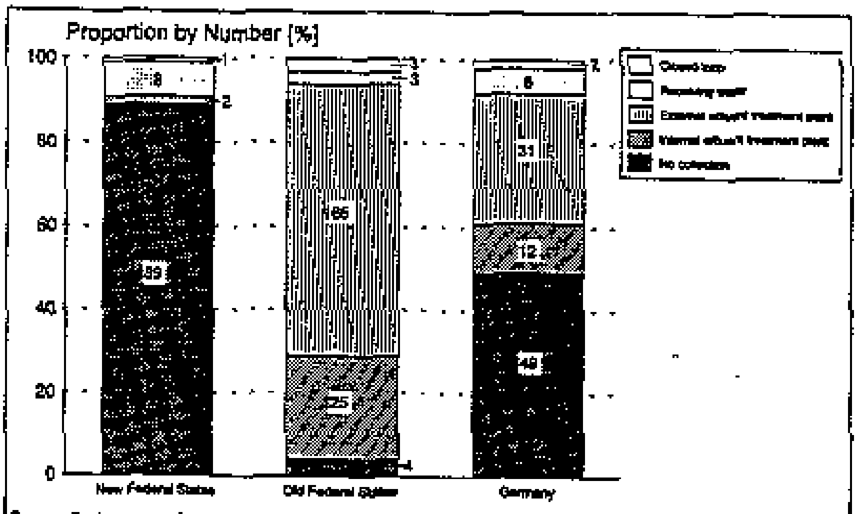


Source: Environmental Data of Germany 1995, Umweltbundesamt, Berlin (1995)

Fig. 1.4.-8 Sealing of Landfill Facilities in Germany (1993)

ITP 1995

the overall thickness of the mineral sealing. It is important that the layers are closely interlinked. This can be achieved by using compacting equipment. Clay and clay soils are the preferred sealing materials. The sealing property of such soils can often be improved by addition of small portions of bentonites with their high swelling capacity. In a further step, a protective layer is applied onto the plastic sealing to protect this layer against damage. For this purpose linings or fine sand are applied. The situation in the New Federal States is quite different. About 90 percent of landfills are not equipped with any sealing.



Source: Environmental Data of Germany 1996, Umweltbundesamt, Berlin (1996)

Fig. 1.4.-9 Collection and Treatment of Landfill Leachate in Germany (1993)

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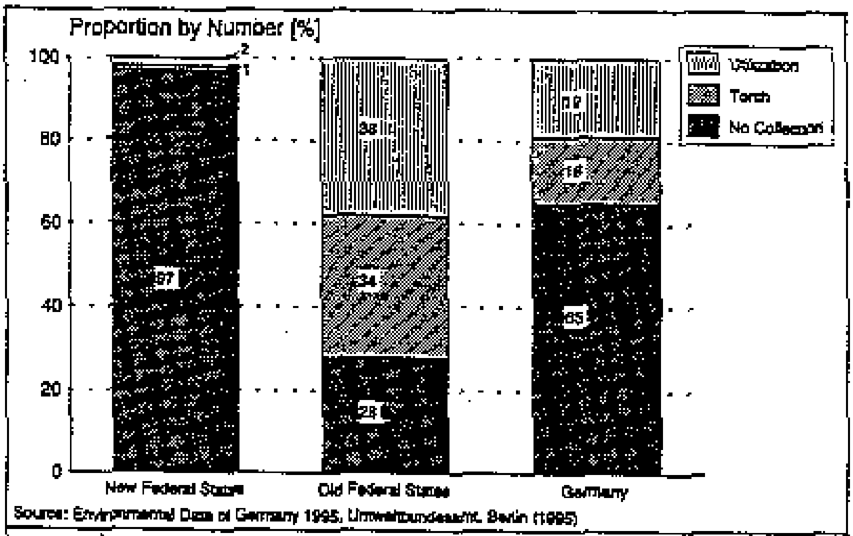
Due to the pollution of landfill leachates, they have to be treated in such a manner that no significant environmental impacts arise. In 1993 the leachates of mostly all landfill facilities of the Old Federal States were collected and treated. The proportions of different technologies on the treatment are shown in Fig. 1.4.-9. A proportion of 65 percent was treated in municipal biological waste water treatment plants, 25 percent of the leachates were treated internally, preferentially with reverse osmosis technology and/or biological treatment systems. Feeding of leachates into receiving waters without any treatment or closed loop operation, which means that the leachates are going back to landfill, were employed only in particular cases. Due to deficient sealings, the leachates of landfills in the New Federal States are collected and treated only to a small extent.

In order to control emissions of landfill gas into the atmosphere, it can be collected from the disposed waste by drainage systems. The collection rate of gas of well-controlled systems is between 50 percent and 60 percent of the generated landfill gas. This collected gas can either be used for energy recovery or is flared off by using torches. Both energy recovery and flaring convert the methane component of landfill gas into carbon dioxide and water vapour. This converting results in a reduction of the contribution of landfill gases to the greenhouse effect.



Source: Environmental Data of Germany 1995, Umweltbundesamt, Berlin (1995)

Fig. 1.4.-10 Collection and Treatment of Landfill Gas in Germany (1993)

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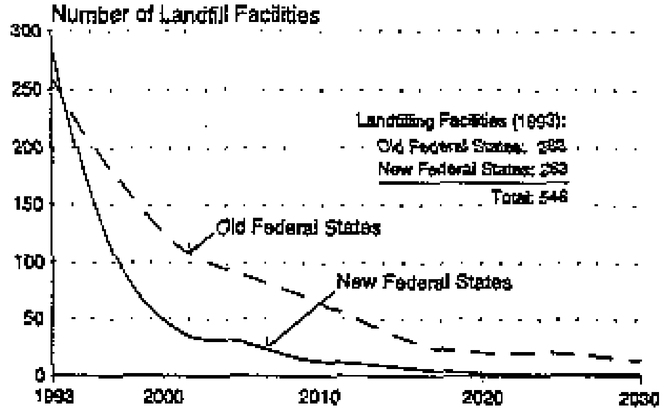
According to Fig. 1.4.-10 about 70 percent of landfill gas was collected in the Old Federal States in 1993. The proportion of gas utilization for energy recovery was about 40 percent. About 35 percent was flared off using torches. This proportion will significantly increase in the future, because many landfill facilities already realize energy recovery. The situation in the New Federal States was quite different. Only three percent of landfill gas produced was collected.

1.4.6.2 Future Trends

The future trend of landfilling in Germany is characterized by Fig. 1.4.-11. In West Germany about 50 percent of the present landfill capacity will be exhausted by 2000. The situation is much more challenging in the New Federal States, where about 80 percent of the present capacity will close. This means that in the New Federal States there is a tremendous need for new landfilling facilities. One must bear in mind that landfill provides the only final disposal path for waste materials including solid residues from waste treatment. Therefore, according to Fig. 1.4.-11, the need for new landfill facilities which fulfil environmentally compatible requirements is evident. In contrast to traditional landfills modern dumps are highly sophisticated engineering works, which require a lot of expertise in terms of planning, execution and operation.



Source: Environmental Data of Germany 1995, Umweltbundesamt, Berlin (1995)

Fig. 1.4.-11 Future of Landfill Facilities in Germany

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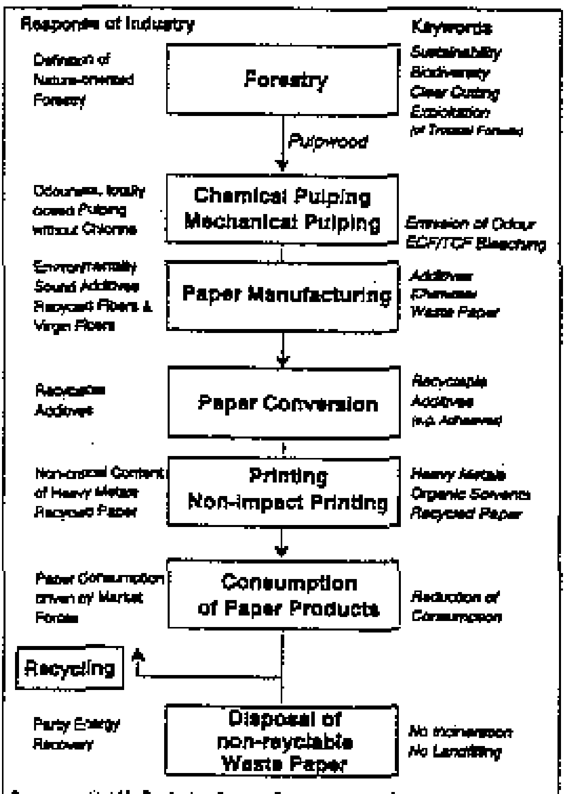
1.4.7 Summary

Considering the increasingly reduced landfill capacities and the Municipal Waste Management Provision, with its target that no organic matter is permitted to be dumped at the latest by 2005, waste management will undergo significant changes in the next few years. Waste incineration, which covers today about a third of the volume of waste for disposal, will become even more important. In addition to the 52 existing incineration facilities, a further 25 to 50 plants of a capacity of 100,000 tonnes each will be required. The suppliers of incineration plants have developed technologies which can compete successfully with the traditional grate furnaces. The first plants of the new types (fluidized bed boilers, Thermoselect Technology, SIEMENS Thermal Waste Recycling Technology, NOELL Conversion Technology) are currently installed.

Separate collection of household biowaste and its conversion by fermentation and composting became more important in the last five years. Today, about 1.4 million tonnes biowaste are separately collected and treated in composting plants of capacities of 10,000 to 20,000 tonnes per year. The volume of separately collected biowaste will be increased to five million tonnes by the year 2000. The realization of this target figure depends on marketing and application options of this kind of compost. In the context of biowaste, it is supposed that a maximum volume of about 0.8 to 1.0 million tonnes of waste paper present in biowaste will serve as a beneficial co-substrate. A higher proportion of waste paper would be inacceptable because of the limiting factor in terms of carbon/nitrogen ratio.

2 *Requirements of Environmentalists with Respect to Recycling and Waste Management*

In previous years, the activities of different NGOs (Non-governmental organizations) in Germany were directed towards almost every area of the paper chain. This involvement in forestry, pulping, papermaking, waste paper recovery and recycling, waste management and further issues refers particularly to **Greenpeace Germany** which was continuously addressing industrial decision makers, federations and companies of the paper chain. Other NGOs such as **Bund für Naturschutz Deutschland (BUND)** and **Öko-Institut Freiburg** are generally in agreement with the concerns of Greenpeace. The areas of the concerns of environmentalists are documented in Fig. 2.1.-1 in terms of keywords which cover the total paper chain from cradle to grave which means from forestry to waste disposal. Furthermore, this figure indicates the response of the industry to these keywords.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 2.1.-1 The Paper Chain: Ecological Keywords of Environmentalists HP 1995

2.1 Greenpeace Germany

In 1990, Greenpeace Germany published guidelines with respect to environmentally sound paper manufacturing. In that year, bleaching of chemical pulp with chlorine and chlorine compounds was the main subject of activities and campaigns. Greenpeace demanded a rapid global abandonment of these bleaching chemicals. This organization demanded the use of alternative, environmentally compatible bleaching chemicals such as oxygen, peroxide and ozone. One year later, Greenpeace published a study entitled "Less Waste, more Forest - Concepts for Saving and Recycling of Paper". On behalf of Greenpeace, this study was performed by the **IFEU-Institut** in Heidelberg (IFEU = Institute for Energy and Environment). According to this study, the German waste paper utilization rate of then 49 percent (1991) should be increased to 75 percent in less than five years. This target figure would be realized by the following measures:

- Expansion of deinking capacities of the German paper industry by about one million tonnes. *(Note: This expansion took place in less than five years due to the establishment of three newsprint mills, which came on stream in 1993 and 1994, and of further deinking plants.)*
- Intensified and optimized collection activities with reference to waste paper.
- Agreements on compulsory recovery of waste paper between countries exporting paper and those importing paper.
- Reduction of quality requirements for individual paper grades, particularly of commodities (this means paper with a short life time such as newsprint or magazine paper).
- Education of the public with reference to waste paper and its ecological significance.

In order to reduce the generation of waste paper in households and offices, the requirements should aim not only at intensified waste paper recycling, but at the same time at a reduction of paper consumption. The potential reduction of paper consumption refers to office paper, magazine paper and newsprint, direct mail, telephone directories (expansion of the time directories are used from one to two years), packaging paper including liquid board. The volume of these paper and board grades which should be reduced in consumption totalled 1.9 million tonnes in 1991. This corresponds to about 15 percent of the total paper consumption in Germany in the same year.

Further requirements demanded the publishing of data with respect to all emissions into the air, water and soil by the paper industry. Additionally, it was proposed that the paper industry makes public the names of chemicals used in production, including their source chemicals. All paper products should be labelled with respect to the fiber materials used, their origin and their treatment (e. g. bleaching).

As indispensable supporting political measures for the benefit of intensified waste paper utilization in different paper grades and for a significant reduction of paper consumption, the study made the following demands:

- Ban of chlorine-containing and recycling-unfriendly chemicals in pulping, papermaking as well as paper converting, printing and recycling of paper either produced at home or abroad.
- Introduction of legal standards for waste paper utilization rates of important paper grades according to the most advanced state-of-the-art (with reference to imported and domesticly produced paper).
- Levy of duties on primary raw materials (which means a chemical pulp tax) to be used for the financing of more efficient waste paper collection and recovery systems.
- Recovery obligation of the trade (retailers) for packaging.
- Establishment of increasing areas of conserved forest land (unmanaged reference forest land).
- Control of managed natural forests for saving biodiversity.

Because Germany is one of the largest net importer of paper in the world, the Federal Government is urged to press for increased waste paper utilization on the international and, at least, on the European scene.

The demands mentioned above had been extended by Greenpeace in a study entitled "Paper - a Natural Product or a Chemical Cocktail?", published in 1993. The criteria for an environmentally compatible, sustainable paper economy were specified as follows:

- *Protection of water, air and soil*
  In the manufacturing, use and recycling of paper, no human- and eco-toxic substances are permitted to be emitted.

- *Protection of water cycles*
  Reduction of water consumption in pulping and papermaking realized by closing white water loops, if possible even totally.
- *Protection of forests*
  Existing original forests are not permitted to be used for industrial or commercial purposes. Economically used forests (natural forests) must be modified in order to re-establish natural habitats. Timber and pulpwood must be harvested in an ecologically sound manner.
- *Protection of the climate*
  Drastic reduction of CO_2 emissions by the German pulp and paper industry by saving of fossil fuels.
- *Closed loops*
  Closed looping in waste paper recycling as far as possible in order to minimize the consumption of energy, chemicals and the production of waste. Substances which are released from the system, must be biodegradable or recyclable.
- *Minimizing of toxicity*
  Toxic or allergy generating substances such as phenols- and formaldehyde-containing resins or chlorine-containing compounds must be not applied as additives in papermaking or paper converting.

To approach the above mentioned targets, Greenpeace proposed the following measures:

- Labelling of paper grades and chemicals which affect waste paper processing.
- Elimination of disturbing paper grades (e.g. carbonless paper, thermosensitive paper) from waste paper processing.
- Separate collection of various paper grades.
- Ban of the application of products containing chlorine.
- Ban of the application of chemicals which hinder recycling.
- Reduction of the number of different chemicals used for the same purpose (e. g. additives for papermaking, printing inks).
- Regulation of waste paper utilization rates for different paper grades.

2.2 *Öko-Institut Freiburg*

The Öko-Institut Freiburg calls for conservation of still existing original forests (primeval forests) to avoid the establishment of man-made forests (plantations). This study. issued in 1992. was dealt with as a case study on strategies for saving raw materials and recycling. Furthermore, existing man-made forests should be transformed into nature-oriented forests.

The Öko-Institut Freiburg promotes an intensified waste paper recovery as well as a reduction of paper consumption. Non-recyclable paper as well as waste of waste paper processing should be primarily treated by biological technologies (composting, fermentation), whereas landfilling and incineration should be put into the second place.

However, in the most recent years the priorities with respect to waste paper and waste disposal changed. According to a study, issued in 1995, the Öko-Institut Freiburg promotes energy recovery based on non-recyclable waste paper and waste material of waste paper processing in order to save fossil energy. Energy recovery should be realized in industrial combustion plants making use of co-generation. It is emphasized that both materials are characterized by a significantly lower contamination compared with household waste and, in many cases, with brown coal and hard coal. This fact is an advantage as far as legally set standards are kept, taking the lower requirement of flue gas purification into account.

2.3 *Bund für Naturschutz Deutschland (BUND)*

This organization is an another partaker in the debates on environmental issues with reference to the paper chain. Information sheets and information campaigns emphasize the needs for a reduction of the consumption of packaging material - including paper and board based material - and advertising.

In the first place the BUND criticises the incineration of household waste. According to the BUND, the choice to incinerate household waste represents a long term commitment to exploit resources and to pollute the environment because of the following reason: A waste incineration plant, once in operation, must be operated continuously at a certain operation temperature which requires a permanent steady input of waste. Therefore, it is not economically or technically feasable to reduce the volume of waste to be processed. The operation of an incineration plant results in an exploitation of resources (including energy) which means a significant retrograde step in the context of the discussion on enviromental protection.

Despite the fact that modern incineration plants emit only small amounts of pollutants the BUND underlines, that the emissions of such plants are a risk with respect to the health of the population. The BUND is aware that waste incineration contributes to the overall toxic pollution only to a minor extent. It is emphasized, however, that these residual emissions must not be underestimated.

The BUND vehemently criticises the Municipal Waste Management Provision with respect to its most important parameter which requires that no waste should be disposed of by landfilling that contains more than five percent organic matter. According to the BUND this requirement cannot be substantiated technically and scientifically. The biological-mechanical technologies for (residual) waste treatment such as fermentation and composting accepted by the BUND do not fulfil the requirement for waste rendered inert and suitable for landfilling. Therefore, the BUND calls for a revision of the Municipal Waste Management Provision.

The BUND urges the public and local authorities to intervene in good time against projected waste incineration plants. In the case that the establishment of an incineration plant cannot be prevented, the size of such a plant should be kept as small as possible.

Unlike the continuing opposition of the BUND, public opinion has changed in the meantime as far as the establishment of additional waste incineration plants are concerned. According to the results of an inquiry on behalf of the Federal Ministry of Environment on the topic of environmental protection, 43 percent of the West Germans and 55 percent of the East Germans agree to the establishment of additional waste incineration plants. In contrast, the proportion of supporters of landfills is further decreasing: only 22 percent of the Germans support the establishment of additional landfills.

According to that inquiry, more than 80 percent of the German population is prepared to collect waste separated into even more waste components than today. This response makes evident that the German society gives priority to recycling and utilization of waste and its different components as secondary materials.

2.4 *General Issues*

Greenpeace as well as BUND and Öko-Institut are intensively and permanently communicating with institutional paper consumers such as publishers, mail order houses, supermarket and department store chains. Greenpeace mainly communicates with leading publishing houses such as Gruner + Jahr and Axel Springer in Hamburg and BURDA in Offenburg, requesting the use of 'clear-cut free' paper and support for intensified waste paper recycling. On the other hand the activities of BUND and Öko-Institut are focusing on consulting. Both are involved, amongst others, in life cycle assessments of packaging made of different materials. Their clients are, for example, institutional paper consumers, consumer organisations, local and state authorities, national and international organizations but also paper manufacturers.

2.5 *Federal Environment Protection Agency (UBA)*

On commission of the Federal Environment Protection Agency (Umweltbundesamt) in Berlin, a life cycle analysis is currently performed by IFEU-Institut, Heidelberg, in co-operation with experts of chemicals and additives for pulping, papermaking and paper converting as well as of forestry (in terms of nature-oriented forestry).

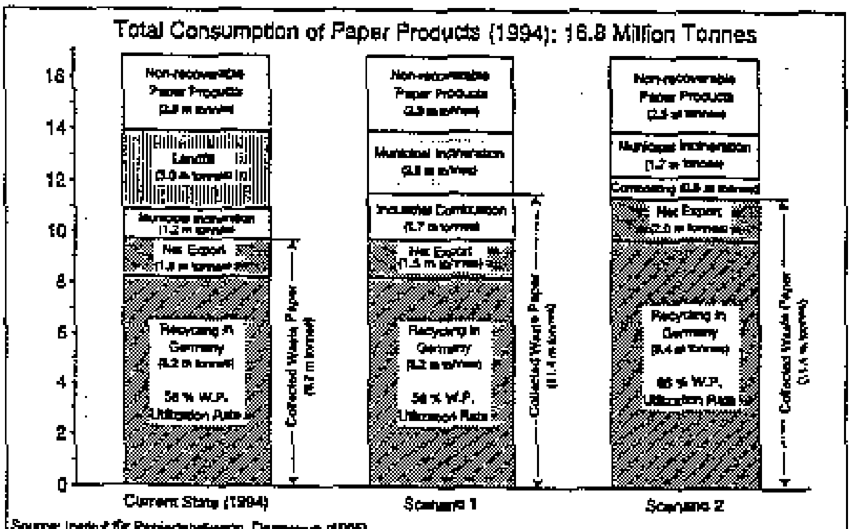
The cradle to grave life cycle assessment refers to graphic products such as news, magazines and office paper in terms of copy paper made of virgin pulps as well as recycled fibers. Data for the establishment of inventories are collected not only in the German speaking paper industries, but also in the Nordic countries. The IFEU-Institut is only responsible for scoping and inventory whereas the Federal Environment Protection Agency is prepared to perform the final assessment with its non-standarized and therefore 'political' boundary conditions and priorities.

In 1996 this project should be finalized with the establishment of a computer program which will be available for any dealer and institutional consumer of paper and paper products. With that program, one should be in a position to assess which paper or paper product on the market place are the most environmentally compatible ones.

3 *Development of Scenarios*

3.1 *Waste Paper in Different Paper Grades*

Apart from the current situation Fig. 3.-1 shows two different scenarios which are affected by legal as well as by economic and ecological forces. The main parameters of the current situation and the scenarios refer to the waste paper utilization rate and waste paper collection rate. In 1994 the total consumption of paper products amounted to 16.8 million tonnes, based on 16.3 million tonnes of paper consumption and 0.5 million tonnes of printing inks, adhesives and further components applied in paper conversion and printing.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 3.-1 Current Situation and Scenarios of Recovery (Collection), Recycling (Utilization) and Disposal of Waste Paper in Germany

IfP 1996

The current waste paper collection rate is 59 percent (9.7 million tonnes of waste paper collected which is statistically related to 16.3 million tonnes of paper consumption), whereas the waste paper utilization rate amounts to 56 percent (8.2 million tonnes of waste paper processed in the German paper industry related to 14.4 million tonnes of paper production).

According to scenario 1 it is assumed that the waste paper collection rate might be increased by 11 percent, approaching 70 percent. This corresponds to a collected waste paper volume of 11.4 million tonnes which must be regarded as a rather ambitious target. With scenario 1 the waste paper utilization rate is kept at the same level as in 1994.

According to scenario 2 the waste paper collection rate of 70 percent is identical with that one of scenario 1. On the other hand, the waste paper utilization rate is supposed to be increased by nine percent, approaching 65 percent. This rate corresponds to a volume of 9.4 million tonnes of waste paper to be processed, exceeding the waste paper volume of the current situation and scenario 1 by 1.2 million tonnes.

In the following sections the various features of both scenarios are explained in detail.

Current Situation

Table 3.-1 shows the German paper production in 1994 divided into four main groups and furthermore into various graphic paper grades. The most relevant figures refer to the waste paper utilization rates and waste paper volume processed as well as the volume of recycled fibers used and their content in different paper grades, such as graphic paper, packaging paper and board, sanitary paper and specialty paper. Additionally the proportion of waste material from waste paper processing and the corresponding volumes of this waste material as air-dry substance are documented. Because of the heterogeneity of the waste paper utilization rates of different grades of graphic papers, the individual figures are given with reference to newsprint, recycled graphic paper, wood-containing and woodfree papers.

Paper Grade	Paper Production [M Tonnes]	Waste Paper Utilization Rate [%]	Volume of Waste Paper used [M Tonnes]	Proportion of Waste Material [%]	Volume of Waste Material [M Tonnes]	Volume of RCF [M Tonnes]	Proportion of RCF [%]
• Graphic Papers	7.00	28	2.00	15	0.30	1.70	24
- Newsprint	1.50	106	1.60	15	0.25	1.35	90
- Recycled Paper	0.30	115	0.35	15	0.05	0.30	100
- Wood-containing Paper	2.40	1	0.03	15	0	0.03	1
- Woodfree Paper	2.80	1	0.02	15	0	0.02	1
• Packaging Paper and Board	5.57	94	5.23	8	0.42	4.81	86
• Sanitary Paper	0.86	69	0.58	35	0.20	0.38	45
• Specialty Paper	1.00	44	0.44	25	0.11	0.33	33
• Total/Average	14.43	56	8.25	12	1.02	7.23	50

RCF: Recycled Fibers

Source: Institut für Papierfabrikation, Darmstadt (1995)

Table 3.-1 Waste Paper in Different Paper Grades -Current Situation and Scenario 1- IfP 1995

At the current waste paper utilization rate of 56 percent, the average proportion of waste material from waste paper processing is not more than 12 percent mainly affected by the waste material generated by processing of waste paper for packaging papers (eight percent). The total volume of this waste amounts to one million tonnes as air-dry substance. It is noteworthy that at a waste paper utilization rate of 56 percent the average content of recycled fibers of the total paper volume produced is not more than 50 percent.

Graphic papers are, on average, characterized by the lowest waste paper utilization rate of 28 percent. The biggest waste paper volume of 1.6 million tonnes out of 2.0 million tonnes is used for newsprint production, followed by 0.35 million tonnes of waste paper processed for manufacturing of recycled graphic paper (e.g. copy paper, computer printouts), whereas wood-containing and woodfree printing and writing paper contains almost no recycled fibers according to the statistics. A certain, but unknown proportion of DIP produced in newsprint mills is used by paper machines of the same mill as well as by other paper mills of the same companies manufacturing SC- and LWC-papers. This results in a lower waste paper utilization rate than indicated in the case of newsprint and consequently in a higher utilization rate in the case of SC- and LWC-papers.

Scenario 1

In Scenario 1 the waste paper utilization rate of 56 percent is kept constant, whereas the collection rate of currently 59 percent is increased to 70 percent (11.4 million tonnes of collected waste paper) which is supposed to be a most challenging target figure (Fig. 3.-1). One must be aware that 2.9 million tonnes of paper products are non-recoverable such as paper products made of sanitary and specialty papers or a certain proportion of office and printing paper, stored in archives, libraries or elsewhere. Considering this, the collected volume of 11.4 million tonnes of waste paper related to the total consumption of paper products of 16.8 million tonnes corresponds in reality to a waste paper collection rate of 82 percent of potentially recoverable paper (16.8 - 2.9 = 13.9 million tonnes). The increase of the collected waste paper volume by (11.4 - 9.7=) 1.7 million tonnes would mainly comprise ordinary waste paper grades which could hardly be used by the German paper industry because they are not suitable for graphic or sanitary papers and most of the specialty papers.

Taking into account the identical waste paper utilization rate of scenario 1, compared with the current situation, the individual waste paper utilization rates of different paper grades are also kept constant.

Scenario 2

Based on the same collection rate of 70 percent as with scenario 1 the waste paper utilization rate is targetted at 65 percent which corresponds to a waste paper volume of 9.4 million tonnes used by the German paper industry being 1.2 million tonnes higher than at the current situation (Fig. 3.-1). From the present point of view of the

German paper industry this utilization rate of 65 percent is not only ambitious but almost unrealistic.

However, the proposed utilization rate of 65 percent is taken as a target figure, because otherwise scenario 2 would not significantly differ from the current situation. On the other hand it would be even more unrealistic to introduce with scenario 2 a lower recycling rate than is already achieved in 1994. Economic and legal forces are definitely against a smaller utilization rate than 56 percent.

Paper Grade	Paper Production [M Tonnes]	Waste Paper Utilization Rate [%]	Volume of Waste Paper used [M Tonnes]	Proportion of Waste Material [%]	Volume of Waste Material [M Tonnes]	Volume of RCF [M Tonnes]	Proportion of RCF [%]
• Graphic Papers	7.00	40	2.80	18	0.50	2.30	33
- Newsprint	1.50	112	1.68	18	0.30	1.38	92
- Recycled Paper	0.30	118	0.35	18	0.06	0.29	100
- Wood-containing Paper	2.40	26	0.63	18	0.11	0.52	21
- Woodfree Paper	2.80	5	0.14	18	0.03	0.11	4
• Packaging Paper and Board	5.57	98	5.46	10	0.56	4.90	88
• Sanitary Paper	0.86	80	0.69	35	0.24	0.45	52
• Specialty Paper	1.00	45	0.45	25	0.11	0.34	34
• Total/Average	14.43	65	9.40	15	1.40	8.00	55.5

RCF: Recycled Fibers

Source: Institut für Papierfabrikation, Darmstadt (1995)

Table 3.-2 Waste Paper in Different Paper Grades -Scenario 2- HP 1995

Table 3.-2 shows the splitting of the additionally processed waste paper volume of (9.4 - 8.2 =) 1.2 million tonnes, based on the following assumptions:

- An increase of the utilization rate in packaging paper and board from 94 percent to 98 percent.
- An increase of the utilization rate in sanitary paper by 11 percent to 80 percent.
- An almost unchanged utilization rate in specialty paper of 45 percent.

These three groups of the German paper production are supposed to use an additional volume of waste paper of almost 0.4 million tonnes compared with the current situation. The residual volume of waste paper of 0.8 million tonnes must be therefore processed by deinking for manufacturing of graphic papers. This results in

- An increase of the utilization rate in graphic papers by 12 percent to 40 percent.

Newsprint with its slightly increased waste utilization rate of now 112 percent has almost reached its saturation point. The same is valid for recycled graphic paper.

Therefore, the major proportion of the additional waste paper volume of 0.8 million tonnes must be used in wood-containing as well as in woodfree graphic papers. It is supposed that the major proportion of the additional waste paper volume will be used in wood-containing printing papers (0.63 million tonnes) such as SC- and LWC-papers, whereas the minor proportion of 0.14 million tonnes will be processed for manufacturing of woodfree paper. This results in the latter case in a waste paper utilization rate of five percent. Wood-containing paper will achieve a utilization rate of 26 percent. With reference to coated papers such as LWC-paper the proportion of waste paper must be then even higher than 26 percent because of the base paper being only about two thirds of the total paper weight.

It must be taken into account, that due to improved upgrading measures in waste paper processing the proportion of waste material generated will be increased from 15 percent (current situation and scenario 1) to 18 percent and in processing waste paper for packaging paper and board from eight percent to ten percent. This results then in an average waste proportion of 15 percent, compared with 12 percent of the current situation and scenario 1.

Despite the fact that the total waste paper utilization rate increases by nine percent from 56 percent to 65 percent, the proportion of recycled fibers present in the processed furnishes will increase by not more than five percent to 55.5 percent. This has to be regarded as a general trend: The higher the waste paper utilization rate, the higher is the proportion of waste material from paper processing in order to achieve well-processed pulps, beneficial for acceptable quality of paper made of recycled fibers.

Finally, the volume of waste material generated by waste paper processing increases by 0.4 million tonnes (air-dry substance) or 0.8 million tonnes (wet state) to 1.4 million tonnes (air-dry substance) or 2.8 million tonnes (wet state).

3.2 *Export and Import of Waste Paper*

Current Situation

In 1994 Germany imported 0.7 million tonnes of waste paper predominantly in terms of medium and superior grades, in the first place from neighbouring countries of the European Union. On the other hand the export of waste paper was mainly realized to West European countries and totalled 2.2 million tonnes (see Fig. 1.2-

15). The balance of imports and exports resulted in a net export of 1.5 million tonnes (Fig. 3.-1).

Scenario 1

According to scenario 1 this net export is kept constant despite the fact that the volume of imported waste paper might increase because of a growing demand of the German paper industry with respect to superior waste paper grades. This extended waste paper import must be balanced by a larger volume of exported waste paper, particularly to regions with fiber shortage such as countries of the Far East.

Scenario 2

Fig. 3.-1 makes evident that in the case of scenario 2 it is assumed that the net export of waste paper might be increased by 0.5 million tonnes approaching a total volume of 2.0 million tonnes. This estimated increase is marginal compared with the continuously increasing demand of the prospering countries of the Far East. However, one must bear in mind that a significant proportion of the exported waste paper comprises ordinary grades such as mixed waste and department store waste, whereas waste paper for deinking, increasingly demanded also by foreign markets, will not be sufficiently available for export due to the increasing demand of the home market. Medium and superior grades, increasingly required by the German paper industry, are virtually unavailable for export.

3.3 *Disposal of Non-Recyclable Waste Paper*

Current Situation

Currently 4.2 million tonnes of waste paper are not recyclable (see Fig. 1.2.-16). This volume must be disposed of either by landfilling (70 percent = 3.0 million tonnes) or by incineration in municipal combustion plants (30 percent = 1.2 million tonnes) (Fig. 3.-1). The proportion of non-recyclable waste paper, going to composting, is so marginal that no reference is made to this issue which is relevant currently for biowaste of households. Municipal incineration stands partly for energy recovery although the main target is the reduction of the waste volume in order to relieve the decreasing capacities of landfills. Due to the Municipal Waste Management Provision landfilling of organic matter such as non-recyclable waste paper will not be permitted any more at the latest by the year 2005.

Scenario 1

Scenario 1 takes this legal requirement mentioned above into account. In the case of an increased waste paper collection rate of 70 percent 1.7 million tonnes of waste paper is identified as an overcollected volume which is supposed to be neither utilized by the German paper industry nor exported (Fig. 3.-1).

This overcollected volume of waste paper characterized by a too low quality must be burnt, preferably by combustion plants of the paper industry, making use of co-generation and saving about 0.7 million tonnes of hard coal or 0.4 million tonnes of fuel oil. The overcollected volume of 1.7 million tonnes of ash-containing waste paper corresponds to approx. 1.4 million tonnes of ash-free waste paper. Ash-free waste paper has a heating value of 15 GJ/tonne, whereas the heating value of hard coal amounts to 30 GJ/tonne and of fuel oil to 42 GJ/tonne.

The remaining proportion of non-recyclable waste paper totals 2.5 million tonnes which must be burnt in municipal incineration plants. This volume mainly generated by private households corresponds to a per-capita waste paper volume of 30 kg/cap, still present as a small proportion of residual waste of households to be disposed of by municipal incineration.

Scenario 2

With reference to scenario 2 no waste paper is supposed to be available for industrial combustion because of the increased waste paper utilization rate of 65 percent and extended waste paper net export (Fig. 3.-1).

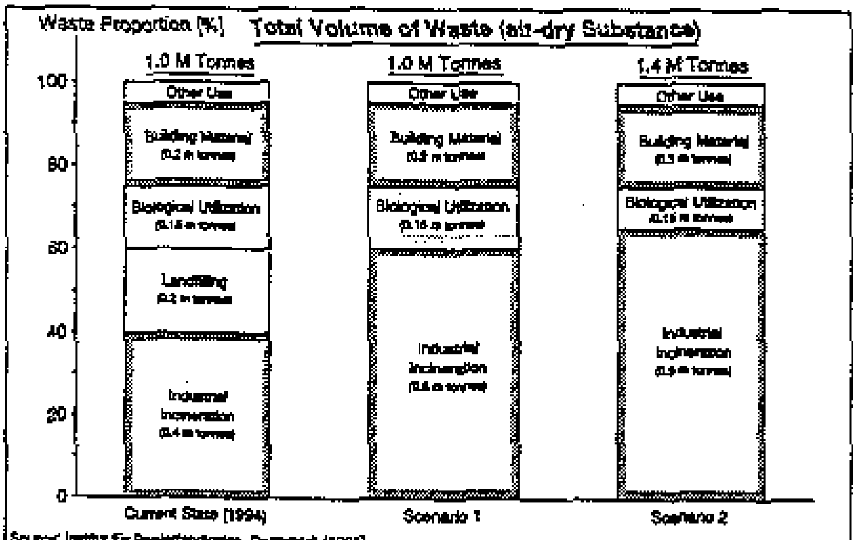
In this case the remaining non-recyclable volume of waste paper (2.5 million tonnes) is divided into two fractions, partly used as a co-substrate for composting (0.8 million tonnes) or as a fuel in municipal incineration plants (1.7 million tonnes). According to chapter 1.4.5.2 the estimated volume of biowaste, collected in private households and which will be composted, totals about five million tonnes. Up to 20 percent of this biowaste can contain 0.8 to 1.0 million tonnes of waste paper with reference to the optimum carbon-nitrogen ratio of the substrate required for an effective composting. The separately collected residual waste is expected to contain further a certain proportion of non-recyclable waste paper for energy recovery because a perfect separation between residual waste and waste paper can be never realized by end-consumers.

3.4 *Utilization and Disposal of Waste Material from Waste Paper Processing*

Table 3.-1 shows that 1.0 million tonnes (air-dry substance) of waste material in terms of rejects and deinking sludge is generated by the processing of waste paper in the different groups of the German paper production. In reality, this waste is produced in a wet state with an average moisture content of 45 percent which results in a total volume of 2.0 million tonnes. To avoid any confusion in the following, reference is made to air-dry substance of waste.

Current situation

In 1994 already 40 percent of the volume of the waste material was burnt in special furnaces of the paper industry (Fig. 3.-2) which have to fulfil stringent requirements with respect to air-born emissions according to the 17th Regulation of the Federal Emission Control Act (see chapter 1.3.3.2). By incinerating filler and pigment containing sludges, bottom and flue ash is produced which is not further taken into account: So far, the major part of the ash is disposed of by landfilling which does not contribute to any air-born emissions or pollution of the leachate water in the case of dumped ash. A smaller proportion is used as raw material by the cement industry.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 3.-2 Current Situation and Scenarios of Treatment of Waste Material from Waste Paper Processing in Germany

IfP 1995

It is supposed that about 120,000 tonnes of bottom and flue ash is produced, assuming an average ash content of the untreated waste material of 40 percent. Furthermore, the untreated ash is based on about 50 percent of china clay and approx. 50 percent of calcium carbonate which is transformed into calcium oxide at the high temperature of the furnaces.

Not more than 20 percent of the waste material of waste paper processing mills is (still) disposed of by landfilling which results in environmental pollution due to the generation of methane and carbon dioxide both contributing to global warming. Because of legal, ecological and economic requirements, landfilling of such organic matter will not be performed in the future. Therefore, both scenarios do not take any landfilling into consideration.

Approximately 15 percent of the waste is treated biologically in terms of soil spreading, composting and further utilization. Soil spreading of untreated waste is currently less well received by farmers and winegrowers as it was in the past.

Approximately 20 percent of the waste is utilized as a raw material by the cement industry, in brick works and the manufacturing of further construction material.

Finally, five percent of the waste serves as a raw material in manufacturing particle board, cat litter or further material.

Scenario 1

Driven by the Municipal Waste Management Provision as well as by dramatically increasing dumping costs, the still landfilled volume of waste must be treated in another manner, preferably by incineration in the paper industry (Fig. 3.-2). Therefore, it is assumed that 60 percent of the total volume of the waste material out of 1.0 million tonnes will be burnt for the benefit of energy recovery.

The residual volume of 40 percent will be further treated biologically (soil spreading, composting) and used as a raw material for different purposes as in the current situation.

Scenario 2

According to scenario 2 (Fig. 3.-2) the capacities of industrial incineration will be further increased achieving a proportion of 65 percent of the total waste volume of 1.4 million tonnes (Table 3.-2). Incineration becomes even more attractive because of significant cost savings compared with landfilling. Even an ash-containing and wet waste from waste paper processing contributes to energy recovery because no additional (fossil) fuel must be applied.

Because of expected restrictions with respect to soil spreading the portion of biologically treated waste will not exceed 150,000 tonnes which corresponds to ten percent of the total volume of waste material .

On the other hand, there will be improved opportunities for the utilization of waste in the cement industry, brick works and for manufacturing of other construction material. The volume of that waste (0.3 million tonnes) is still marginal compared with the capacity of the cement industry being as big as 33 million tonnes. The waste material from paper mills must be free of inorganic pollutants (heavy metals). This requirement will be fulfilled almost perfectly of the future printing inks whereas fillers and pigments will further contain heavy metals.

The final proportion of five percent of the total volume of waste for other utilization will be kept constant. The alternative would be either industrial incineration or utilization as a raw material for construction material.

4 *Comparison of the Scenarios*

4.1 *Environmental Impacts*

4.1.1 *Definition of the Scenarios*

Table 4.1.-1 shows the basic figures of the current situation and both scenarios of

- raw material input for paper production
- utilization and disposal of waste paper
- utilization and disposal of waste material

as presented and discussed in chapters 3.1 to 3.4.

Table 4.1.-1: Basic Figures of Current Situation and both Scenarios

	Current Situation		Scenario 1		Scenario 2	
Raw Material Input for Paper Production[1]	[%]	[M Tonnes]	[%]	[M Tonnes]	[%]	[M Tonnes]
Waste Paper	50	8.2	50	8.2	57	9.4
Sulfate Pulp	19	3.1	19	3.1	17	2.8
Sulfite Pulp	5	0.8	5	0.8	4	0.7
SGW/PGW	6	1.0	6	1.0	2	0.3
TMP	2	0.3	2	0.3	4	0.7
Fillers and Additives	18	3.0	18	3.0	16	2.6
Total	100	16.4	100	16.4	100	16.4
Utilization and Disposal of Waste Paper[2]						
Recycling in Germany	49	8.2	49	8.2	56	9.4
Net Export	9	1.5	9	1.5	12	2.0
Non-Recoverable	17	2.9	17	2.9	17	2.9
Landfilling	18	3.0	0	0	0	0
Municipal Incineration	7	1.2	15	2.5	10	1.7
Composting	0	0	0	0	5	0.8
Industrial Incineration	0	0	10	1.7	0	0
Total	100	16.8	100	16.8	100	16.8
Utilization and Disposal of Waste Material[3]						
Industrial Incineration	40	0.8	60	1.2	65	1.8
Landfilling	20	0.4	0	0	0	0
Biological Utilization[4]	15	0.3	15	0.3	10	0.3
Building Material[5]	20	0.4	20	0.4	20	0.6
Others[6]	5	0.1	5	0.1	5	0.1
Total	100	2.0	100	2.0	100	2.8

[1] air-dry tonnes; related to 16.4 million tonnes of raw material consumption in Germany (1994)

[2] air-dry tonnes; related to 16.8 million tonnes of consumption of paper products in Germany (1994)

[3] wet tonnes; dry content approx. 45 %

[4] composting, soil spreading and other biological utilization

[5] cement, brick and other building material manufacturing

[6] particle board, cat litter etc.

The waste paper as a percentage of total raw material consumption does not correspond to the waste paper utilization rate as percentage which refers to the paper production. Paper production is less (=14.4 M tonnes) than the total raw material consumption (= 16.4 M tonnes). The difference between total raw material consumption and paper production is affected by losses (in terms of rejects and sludges) in processing waste paper as well as virgin pulps and fillers in the stock preparation plants of paper mills.

Greenpeace is advocating a waste paper utilization rate of 75 percent (10.8 M tonnes waste paper : 14.4 M tonnes paper production) corresponding to a waste paper proportion of the total raw material consumption of 65 percent (10.8 M tonnes waste paper : 16.4 M tonnes raw material consumption) in 1994. It is not worth considering 75 percent utilization rate = 65 percent waste paper proportion as a scenario because of lack of an additional waste paper volume which fulfils quality requirements (e.g. in terms of pre-consumer waste) and because of the deterioration of paper quality with respect to printing and writing papers. Additional sludge generation, however, would not cause serious problems taking into account that an increasing sludge volume is going to be incinerated or used as a raw material in other industries, e.g. for manufacturing construction material such as cement or bricks.

4.1.2 *Procedure of Valuation*

To compare the environmental impacts of the current situation and both scenarios, modules are created for the production of chemical, mechanical and deinked pulps, preparation of fillers and paper manufacturing as well as for landfilling, incineration and utilization of waste paper and industrial waste material from paper manufacturing.

The categories and parameters dealt with are as follows:

- use of thermal and electrical energy (parameter: energy content in [GJ])
- air emissions (parameters: particles, NO_x, SO_2, CO_2 (fossil or biogenetic)
- water emissions (parameters: volume of waste water, COD, BOD and AOX)
- landfilled waste (parameter: mass)
- by-products energy (parameter: energy content in [GJ]), utilized waste material and compost (parameter: amount).

The following simplifications are made:

- Transportation is not taken into account. Its effect is more or less identical with the current situation as well as with both scenarios. Furthermore, it is well known that its environmental impact is small compared with the other, production related environmental issues.
- Paper conversion is also left out because its effect is identical with the current situation and both scenarios.
- The proportion of 18 percent of the material input in terms of fillers, pigments and additives are taken together as fillers.
- The energy required for disposal of waste paper as well as for utilization and disposal of waste material is negligible in comparison with the energy used by production processes. Therefore, this proportion is not taken into account.
- Mechanical and deinked pulps are considered to be produced in integrated paper mills. Chemical pulps are considered to be supplied as market pulps.

4.1.3 Calculation of Environmental Impacts

4.1.3.1 Energy Use and related Air Emissions in the German Paper Industry

For the calculation of the air emissions resulting from energy consumption in the pulp and paper industry, the following model is used:
61 percent of the electrical energy of the German paper industry was provided by purchasing electricity from the public supply grid and 39 percent by industrial generation in term of co-generation.

The average fuel mix for the production of grid electricity in Germany (1993) is illustrated in Fig. 4.1.-1. Table 4.1.-2 shows the air emissions related to the consumption of grid electricity.

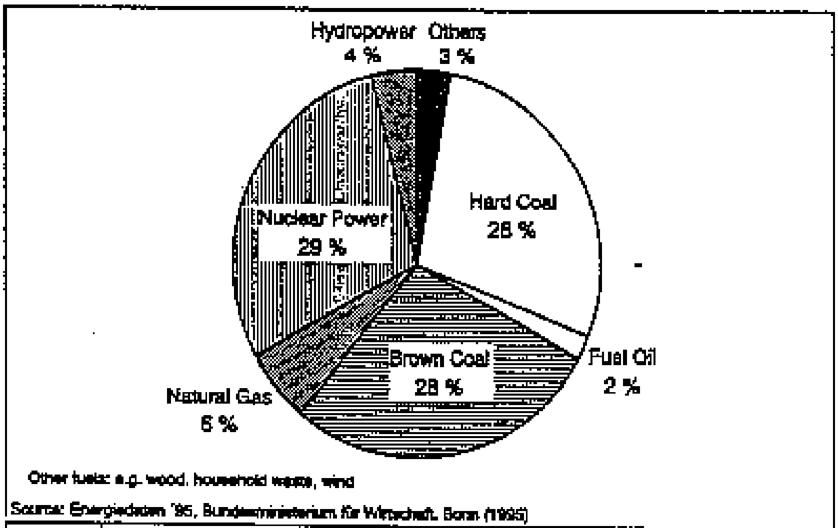
Table 4.1.-2: Fuel Mix for the Production of Grid Electricity and specific Air Emissions per GJ of Electrical Energy Consumption

Fuel Mix	[%]
Nuclear Power	29
Hard Coal	28
Brown Coal	28
Natural Gas	6
Hydropower	4
Fuel Oil	2
Other Fuels[1]	3
Total	**100**
Air Emissions	[g/GJ$_{el}$]
Particles	22
SO_2	135
NO_x	208
CO_2 (fossil)	186,200

1) Other Fuels: e.g. windpower, incineration of household waste

Source: GEMIS (1995)
Bundeministerium für Wirtschaft/Bonn (1996)

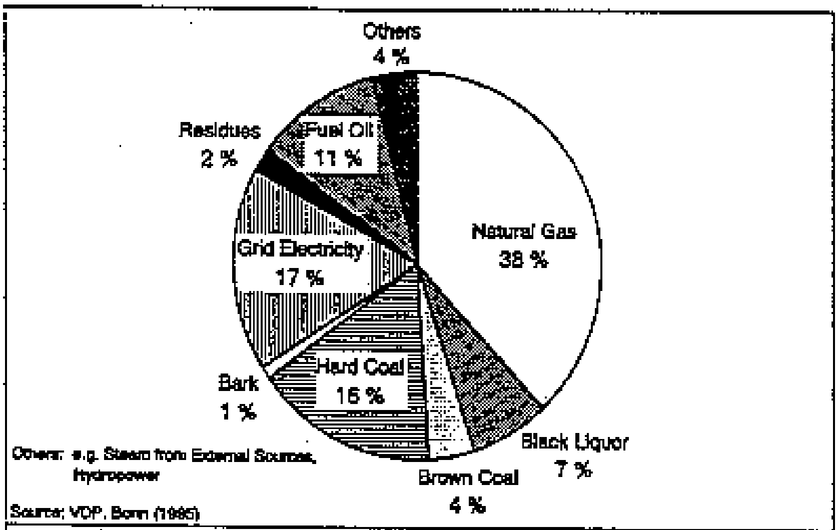
The average fuel mix used by the German pulp and paper industry for the generation of thermal and electrical energy is shown in Fig. 4.1.-2. To calculate the emissions from the consumption of industrially generated electrical and thermal energy only the fuels hard coal, brown coal, fuel oil and natural gas are taken into account. The composition of the category "other fuels" is not sufficiently specified in the statistics and therefore not included. The incineration of black liquor is considered separately within the air emissions from the pulping process. The incineration of waste material is also treated separately together with recycling and landfilling of waste material. The energy generated by industrial co-generation of waste matererial is credited.



Other fuels: e.g. wood, household waste, wind

Source: Energiedaten '95, Bundesministerium für Wirtschaft, Bonn (1995)

Fig. 4.1.-1 Fuel Mix for the Production of Grid Electricity in Germany (1993) IfP 1995



Others: e.g. Steam from External Sources, Hydropower

Source: VDP, Bonn (1995)

Fig. 4.1.-2 Energy Sources in German Paper Industry (1994) IfP 1995

This leads to the following proportions of energy sources in terms of their energy content (Germany 1994):

Natural Gas	54 %
Hard Coal	22 %
Brown Coal	6 %
Fuel Oil	15 %
Sub-Total	97 %
Residues	2 %
Bark	1 %
Total	100 %

Table 4.1.-3 shows characteristic emissions of industrial power plants for co-generation operating with different fuels.

Table 4.1.-3: Specific Air Emissions of Industrial Power Plants operating with Different Fuels per GJ of Electrical Energy Comsumption

Air Emission Parameters	Natural Gas [g/GJ]	Hard Coal [g/GJ]	Brown Coal [g/GJ]	Fuel Oil [g/GJ]
Particles	3	35	35	118
SO_2	14	284	158	295
NO_x	124	272	272	352
CO_2 (fossil)	130,770	368.130	430.470	221.788

Source: GEMIS

Table 4.1.-4: Specific Air Emissions related to Energy Consumption of the German Paper Production

Air Emission Parameters	Steam [g/GJ]	Electricity [g/GJ]
Particles	15	19
SO_2	66	105
NO_x	104	163
CO_2 (fossil)	111.550	152.250

The emission factors for the consumption of 1 GJ thermal or electrical energy listed in Table 4.1.-4 are calculated with the following equations:

$$\text{steam:} \quad \sum_{\text{fuels}} \left(\frac{\eta_{th}}{\eta_{total}} \cdot e_{j\,fuel} \cdot p_{fuel}\right) \quad [g/GJ]$$

$$\text{electricity:} \quad \sum_{\text{fuels}} \left(\frac{\eta_{el}}{\eta_{total}} \cdot e_{j\,fuel} \cdot p_{fuel} \cdot q_{el\,ind.} + e_{j\,grid} \cdot q_{el\,grid}\right) \quad [g/GJ]$$

with

η_{th} = thermal efficiency (45%)

η_{el} = electrical efficiency (40%)

η_{total} = overall efficiency (85%)

e_j = specific emission factor (e.g. SO_2)

p_{fuel} = share of the fuel of industrial energy mix

$q_{el\,ind.}$ = share of electrical energy co-generated in industry (39%)

$q_{el\,grid}$ = share of electrical energy purchased from grid (61%)

4.1.3.2 Production of Pulps, Fillers and Paper

Sulfate Pulp

Table 4.1.-5 shows the averaged environmental impacts of the production of elementally chlorine-free (ECF) bleached sulfate pulp. Sulfate pulp is supposed to be market pulp produced in non-integrated pulp mills.

Electrical and thermal energy is generated by incinerating bark and black liquor, in which about 50 percent of the used wood is dissolved. A small proportion of fossil energy (fuel oil) is required as support fuel (e.g. at the lime kiln). The generated energy covers more than is required by the process, so that a surplus of electricity can be used by other consumers, for example, by supplying it to the grid. The surplus is treated as a by-product.

Pulping of sulfate pulp is energy self-sufficient due to the energy content of bark and black liquor. Therefore, pulping is taken to be a process which does not require external energy supply.

The CO_2 emissions resulting from combusting bark and black liquor is classified as biogenetic, not contributing to the greenhouse effect.

Table 4.1.-5: Environmental Impacts of ECF Sulfate Pulp Production

Sulfate Pulp Production			
INPUT per tonne Sulfate Pulp		**o.d.**	**a.d.**
Energy			
Electricity	[GJ]	0*	0
Heating	[GJ]	0*	0
Total	*[GJ]*	*0*	*0*
Raw Materials			
Wood, o.d. undebarked	[t]	2.7	2.4
Water	[m^3]	50.0	45.0
OUTPUT per tonne Sulfate Pulp		**o.d.**	**a.d.**
Air Emissions			
Particles	[kg]	2.5	2.3
SO_2	[kg]	1.5	1.4
NO_x	[kg]	2.2	2.0
CO_2 (fossil)	[kg]	130	117.0
CO_2 (biogenetic)	[kg]	3.210.0	2.889.0
Water Emissions			
Volume of Waste Water	[m^3]	46.0	41.0
COD	[kg]	34.0	31.0
BOD	[kg]	1.4	1.3
AOX	[kg]	0.7	0.6
By-Products			
Electrical Energy	[GJ]	1.1	1.0

o.d.:oven-dry *Energy input based on black liquor: 3.5 GJ electricity/o.d. tonne pulp
a.d.: air-dry 16.1 GJ thermal energy/o.d. tonne pulp
BOD in terms of BOD_7

Source: KCL Eco Database/Espoo (1995)
Institut für Papierfabrikation/Darmstadt (1995)

Sulfite Pulp

Table 4.1.-6 shows the average environmental impacts of the production of totally chlorine-free (TCF) bleached sulfite pulp. Sulfite pulp is, as in the case of sulfate pulp, supposed to be market pulp produced in non-integrated pulp mills.

Pulping of sulfite pulp is energy self-sufficient. Therefore, pulping of sulfite pulp is also taken to be a process which does not require external energy supply. However, due to a higher yield and a higher energy demand with TCF bleaching no surplus energy is generated in contrast to sulfate pulping.

Table 4.1.-6: Environmental Impacts of TCF Sulfite Pulp Production

Sulfate Pulp Production			
INPUT per tonne Sulfite Pulp		**o.d.**	**a.d.**
Energy			
Electricity	[GJ]	0*	0
Heating	[GJ]	0*	0
Total	*[GJ]*	*0*	*0*
Raw Materials			
Wood, o.d. undebarked	[t]	2.4	2.2
Water	[m^3]	42.0	39.0
OUTPUT per tonne Sulfite Pulp		**o.d.**	**a.d.**
Air Emissions			
Particles	[kg]	0.9	0.8
SO$_2$	[kg]	2.0	1.8
NO$_x$	[kg]	1.8	1.6
CO$_2$ (fossil)	[kg]	113.0	101.7
CO$_2$ (biogenetic)	[kg]	2,276.0	2,048.0
Water Emissions			
Volume of Waste Water	[m^3]	38.0	34.2
COD	[kg]	20.0	18.0
BOD	[kg]	1.8	1.6
AOX	[kg]	0.0	0.0

o.d.: oven-dry; a.d.: air-dry

BOD in terms of BOD_7

*Energy input based on black liquor: 3.3 GJ electricity/o.d. tonne pulp
13.1 GJ thermal energy/o.d. tonne pulp

Source: KCL Eco Database/Espoo (1995)
Institut für Papierfabrikation/Darmstadt (1995)

Table 4.1.-7: Environmental Impacts of TMP Production

TMP Production			
INPUT per tonne TMP		**o.d.**	**a.d.**
Energy			
Electricity	[GJ]	10.0	9.0
Heating	[GJ]	0	0
Total	*[GJ]*	*10.0*	*9.0*
Raw Materials			
Wood, o.d. undebarked	[t]	1.2	1.1
OUTPUT per tonne TMP		**o.d.**	**a.d.**
Air Emissions			
Particles	[kg]	0.2	0.2
SO$_2$	[kg]	1.2	1.1
NO$_x$	[kg]	1.8	1.6
CO$_2$ (fossil)	[kg]	1,730.0	1,557.0
CO$_2$ (biogenetic)	[kg]	0	0
By-Products			
Thermal Energy	[GJ]	4.2	3.8

o.d.: oven-dry; a.d.: air-dry

Source: KCL Eco Database/Espoo (1995)
Institut für Papierfabrikation/Darmstadt (1995)

Thermomechanical Pulp

Table 4.1.-7 shows the environmental impacts of the production of thermomechanical pulp (TMP).

TMP production is performed in an integrated mill. Waste water emissions are considered within the paper module in order to avoid a double valuation. A TMP plant is free from (direct) emissions to a waste water treatment plant.

The energy consumption of TMP production depends on the pulp quality produced (particularly with respect to the freeness of the pulp). The energy demand of refiners, screening/cleaning and further processes varies between 7.2 GJ and 9.5 GJ per air-dry tonne TMP. Additionally the energy consumption of wood handling is taken into account.

TMP production is characterized by the generation of steam which is used for pre-steaming of the wood chips as well as for drying in the paper machine.

Stone Groundwood/Pressure Groundwood

Table 4.1.-8 shows the environmental impacts of the production of stone groundwood (SGW) and pressure groundwood (PGW).

Table 4.1.-8: Environmental Impacts of SGW/PGW Production

SGW/PGW Production			
INPUT per tonne SGW/PGW		o.d.	a.d.
Energy			
Electricity	[GJ]	8.7	7.8
Heating	[GJ]	0.3	0.3
Total	*[GJ]*	*9.0*	*8.1*
Raw Materials			
Wood, o.d. undebarked	[t]	1.1	1.0
OUTPUT per tonne SGW/PGW		o.d.	a.d.
Air Emissions			
Particles	[kg]	0.2	0.2
SO_2	[kg]	0.9	0.8
NO_x	[kg]	1.5	1.4
CO_2 (fossil)	[kg]	1.358.0	1.222.0
CO_2 (biogenetic)	[kg]	0	0

o.d.: oven-dry; a.d.: air-dry

Source: KCL Eco Database/Espoo (1995)
Institut für Papierfabrikation/Darmstadt (1995)

As in the case of TMP, SGW and PGW are produced in integrated mills. Waste water emissions are therefore considered within the paper module in order to avoid a double valuation.

The demand of electrical energy is affected by the quality of the pulp produced. Depending on the freeness aimed at the pulping, cleaning/screening and bleaching the energy demand ranges between 5.5 GJ to 7 GJ per air-dry tonne of SGW and PGW. Additionally electrical and thermal energy for wood handling and bleaching is consumed.

Waste Paper Processing

The environmental impacts of waste paper processing are shown in Table 4.1.-9. As waste paper (for undeinked as well as deinked pulp) is generally processed in integrated mills, waste water emissions are treated within the paper manufacturing module. About one third of waste paper used by paper production is treated by deinking whereas about two thirds of waste paper is required as undeinked pulp for manufacturing packaging paper and board

Processing of waste paper requires electrical energy (1 GJ to 1.8 GJ per air-dry tonne recycled fibers) as well as 0.8 to 1.4 GJ steam/tonne depending on the upgrading measures such as cleaning and screening, fractionation, dispersion, deinking or bleaching including sludge and reject treatment (dewatering).

Table 4.1.-9: Environmental Impacts of Waste Paper Processing

Waste Paper Processing			
INPUT per tonne Recycled Fiber		o.d.	a.d.
Energy			
Electricity	[GJ]	1.2	1.1
Heating	[GJ]	0.6	0.5
Total	*[GJ]*	*1.8*	*2.1*
Raw Materials			
Waste Paper	[t]	1.2	1.1
OUTPUT per tonne Recycled Fiber		o.d.	a.d.
Air Emissions			
Particles	[kg]	0.03	0.03
SO_2	[kg]	0.2	0.2
NO_x	[kg]	0.3	0.2
CO_2 (fossil)	[kg]	248.0	223.0
CO_2 (biogenetic)	[kg]	0	0

o.d.: oven dry

Source: Institut für Papierfabrikation/Darmstadt (1995)

Fillers

In papermaking 18 percent of non-fiber material comprises fillers and pigments (14 percent), chemicals and additives (4 percent). For simplification the total proportion of non-fiber material is regarded as fillers and pigments as calcium carbonate.

By burning calcium carbonate ($CaCO_3$) in combustion plants of the industry (sludge disposal and waste paper incineration) or of the communities (waste paper disposal) carbon dioxide (CO_2) is released because of the decomposition of $CaCO_3$. This proportion of released fossil CO_2 and the remaining ash (CaO) are not taken into account because they are negligible compared with the corresponding environmental impacts of the main production processes and energy generation.

The environmental impacts of the production of calcium carbonate, including mining and refining, are shown in Table 4.1.-10.

Table 4.1.10: Environmental Impacts of Filler Production (Mining and Refining)

Filler Production		
INPUT per tonne Fillers		o.d.
Energy		
Electricity	[GJ]	0.2
Heating	[GJ]	0.1
Total	*[GJ]*	0.3
Raw Materials		
Limestone Rock	[t]	1.1
OUTPUT per tonne Fillers		o.d.
Air Emissions		
Particles	[kg]	0.01
SO_2	[kg]	0.03
NO_x	[kg]	0.04
CO_2 (fossil)	[kg]	42.0
CO_2 (biogenetic)	[kg]	0

o.d.: oven-dry

Source: KCL Eco Database/Espoo (1995)
Institut für Papierfabrikation/Darmstadt (1995)

Stock Preparation

When chemical pulp is used for paper production, stock preparation (cleaning, screening, refining etc.) is necessary. Table 4.1.-11 shows the environmental data of stock preparation.

Table 4.1.-11: Environmental Impacts of Stock Preparation

Stock Preparation			
INPUT per tonne Chemical Pulp		o.d.	a.d.
Energy			
Electricity	[GJ]	1.0	0.9
Heating	[GJ]	0	0
Total	*[GJ]*	1.0	*0.9*
OUTPUT per tonneChemical Pulp			
Air Emissions			
Particles	[kg]	0.02	0.02
SO_2	[kg]	0.2	0.2
NO_x	[kg]	0.1	0.1
CO_2 (fossil)	[kg]	152.0	137.0
CO_2 (biogenetic)	[kg]	0	0

o.d.: oven-dry; a.d.: air-dry

Source: Institut für Papierfabrikation/Darmstadt (1995)

Table 4.1.-12: Environmental Impacts of Paper Production

Paper Production			
INPUT per tonne Paper		o.d.	a.d.
Energy			
Electricity	[GJ]	3.0	2.7
Heating	[GJ]	2.5	2.3
Total	*[GJ]*	*5.5*	*5.0*
Raw Materials			
Pulp and Fillers	[t]	1.0	1.0
Water	$[m^3]$	17.0	15.0
OUTPUT per tonne Paper		o.d.	a.d.
Air Emissions			
Particles	[kg]	0.1	0.1
SO_2	[kg]	0.5	0.5
NO_x	[kg]	0.8	0.7
CO_2 (fossil)	[kg]	736.0	662.0
CO_2 (biogenetic)	[kg]	0	0
Water Emissions			
Volume of Waste Water	$[m^3]$	15.0	13.5
COD	[kg]	3.0	2.7
BOD	[kg]	0.3	0.3
AOX	[kg]	0	0

o.d.: oven-dry; a.d.: air-dry

BOD in terms of BOD_5

Source: Institut für Papierfabrikation/Darmstadt (1995)

Paper Production

Paper production requires electrical and thermal energy. Depending on the paper or board grade produced the energy consumption ranges between 2 GJ and 4 GJ of electrical energy per air-dry tonne paper and between 1.2 GJ and 3.5 GJ of thermal energy per air-dry tonne paper. This includes the paper manufacturing itself but also secondary processes as e.g. waste water treatment, treatment of sludge (dewatering) and waste material handling.

The environmental impacts of paper production are shown in Table 4.1.-12.

4.1.3.3 Utilization and Disposal of Waste Paper

Landfilling of non-recyclable Waste Paper

The energy demand for landfilling (mainly as fuels to operate technical equipment for distribution and compression of waste) is about 20 MJ to 40 MJ per tonne of waste. This demand is negligible compared with the energy demand for pulp and paper production and therefore it is not taken into account (Table 4.1.-13).

About 40 percent to 60 percent of the landfilled waste paper will decay under landfilling conditions in a period of several decades. Air and water emissions occuring during degradation of landfilled waste depend on the elemental composition of the dumped material. As the content of sulphur and nitrogen of paper products is less than one percent, only gaseous emissions in terms of CH_4 and biogenetic CO_2 are considered to be of significance. The degraded organic carbon (200 kg carbon per oven-dry tonne waste paper) is transformed to 50 percent each into CO_2 and CH_4 (in terms of their carbon content).

Furthermore, emissions of landfill leachate of dumped waste paper are largely unknown. The volume of the leachate generated during the long-term degradation period depends on regionally different rainfalls and cannot be quantified. For that reason only COD and BOD loads are taken into account. They are approximated by using COD values measured in the water extract of waste paper (see chapter 1.3.1.5.1).

Table 4.1.-14: Environmental Impacts of Waste Paper Incineration

Incineration of Waste Paper			
OUTPUT per tonne Waste Paper		o.d.	a.d.
Air Emissions			
Particles	[kg]	0.2	0.2
SO_2	[kg]	0.3	0.3
NO_x	[kg]	1.6	1.4
CO_2 (fossil)	[kg]	0	0
CO_2 (biogenetic)	[kg]	1.300.0	1.170.0
By-Products			
Municipal Incineration			
Electrical Energy	[GJ]	2.5	2.25
Industrial Incineration			
Electrical Energy	[GJ]	6.7	6.0
Thermal Energy	[GJ]	7.5	6.75

o.d.: oven-dry; a.d.: air-dry

Source: *KCL Eco Database/Espoo (1995)*
Institut für Papierfabrikation/Darmstadt (1995)

Composting of Waste Paper

The energy demand of the technical equipment for composting is of the same order as for landfilling. This energy demand is, however, not taken into account.

Composting of waste paper together with biowaste from households results in a final compost which amounts to 50 percent of the original mass of the input substrates. The compost produced is regarded as a by-product.

The biodegradation of waste paper under aerobic decomposition conditions produces biogenetic CO_2 emissions which do not contribute to the greenhouse effect. Methane production is so marginal that it is not taken into account.

Leachate emissions cannot be quantified as in landfilling of waste paper. The volume of leachate is affected by the composting method and the locally different rainfalls. Therefore, only COD and BOD loads are approximated with reference to the corresponding loads obtained by water extract of waste paper (see chapter 1.3.1.5.1).

Table 4.1.-15 shows the environmental impacts of waste paper composting.

Table 4.1.-15: Environmental Impacts of Waste Paper Composting

Composting of Waste Paper			
OUTPUT per tonne Waste Paper		**o.d.**	**a.d.**
Air Emissions			
CO_2 (biogenetic)	[kg]	734.0	660.0
CH_4	[kg]	0	0
Water Emissions			
Volume of Waste Water	[m^3]	-	-
COD	[kg]	20.0	18.0
BOD	[kg]	2.0	1.8
By-Products			
Compost	[t]	0.5	0.5

o.d.: oven-dry; a.d.: air-dry
BOD in terms of BOD_5

Source: Institut für Papierfabrikation/Darmstadt (1995)

4.1.3.4 *Utilization and Disposal of Waste Material*

Landfilling of Waste Material

As in the case of waste paper disposal by landfilling the energy consumption of the disposal of waste material is not taken into account.

Waste material to be dumped consists mainly of ash, rejects, deinking sludge and sludge from waste water treatment. The extent of decomposition of waste material is supposed to be of the same order as that of waste paper (40 percent to 60 percent). According to the reasons explained with reference to landfilled waste paper air emissions only refer to carbon dioxide and methane whereas the water emissions comprise COD and BOD loads. For the calculation of the air-born emissions reference is made to the carbon content of deinking sludge. Deinking sludge contains about 50 percent ash, considered to be free of carbon, and 50 percent organic matter with a carbon content of 40 percent (200 kg carbon per tonne of oven-dry waste material prior to degradation). Furthermore, it is supposed that the carbon present in waste material is transformed to 50 percent each into CO_2 and CH_4 as far as the carbon content of these emissions is concerned.

The water-born emissions of waste material are set as identical with those of waste paper.

Table 4.1.-16 shows the environmental impacts of waste material landfilling.

Table 4.1.-16: Environmental Impacts of Landfilling of Waste Material

Landfilling of Waste Material		
OUTPUT		per wet tonne Waste Material
Air Emissions		
CO_2 (biogenetic)	[kg]	90.0
CH_4	[kg]	25.0
Water Emissions		
Volume of Waste Water	[m^3]	-
COD	[kg]	20.0
BOD	[kg]	2.0

BOD in terms of BOD_5

Source: KCL Eco Database/Espoo (1995)
Institut für Papierfabrikation/Darmstadt (1995)

Incineration of Waste Material

Waste material to be incinerated consists mainly of sludges and rejects from waste paper processing and waste water treatment with a dry content of 40 percent to 50 percent and a heating value of 4 GJ to 5 GJ per wet tonne.

The efficiency of industrial boilers is 40 percent for electrical energy and 45 percent for thermal energy (85 percent overall efficiency), so that 2 GJ electrical and 2.25 GJ thermal energy per wet tonne waste material can be generated.

Bottom and flue ashes which must be dumped or can be used as raw material for the manufacturing of building material are not taken into account.

In Table 4.1.-17 the data of waste material incineration are shown.

Table 4.1.-17: Environmental Impacts of Incineration of Waste Material

Incineration of Waste Material		
OUTPUT		per wet tonne Waste Material
Air Emissions		
Particles	[kg]	0.01
SO_2	[kg]	0.06
NO_x	[kg]	0.80
CO_2 (fossil)	[kg]	0
CO_2 (biogenetic)	[kg]	734.0
By-Products		
Electrical Energy	[GJ]	2.00
Thermal Energy	[GJ]	2.25

Source: KCL Eco Database/Espoo (1995)
Institut für Papierfabrikation/Darmstadt (1995)

Biological Utilization of Waste Material

Biological treatment of waste material refers mainly to composting and soil spreading.

As in the case of landfilling of waste material, a yield of 50 percent is assumed. The carbon content of waste material is supposed to be approximately 20 percent (200 kg carbon per oven-dry tonne of waste material). It is assumed that 50 percent of that carbon content is transformed into biogenetic CO_2. Because of aerobic conditions in composting or soil spreading, only a marginal volume of methane might be produced.

Leachate cannot be quantified. Therefore, COD and BOD loads generated are supposed to be identical with the corresponding loads of waste paper.

The compost produced (50 percent of the original waste material) is regarded as a by-product.

Table 4.1.-18 shows the environmental impacts of the biological utilization of waste material.

Table 4.1.-18: Environmental Impacts of Biological Utilization of Waste Material

Biological Utilization of Waste Material		
OUTPUT		per wet tonne Waste Material
Air Emissions		
CO_2 (biogenetic)	[kg]	180.0
CH_4	[kg]	0
Water Emissions		
Volume of Waste Water	[m^3]	-
COD	[kg]	20.0
BOD	[kg]	2.0
By-Products		
Compost (wet)	[t]	0.5

BOD in terms of BOD_5

Source: Institut für Papierfabrikation/Darmstadt (1995)

Utilization of Waste Material for Building Material Manufacturing and Other Utilization

Any environmental impact of waste material used as raw material for the manufacturing of building material or other purposes is neglected. It is supposed that the environmental parameters concerned are irrelevant. Furthermore, a proportion of the waste material is burnt in the cement industry for energy recovery and at the same time used as a raw material (ash content of the waste material). This proportion is unknown but considered to be small.

The utilized waste material is regarded as a raw material and therefore classified as a by-product (Table 4.1.-19).

Table 4.1.-19: Environmental Impacts of Utilization of Waste Material for Building Material Manufacturing and other Utilization

Utilization of Waste Material		
OUTPUT		per wet tonne Waste Material
By-Products		
Secondary Raw Materials (wet)	[t]	1.0

4.1.4 *Comparison of the Environmental Impacts of the Scenarios*

4.1.4.1 *Raw Material Input Scenarios*

Table 4.1.-20 shows the results of the calculations of the raw material input scenarios for producing chemical and mechanical pulps, for waste paper processing and for papermaking in terms of an averaged model paper based on the furnishes documented in Table 4.1.-1. The figures are related to 16.4 million air-dry tonnes of raw material input for manufacturing 14.4 million tonnes of paper. As the basic figures of current situation and scenario 1 are identical, there is no difference between the environmental related characteristics such as energy consumption, air and water emissions and generated by-products.

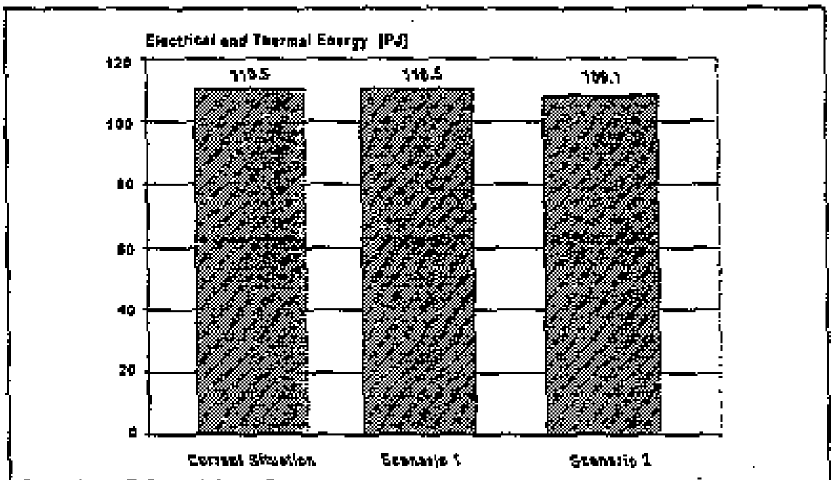
Table 4.1.-20: Environmental Impacts of Current Situation and Scenarios of Raw Material Input (Pulping and Papermaking)

Raw Material Input				
		Current Situation	Scenario 1	Scenario 2
INPUT				
Energy				
Electricity	[PJ]	68.1	68.1	66.3
Heating	[PJ]	42.4	42.4	42.9
Total	*[PJ]*	*110.5*	*110.5*	*109.1*
OUTPUT				
Air Emissions				
Particles	[1000 t]	10.1	10.1	9.2
SO_2	[1000 t]	18.8	18.8	17.7
NO_x	[1000 t]	21.9	21.9	20.8
CO_2 (fossil)	[1000 t]	15.510.0	15.510.0	15.229.0
CO_2 (biogenetic)	[1000 t]	10.681.0	10.681.0	9.398.0
Water Emissions				
Volume of Waste Water	[M m^3]	377.2	377.2	358.1
COD	[1000 t]	155.6	155.6	142.5
BOD	[1000 t]	10.3	10.3	9.6
AOX	[1000 t]	1.9	1.9	1.7
By-Products				
Electrical Energy	[PJ]	3.1	3.1	2.8
Thermal Energy	[PJ]	1.3	1.3	2.5

Figures relate to 16.4 million air-dry tonnes of raw material consumption for 14.4 million tonnes paper production in Germany (1994)

Energy Consumption

Fig. 4.1.-3 shows the total energy consumption (thermal and electrical energy) of current situation and both scenarios. As the basic figures of the current situation and scenario 1 are identical, there is no difference in energy consumption. In scenario 2 the energy consumption is slightly lower than with the current situation and scenario 1. This results from the higher waste paper utilization rate in scenario 2 compared with the current situation. In scenario 2, waste paper partly replaces chemical and mechanical pulps. Since waste paper processing is not as energy intensive as the production of mechanical pulp, energy consumption is decreased.



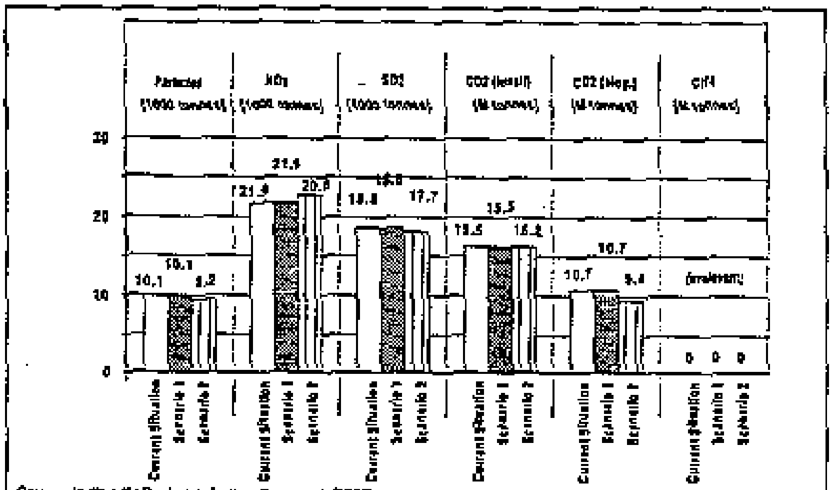
Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.1.-3

Raw Material Input Scenarios
Energy Consumption of Pulping and Papermaking

IfP
1995

Due to the reduced input of chemical and mechanical pulp and a higher proportion of waste paper used, the amount of fossil energy fuels used for energy generation is higher with scenario 2 compared to current situation and scenario 1.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.1.-4

Raw Material Input Scenarios
Air Emissions of Pulping and Papermaking

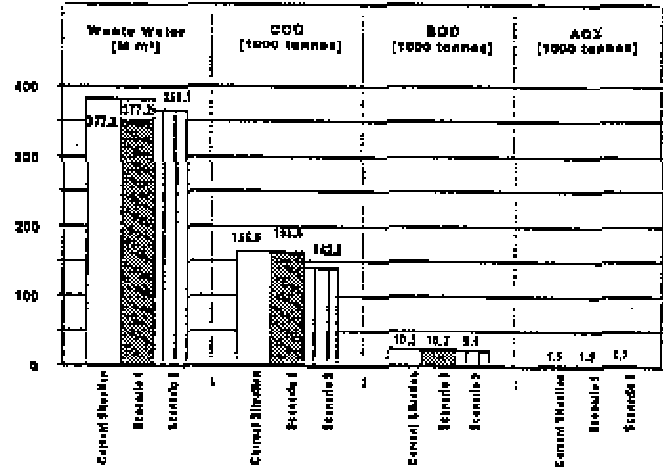
IfP
1995

Air Emissions

The air emissions of current situation and both scenarios are displayed in Fig. 4.1.-4. They are identical for current situation and scenario 1. The air emissions are correlated with energy consumption. Therefore, air emissions of scenario 2 are lower than with the current situation.

Water Emissions

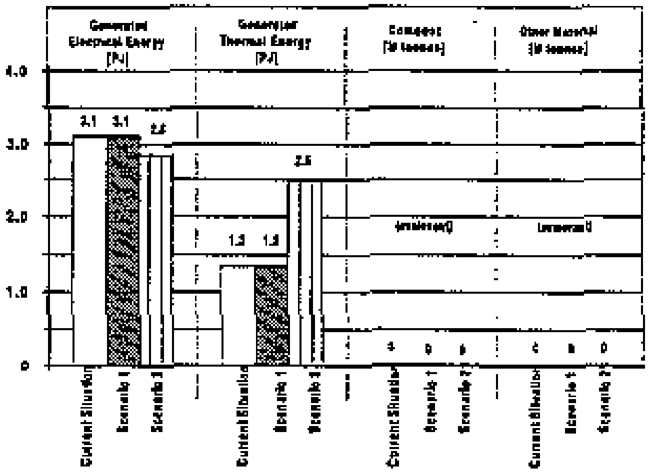
Fig. 4.1.-5 shows the water emissions of current situation and both scenarios. The figures of current situation and scenario 1 are identical. In scenario 2 the emissions are five percent to ten percent lower than with the current situation because of the higher waste paper utilization rate. Integrated waste paper processing causes less waste water emissions than non-integrated chemical pulping.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.1.-5 Raw Material Input Scenarios Water Emissions of Pulping and Papermaking

IfP 1995



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.1.-6 Raw Material Input Scenarios By-Products of Pulping and Papermaking

IfP 1995

By-Products

The amount of electrical and thermal energy produced as by-products in current situation and scenario 2 are shown in Fig. 4.1.-6. Electrical energy is generated as a by-product by the sulfate pulping process. Thermal energy is generated as a by-product in manufacturing of TMP. Due to the lower input of sulfate pulp with scenario 2 compared to current situation and scenario 1 the production of electrical energy is less in scenario 2 but more thermal energy is produced because of the higher input rate of TMP.

4.1.4.2 Scenarios of Utilization and Disposal of Waste Paper

Table 4.1.-21 shows the results of the calculations of the recycling and disposal of waste paper scenarios. The figures are related to 16.8 million air-dry tonnes consumption of paper products in Germany (1994).

Table 4.1.-21: Environmental Impacts of Current Situation and Scenarios of Utilization and Disposal of Waste Paper

Utilization and Disposal of Waste Paper				
		Current Situation	Scenario 1	Scenario 2
INPUT				
Energy	[PJ]	0	0	0
OUTPUT				
Air Emissions				
Particles	[1000 t]	0.2	0.8	0.3
SO_2	[1000 t]	0.02	0.6	0.03
NO_x	[1000 t]	1.7	5.9	2.4
CO_2 (fossil)	[1000 t]	0	0	0
CO_2 (biogenetic)	[1000 t]	2,374.0	4,914.0	2,520.0
CH_4	[1000 t]	272.2	0	0
Water Emissions				
Volume of Waste Water	[M m^3]	-	-	-
COD	[1000 t]	54.4	0	15.1
BOD	[1000 t]	5.4	0	1.5
AOX	[1000 t]	-	-	-
By-Products				
Electrical Energy	[PJ]	2.7	15.8	3.8
Thermal Energy	[PJ]	0	11.3	0
Compost	[M t]	0	0	0.4
Other Material	[M t]	0	0	0

Figures relate to 16.8 million air-dry tonnes consumption of paper products in Germany (1994)

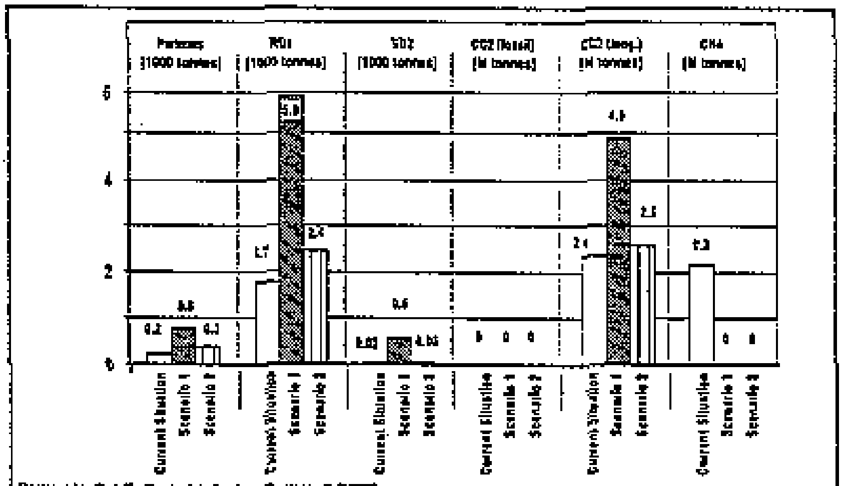
Energy Consumption

The energy demand of waste paper disposal is not taken into account. Therefore, the scenarios are not compared from this point of view.

Air Emissions

Fig. 4.1.-7 shows the air emissions of current situation and both scenarios. The emissions of fossil CO_2 are zero in all three compartments because the CO_2 generated in landfilling or composting of waste paper is biogenetic and because no energy demand, probably covered by fossil fuels, is considered.

In scenario 1 the emissions of particles, NO_X, SO_2 and biogenetic CO_2 are significantly higher then in current situation or scenario 2. This results from the much higher volume of waste paper incinerated in scenario 1 (25 percent) compared with current situation (7 percent) and scenario 2 (10 percent).



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.1.-7	Utilization and Disposal of Waste Paper Air Emissions of Current Situation and Scenarios	IfP 1995

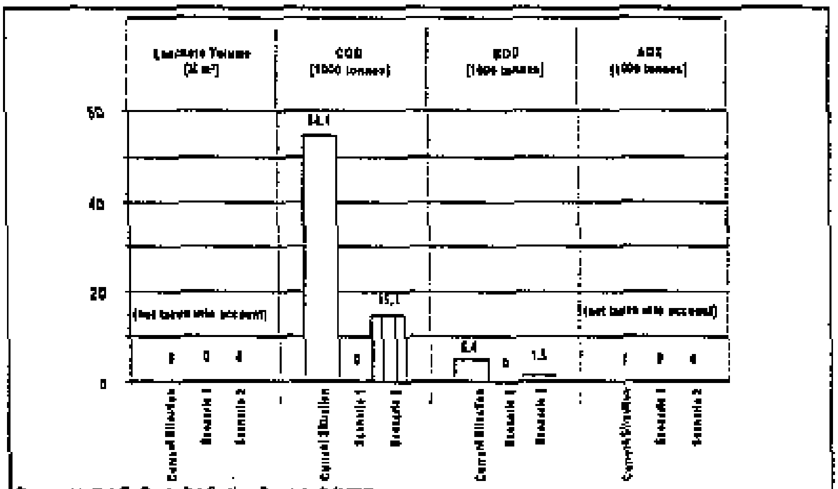
Emissions of CH_4 only occur in current situation because there is no waste paper landfilled in either scenario.

Water Emissions

In Fig. 4.1.-8 waste water emissions of the scenarios of waste paper utilization and disposal are illustrated.

The volume of waste water and AOX emissions are zero because these parameters were not taken into account.

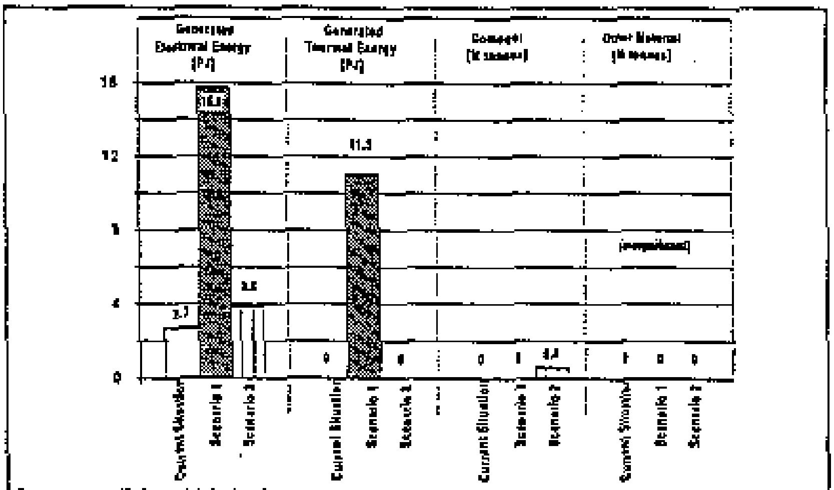
COD and BOD loads are highest in current situation due to the high proportion of non-recovered waste paper going to landfilling. These loads are zero in the case of scenario 1 because there is no landfilling or composting of non-recovered waste paper in this scenario.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.1.-8 Utilization and Disposal of Waste Paper
Water Emissions of Current Situation and Scenarios

IfP 1995



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.1.-9 Utilization and Disposal of Waste Paper
By-Products of Current Situation and Scenarios

IfP 1995

By-Products

Fig. 4.1.-9 shows the by-products generated. In scenario 1 the generation of thermal energy as a by-product is about three times as high as in current situation and scenario 2 due to the high rate of waste paper incineration in scenario 1. Thermal energy is only generated in scenario 1 because in this scenario waste paper is also burnt in industrial co-generation plants. The energy recovered from industrial incineration, in total (1.7 million tonnes waste paper x 15 GJ/tonne x 0.85 efficiency

=) 23 PJ, could cover twenty percent of the energy demand for pulp and paper production, which amounts to 110.5 PJ in scenario 1.

Compost is only produced in scenario 2 because the proportions of waste paper composted are zero in current situation and scenario 1.

4.1.4.3 Scenarios of Utilization and Disposal of Waste Material

Table 4.1.-22 shows the results of the calculations of current situation and both scenarios with reference to utilization and disposal of waste material from paper production. The figures shown are related to 2.0 million wet tonnes of waste material in current situation and 2.8 million wet tonnes of waste material in scenario 2.

Table 4.1.-22: Environmental Impacts of Current Situation and both Scenarios of Utilization and Disposal of Waste Material

Utilization and Disposal of Waste Material				
		Current Situation	**Scenario 1**	**Scenario 2**
INPUT				
Energy	[PJ]	0	0	0
OUTPUT				
Air Emissions				
Particles	[1000 t]	0.01	0.01	0.02
SO_2	[1000 t]	0.05	0.07	0.11
NO_x	[1000 t]	0.64	0.96	1.46
CO_2 (fossil)	[1000 t]	0	0	0
CO_2 (biogenetic)	[1000 t]	677.00	935.00	1.386.00
CH_4	[1000 t]	10.00	0	0
Water Emissions				
Volume of Waste Water	[M m³]	-	-	-
COD	[1000 t]	14.00	6.00	5.60
BOD	[1000 t]	1.40	0.60	0.56
AOX	[1000 t]	-	-	-
By-Products				
Electrical Energy	[PJ]	1.60	2.40	3.64
Thermal Energy	[PJ]	1.80	2.70	4.10
Compost	[1000 t]	0.15	0.15	0.14
Other Material	[1000 t]	0.50	0.50	0.70

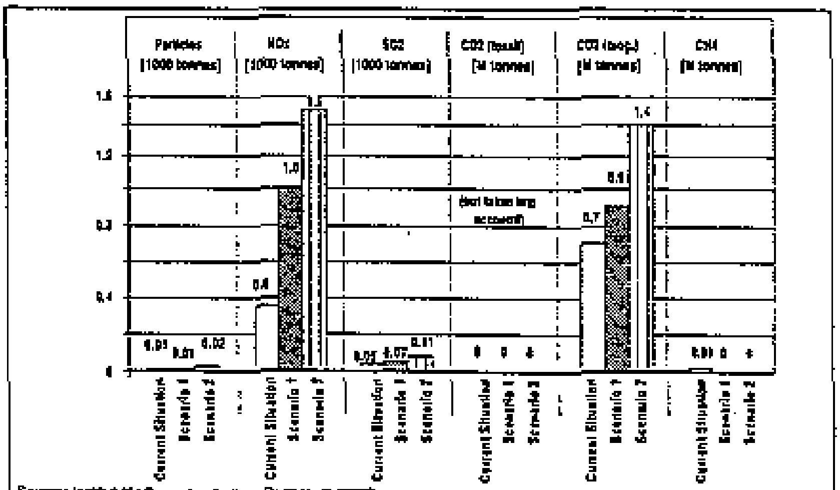
Figures relate to 2.0 million wet tonnes waste material in current situation and scenario 1 and 2.8 million wet tonnes waste material in scenario 2

Energy Consumption

No energy demand for waste material disposal and utilization was taken into account.

Air Emissions

Fig. 4.1.-10 shows the air emissions of current situation and both scenarios of the utilization and disposal of waste material from paper production.



Source: Institut für Papierfabrikation, Darmstadt (1995)

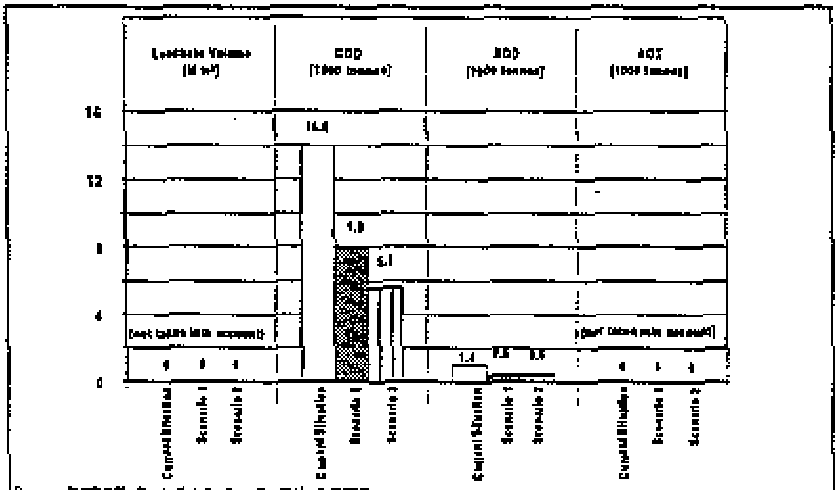
Fig. 4.1.-10 Utilization and Disposal of Waste Material Air Emissions of Current Situation and Scenarios ffP 1995

Emissions of particles, NO_X, SO_2 and biogenetic CO_2 are significantly higher in scenarios 1 and 2 compared with current situation due to the increased proportion of waste material incinerated.

Emissions of CH_4 only occur in current situation because no waste paper is landfilled in either scenario.

Water Emissions

Fig. 4.1.-11 shows the waste water emissions of the scenarios of waste paper recycling and disposal.



Source: Institut für Papierfabrikation, Darmstadt (1995)

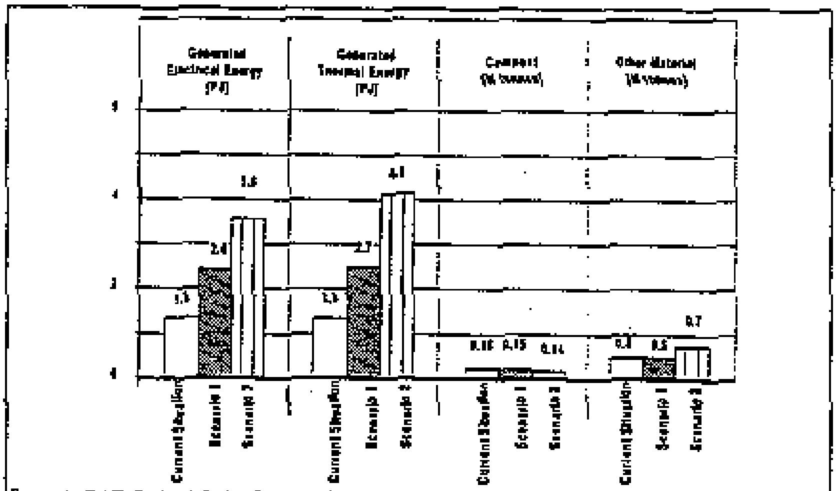
Fig. 4.1.-11 Utilization and Disposal of Waste Material
Water Emissions of Current Situation and Scenarios
IfP 1995

The volume of waste water and AOX emissions are zero because these parameters were not taken into account.

The loads of COD and BOD are as twice as high with current situation compared with both scenarios because of the large proportion of landfilled waste material.

By-Products

Fig. 4.1.-12 shows the by-products generated. The energy recovered by incinerating waste material covers two percent of the energy demand of pulp and paper production in current situation, three percent in the case of scenario 1 and four percent in case of scenario 2.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.1.-12 Utilization and Disposal of Waste Material
By-Products of Current Situation and Scenarios
IfP 1995

Furthermore, compost and raw materials for use in building material manufacturing and other purposes is generated. The amount of these by-products is in the same range in current situation and both scenarios.

4.1.4.4 *Combined Data*

Table 4.1.-23 shows the combined data of the environmental impacts of current situation and both scenarios.

Table 4.1.-23: Combined Data of Current Situation and both Scenarios

Combined Data				
		Current Situation	Scenario 1	Scenario 2
INPUT per tonne a.d. paper				
Energy				
Electricity	[PJ]	68.1	68.1	66.3
Heating	[PJ]	42.4	42.4	42.9
Total	*[PJ]*	*110.5*	*110.5*	*109.1*
OUTPUT per tonne a.d. paper				
Air Emissions				
Particles	[1000 t]	10.3	10.9	9.5
SO_2	[1000 t]	18.9	19.5	17.8
NO_x	[1000 t]	24.2	28.8	24.8
CO_2 (fossil)	[1000 t]	15.310.0	15.510.0	15.229.0
CO_2 (biogenetic)	[1000 t]	13.732.0	16.530.0	13.304.0
CH_4	[1000 t]	282.0	0	0
Water Emissions				
Volume of Waste Water	[M m^3]	377.2	377.2	358.1
COD	[1000 t]	224.0	161.6	163.2
BOD	[1000 t]	17.1	10.9	11.7
AOX	[1000 t]	1.9	1.9	1.7
By-Products				
Electrical Energy	[PJ]	7.4	21.3	10.2
Thermal Energy	[PJ]	3.1	15.3	6.6
Compost (wet)	[1000 t]	0.2	0.2	0.5
Other Material (wet)	[1000 t]	0.5	0.5	0.7

a.d.: air-dry

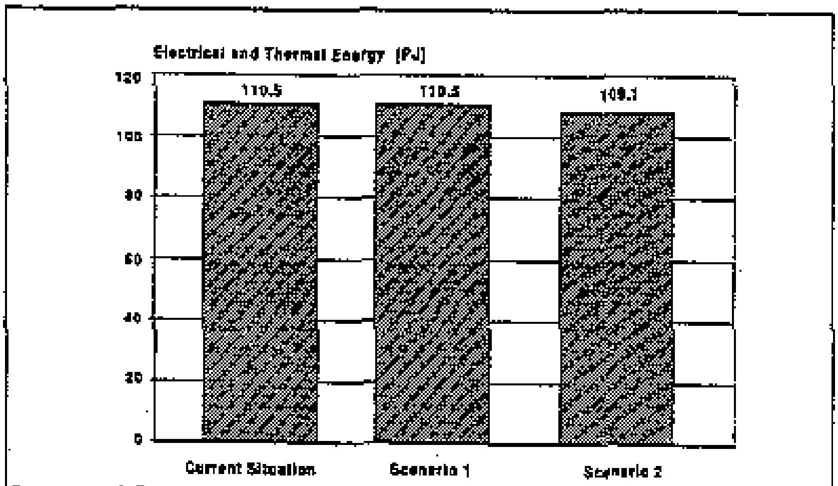
Energy Consumption

Fig. 4.1.-13 illustrates the total energy consumption (thermal and electrical energy) of current situation and both scenarios. Since the energy consumption of disposal, composting and utilization of waste paper and waste material was not taken into account due to the very low impact the combined energy consumption is identical

with the raw material input scenarios (representing the energy demand of pulping and papermaking).

Air Emissions

The combined figures of air emissions are shown in Fig. 4.1.-14. With exception of fossil CO_2 and CH_4 the emissions are highest in scenario 1. This results mainly from the high rate of waste paper incinerated which does not affect the emissions of fossil CO_2. Emissions of CH_4 only occur with current situation because there is no landfilling of waste paper or waste material in either scenario.

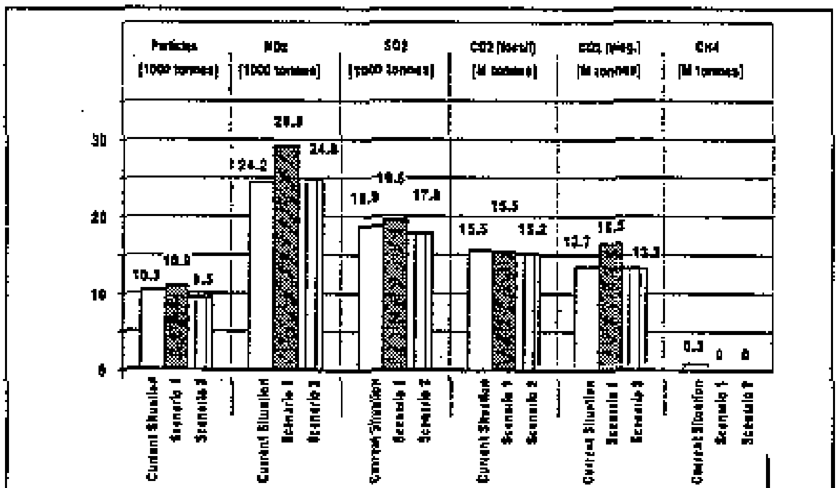


Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.1.-13

Combined Data
Energy Consumption of Current Situation and Scenarios

HP
1995



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.1.-14

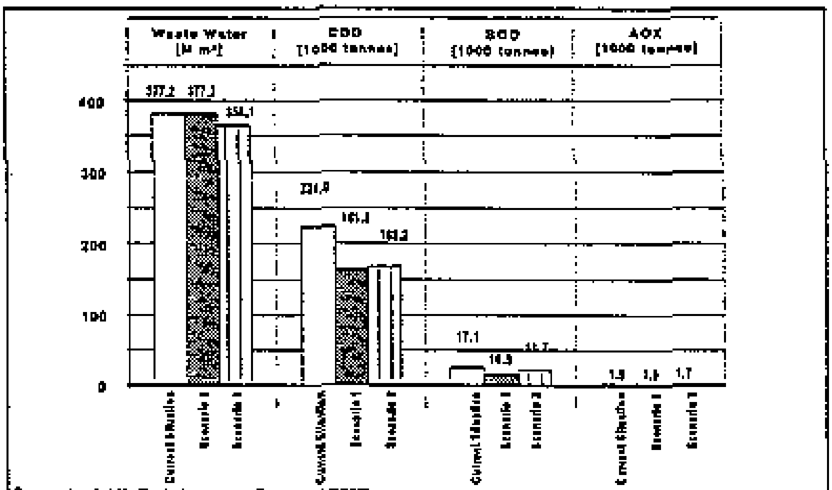
Combined Data
Air Emissions of Current Situation and Scenarios

HP
1995

Water Emissions

Fig. 4.1.-15 illustrates the combined data of water emissions in current situation and both scenarios. Since the volume of waste water and loads of AOX were quantifiable only for pulping and papermaking these figures are identical with the corresponding figures of the raw material input scenarios.

COD and BOD loads are highest with current situation. This is mainly determined by the high rates of waste paper and waste material going to landfilling or composting. The largest proportions of COD and BOD loads are determined by pulping and papermaking (70 percent in current situation, 96 percent in scenario 1 and 87 percent in scenario 2). Waste paper disposal has an influence on these loads of 24 percent in current situation, none at all in scenario 1 (no waste paper dumped or composted) and 9 percent in scenario 2.

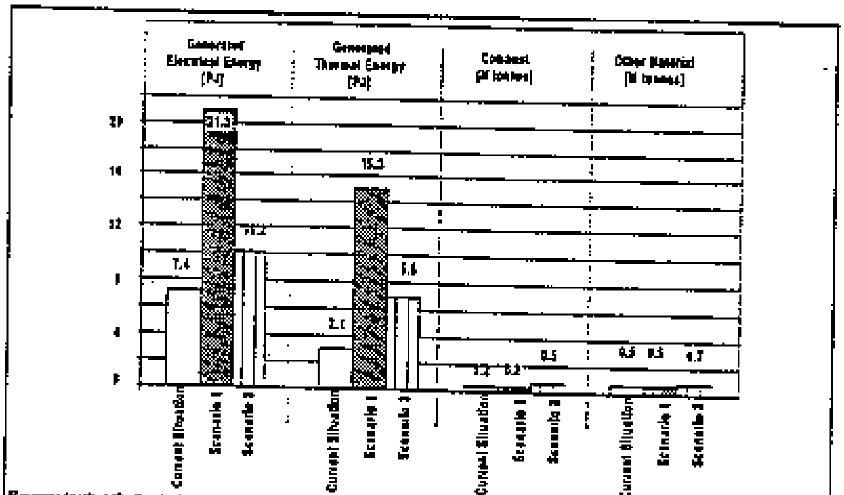


Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.1.-15 Combined Data
Water Emissions of Current Situation and Scenarios
IfP 1995

By-Products

Fig. 4.1.-16 shows the by-products generated. Due to the proportion of waste paper incinerated, the amount of generated electrical and thermal energy is significantly higher in scenario 1 compared with current situation and scenario 2. The total generated energy amounts to 36.6 PJ with scenario 1 which covers one third of the energy consumed by pulping and papermaking (10 percent with current situation and 15 percent with scenario 2). As far as the energy is generated by waste paper or waste material incineration (90 percent of the total energy generated with scenario 1), it might replace fossil energy fuels and so reduce emissions of fossil CO_2 by one third.



Source: Institut für Papierfabrikation, Darmstadt (1996)

Fig. 4.1.-16 Combined Data
By-Products of Current Situation and Scenarios
IfP
1996

The output of compost is three times higher with scenario 2 because of the increased proportion of waste paper going to composting.

4.2 Impacts on Paper Quality

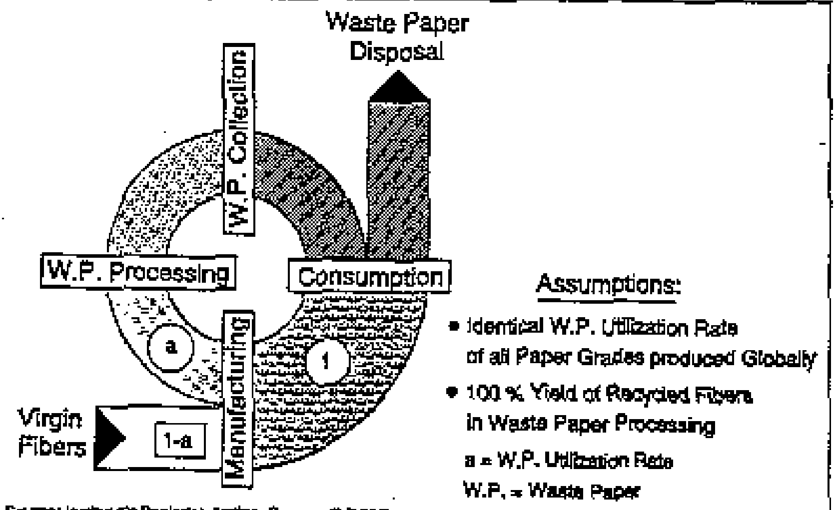
4.2.1 Effect of Recycling on Fiber Age Distribution and Characteristics of Paper containing Recycled Fibers

4.2.1.1 Fiber Age Distribution

The higher the waste paper utilization rate, the higher is statistically the number of times fibers have been recycled and the greater is the probability that mechanical, optical and further paper characteristics have deteriorated. Considering this, it makes sense to calculate fiber distribution by weight according to the age of fiber generations present in pulps and paper containing recycled fibers. Paper made of recycled fibers can contain fibers of different generations (different number of cycles) depending on the waste paper grade(s) used. Because it is quite impossible to analyse the age of fiber generations (in terms of the number of passes through recycling loops) by any test method one is forced to make reference to mathematical evaluations.

Simplified Global Model

The most simplified model based on the single, most important parameter 'waste paper utilization rate *a*' is shown in Fig. 4.2.-1. It is assumed that all paper grades produced globally are made of the identical furnish in respect of its proportion (*1-a*) of virgin fibers and the proportion *a* of recycled fibers. The globally manufactured paper volume and the volume of consumed paper products, respectively, are then separated in the proportion *a* for collection and reuse and (*1-a*) as waste paper for disposal. In this simplified model, the proportion of disposed waste paper is identical with the proportion of virgin fibers used for paper manufacturing because no losses of fiber material is taken into account which means a yield of 100 percent.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.2.-1. Calculation of Age Distribution of Recycled Fibers (Simplified Global Model) IfP 1995

Fig. 4.2.-2 illustrates the mathematical procedure for the calculation of the distribution of the fiber generations as well as the average number of cycles of fiber of the total furnish for paper manufacturing. For mathematical reasons the parameter 'waste paper utilization rate *a*' is defined in relative terms as a fraction and not as generally as percentage. Therefore 50 percent utilization rate is identical with $a = 0.5$ and G_n can be expressed as fraction or as a percentage.

Age Distribution of Fibers (by Weight)

Total Pulp = Virgin Pulp + Recycled Pulp
Share of Recycled Pulp $\hat{=}$ Waste Paper Utilization Rate
a = Waste Paper Utilization Rate
$1-a$ = Proportion of Virgin Pulp (G_0)
G_{tot} = Total Pulp

$G_{tot} = G_0 + G_1 + G_2 + \dots G_n = 1.0$ (100 %)
$G_0 = (1-a)$
$G_1 = a \cdot (1-a)$
$G_2 = a^2 \cdot (1-a)$
$\vdots$
$G_n = a^n \cdot (1-a)$

G_1 = Proportion of Recycled Fibers of the first Generation

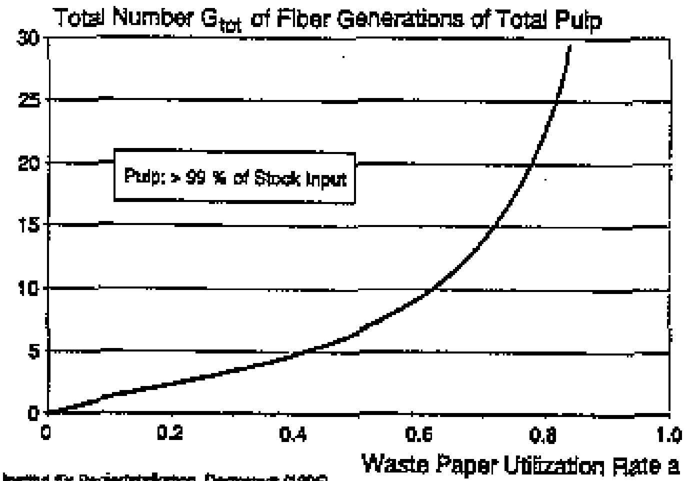
Average Number $\overline{G}$ of Fiber Generations

$$\overline{G} = \sum_{n=0}^{\infty} n\, G_n = \frac{a}{1-a}$$

Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.2.-2 Simplified Global Model
Age Distribution of Recycled Fibers (by Weight)
Average Number of Fiber Generations of Total Pulp
IfP 1995

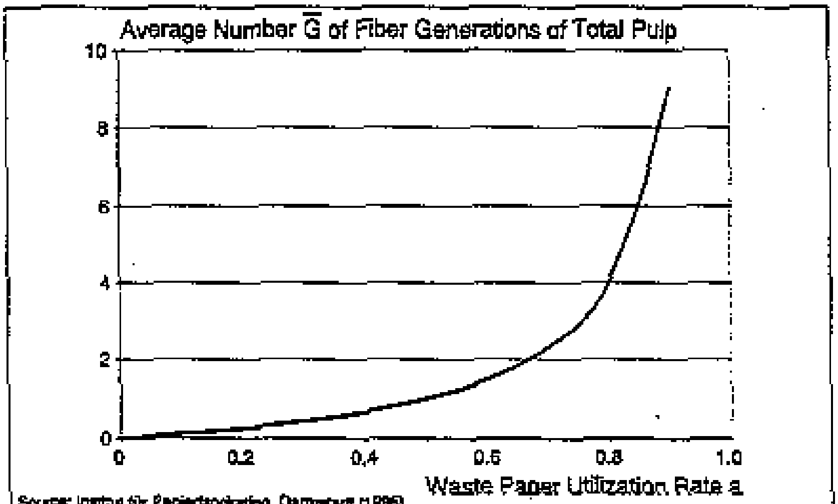
The total number of fiber generations of the furnish plotted versus waste paper utilization rate is presented in Fig. 4.2.-3. (Only the younger generations contributing to 99 percent of the furnish are included.) Up to a rate of about 50 percent the gradient of the exponential curve is rather small followed by a significant increase of the slope above 50 percent. At that rate of 50 percent, seven fiber generations are present.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.2-3 Total Number of Fiber Generations of Total Pulp for Paper containing Recycled Fibers
IfP 1995

The corresponding trend becomes evident with respect to the average number of cycles (generations) versus waste paper utilization rate (Fig. 4.2.-4). The number *0* stands for a furnish which only contains virgin fibers. At a waste paper utilization rate of 50 percent this average number of fiber generations is exactly *1*, whereas the total number of generations amounts, as mentioned, to seven including the generation G_0 in terms of virgin fibers contributing to 99 percent of the furnish. Increasing the waste paper utilization rate to $a = 0.66$ (66 % waste paper utilization rate) the average number of generations doubles to two. At the waste paper utilization rate of $a = 1 = 100$ percent not only the total number of fiber generations becomes infinite but also the average number of cycles. Because wood fibers cannot keep their length and fiber-to-fiber bonding strength infinite times a global recycling at $a = 1 = 100$ percent is absolutely unrealistic.



Source: Institut für Papierfabrikation, Darmstadt (1996)

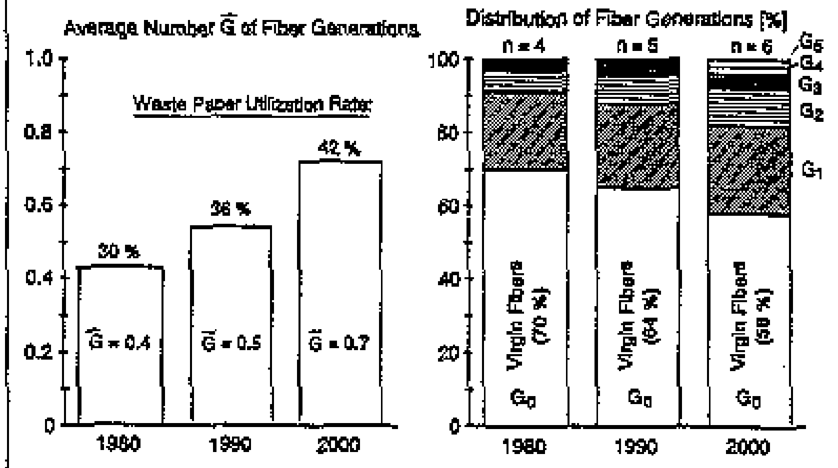
Fig. 4.2-4 Average Number of Fiber Generations of Total Pulp for Paper containing Recycled Fibers

HP 1996

Fig. 4.2.-5 shows the results of that simplified global model with reference to the average and the total number of fiber generations and distribution of fiber generations by weight. The basis of that assessment is the global waste paper utilization rate of the past and the year 2000 forecast of 42 percent. It can be concluded that the average number of fiber generations increases insignificantly between 1990 and 2000 from 0.5 to 0.7.

In reality the average number of fiber generations of a pulp or a paper containing a higher proportion of recycled fibers than assumed according to Fig. 4.2.-5 can increase considerably. Therefore, it is necessary to calculate the average number of fiber generations with reference to the conditions of a specific paper produced.

On the right hand side of the figure the weight distribution of fiber generations and the total number of fiber generations are shown. Due to the growing waste paper rate the proportion of virgin fibers decreases from 70 percent to 58 percent and the proportion of the recycled fibers increases from 30 percent to 42 percent whereas the total number of fiber generations only slightly increases from four (1980) to five (1990) and then six in the year 2000.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.2.-5 Average Number and Total Number of Fiber Generations of Total Pulp (Simplified Global Model) IfP 1995

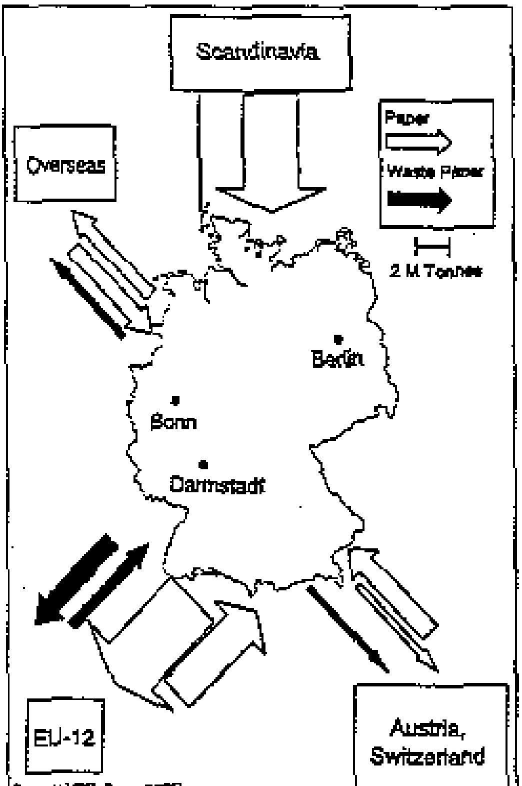
With respect to an estimation of mechanical properties of pulp and paper containing recycled fibers, it makes sense to evaluate, for example, the proportion of the pulp which contains, besides virgin fibers, the generations of recycled fibers which have passed through the recycling system not more than twice. In 1980 the proportion of these three generations mentioned totalled 97 percent and in the year 2000 the corresponding figure will amount to 93 percent. In the latter case (theoretically) not more than seven percent of the globally averaged pulp furnish or paper will contain recycled fibers which are older than two generations. Assuming that older generations contain a higher proportion of fines, it might be expected that the sludges removed in waste paper processing will mainly contain fibers and fines of the multiple-treated proportion of recycled fibers. (For the benefit of recycling and the consolidation of paper characteristics, it would be ideal if, with each recycling loop, the oldest generation(s) of recycled fibers (and fillers/pigments) could be removed by waste paper processing.)

Multi-Parameter Model with Reference to Newsprint in Germany

The next step of modelling approaches the reality of waste paper recycling in many countries taking paper imports with their different waste paper content into account, depending on individual paper grades and their origin by country and specific paper mills. For a better understanding of the rather complicated model with its large number of parameters reference is made to German conditions of the year 1991 and to the production of newsprint with its waste paper content of 70 percent at that time (State 1). Furthermore, calculations are conducted with a waste paper utilization rate of $a = 1 = 100$ percent of German newsprint (State 2). At least as important are further factors which affect the average age and the age distribution of the recycled fiber generations present in German newsprint. These factors are as follows:

- Composition of waste paper processed (e.g. proportions of news, magazines etc)
- Origin of waste paper components (by country or region where original papers had been produced)
- Composition of original paper (e.g. content of mechanical and chemicals pulps).

Fig. 4.2.-6 shows the imports and exports of paper as well as of waste paper of Germany in 1994. These material inputs and outputs affect the average number and the distribution of the fiber generations of any paper produced in Germany with recycled fibers.

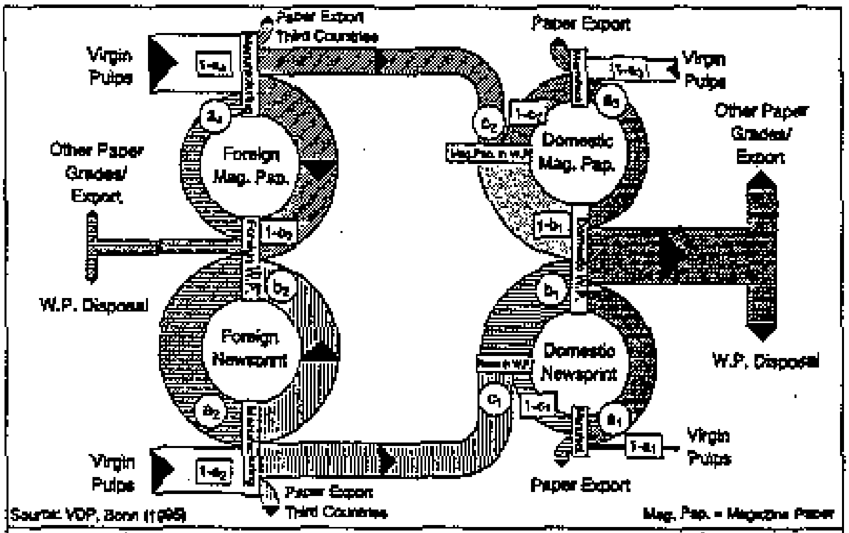


Source: VDP, Bonn (1995)

Fig. 4.2.-6 Import and Export of Paper and Waste Paper (Germany, 1994) IfP 1995

About 40 percent of the domestic paper production is exported mainly into other EU states, and, to a smaller extent, to overseas countries as well as to Austria and Switzerland. (The East European market broke down.) On the other hand, almost half of the German paper consumption must be imported, mainly from Northern Europe and other EU states, to a lesser extent from overseas. Furthermore, there is an international trade of waste paper. Germany exports almost 25 percent of its recovered waste paper mainly in terms of lower grades such as mixed waste and department store waste, whereas imports are predominantly superior grades. Imports and exports of paper as well as of waste paper affect the age distribution of recycled fibers of any paper grade containing processed waste paper.

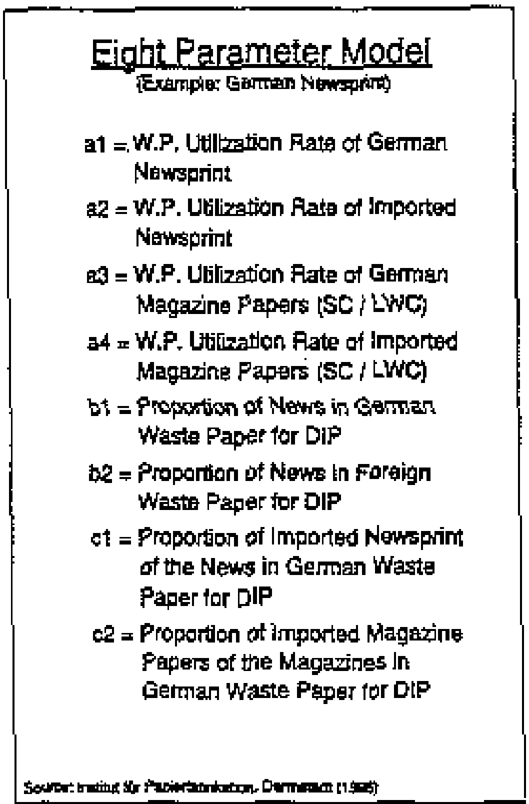
What does the pulp furnish of German newsprint look like? The waste paper mix for newsprint consists roughly of 50 percent news and 50 percent magazines (SC- and LWC-papers). So far, domestic as well as imported magazine papers are made of (almost) 100 percent virgin components (pulps and fillers/pigments). News printed on domestic newsprint contained 70 percent recycled fibers, whereas news printed on imported newsprint include on average only 20 percent recycled fibers. The flows of domestic and imported newsprint as well as of domestic and imported magazine papers which become components of waste paper for DIP are shown in Fig. 4.2.-7. The eight parameters on which the Multi-Parameter Model is based, are explained in Fig. 4.2.-8. This model does not take losses in waste paper processing or elsewhere into account.



Source: VDP, Bonn (1995)

Fig. 4.2.-7 Eight Parameter Model: Calculation of Age Distribution of Recycled Fibers and Recycled Fillers/Pigments IfP 1995

The distribution of recycled fiber generations in 1991 with the main parameter $a_1 = 0.70$ (which is equivalent to a waste paper utilization rate of 70 percent at that time) is shown in Fig. 4.2.-9. On the same figure the results of a further calculation is presented (State 2: 2000), referring to a waste paper utilization rate of 100 percent ($a_1 = 1.0$). This scenario already reflects the current situation in Germany. On the other hand it is assumed that the waste paper utilization rate a_2 of imported newsprint increased from 20 percent (1991) to 50 percent (2000) whereas magazine papers produced at home are based on 50 percent waste paper in 2000 (a_3).

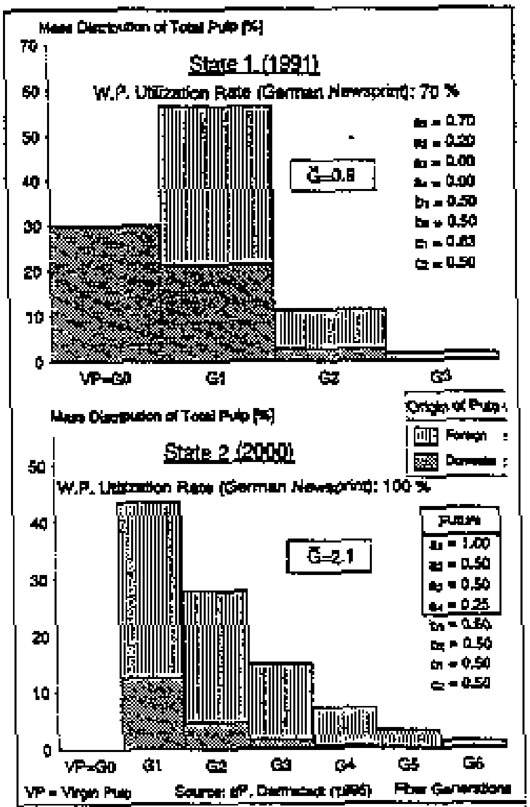


Eight Parameter Model
(Example: German Newsprint)

a1 = W.P. Utilization Rate of German Newsprint
a2 = W.P. Utilization Rate of Imported Newsprint
a3 = W.P. Utilization Rate of German Magazine Papers (SC / LWC)
a4 = W.P. Utilization Rate of Imported Magazine Papers (SC / LWC)
b1 = Proportion of News in German Waste Paper for DIP
b2 = Proportion of News in Foreign Waste Paper for DIP
c1 = Proportion of Imported Newsprint of the News in German Waste Paper for DIP
c2 = Proportion of Imported Magazine Papers of the Magazines in German Waste Paper for DIP

Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.2-8 | Eight Parameter Model Definition of Parameters | IfP 1995



Source: IfP, Darmstadt (1995)

Fig. 4.2-9 | Age Distribution of Total Pulp for German Newsprint (Eight Parameter Model) | IfP 1995

The results of state 1 are surprising because the total number of recycled fiber generations is rather low (three generations) in the year 1991 and will not be more than six generations by 2000. (All generations which contribute less than one percent to the newsprint produced are not taken into account that is, those older than six generations.) In both cases the dominating proportion of recycled fibers is composed of the youngest recycled generation G_1. The other figure of concern is the average number of fiber generations which is almost one in 1991 and not more than 2.1 for the scenario 2000.

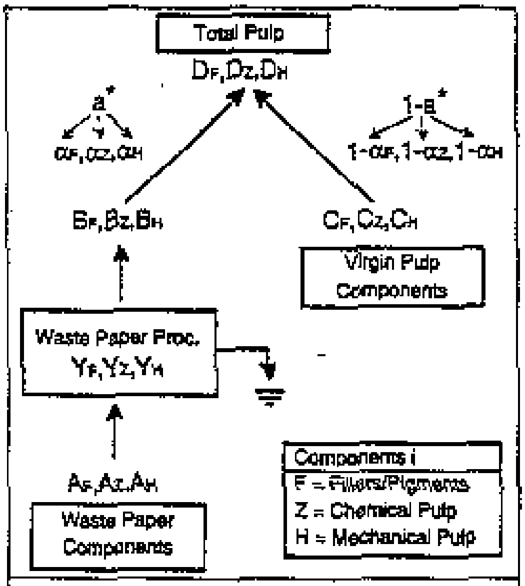
Fig. 4.2.-9 gives further information. The columns documenting the frequency of the recycled fiber generations are divided into two parts according to the origin of the fibers, namely into imported and domestic fibers. Imported fibers are identified as such despite the fact that they pass through the German recycling system several times after the corresponding imported newsprint or magazine paper becomes waste paper. The different characteristics of imported and domestic fibers, such as

imported TMP and domestic SGW, make it worthwhile to keep them separate in modelling.

Modified Multi-Parameter Model with Reference to German Newsprint

The modified Multi-Parameter Model takes the yield of the different waste paper components such as chemical pulp, mechanical pulp and fillers/pigments in waste paper processing into account. According to Fig. 4.2.-10 the composition of paper to be produced with its three stock components D_F, D_Z and D_H contains the three corresponding virgin components C_F, C_Z and C_H as well as the three recycled components B_F, B_Z and B_H of the deinked pulp. The overall yield Y_{total} of the waste paper processing is affected by the individual yields Y_F, Y_Z and Y_H of the three recycled components. It is assumed that the yields of these components are as follows: fillers = 60 percent; mechanical pulp = 90 percent; chemical pulp = 95 percent. According to the composition of the newsprint concerned these individual yields result in a total yield of 85 percent which is in agreement with the real situation of waste paper processing (two-stage flotation).

Because the yield is lower than 100 percent, the waste paper utilization rate is not identical with the real waste paper content of the total pulp and the newsprint produced. This means that the real waste paper content is 15 percent lower than the statistical waste paper utilization rate, which becomes indirectly evident in the legend of Fig. 4.2.-10.



a^* = Real W.P. Content of Paper produced ($a^* = a \cdot Y_{total}$)
a = W.P. Utilization Rate
α_i = Share of Component i of treated W.P. related to total Pulp Component i of Paper to be produced ($\alpha_i = a^* \cdot B_i / D_i$)
A_i = Component i of purchased W.P. (before its Processing)
B_i = Component i of processed W.P.
C_i = Component i of Virgin Pulp
D_i = Component i of Paper to be produced
Y_i = Yield of W.P. Component i affected by Waste Paper Processing

Fig. 4.2.-10 Mass Balance affected by Different Yields of Three Components of Total Pulp IfP 1995

Source: Institut für Papierfabrikation, Darmstadt [illegible]

Eight-Parameter Model

(Example: German Newsprint)

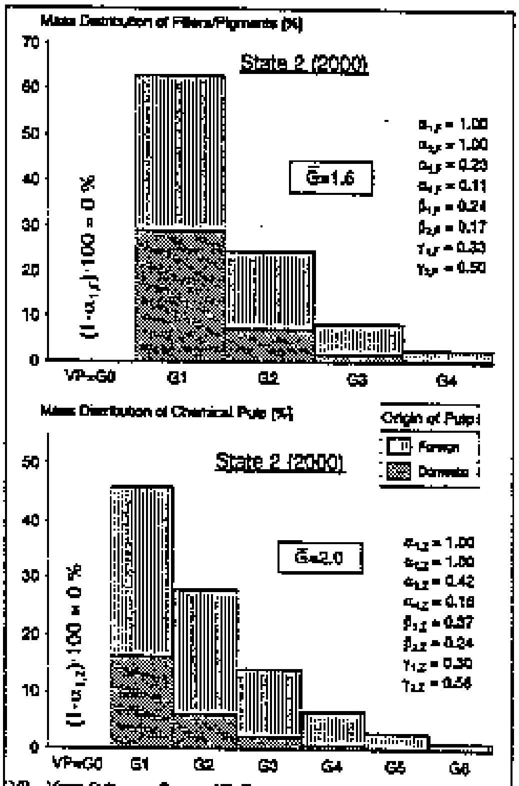
α1,i = Proportion of Recycled Component i related to Total Component i of German Newsprint
α2,i = Proportion of Recycled Component i related to Total Component i of Imported Newsprint
α3,i = Proportion of Recycled Component i related to Total Component i of German Magazine Papers
α4,i = Proportion of Recycled Component i related to Total Component i of Imported Magazine Papers
β1,i = Proportion of Stock Component i of News related to Total Component i of German Waste Paper for DIP
β2,i = Proportion of Stock Component i of News related to Total Component i of Foreign Waste Paper for DIP
γ1,i = Proportion of Stock Component i of News produced from Imported Newsprint related to Total Pulp Component i of News of German Waste Paper for DIP
γ2,i = Proportion of Stock Component i of Magazines produced from Imported Magazine Papers related to Total Pulp Component i of Magazines of German Waste Paper for DIP

Source: Institut für Papierfabrikation, Darmstadt [illegible]

Fig. 4.2-11 Modified Eight Parameter Model: Definition of Parameters IfP 1995

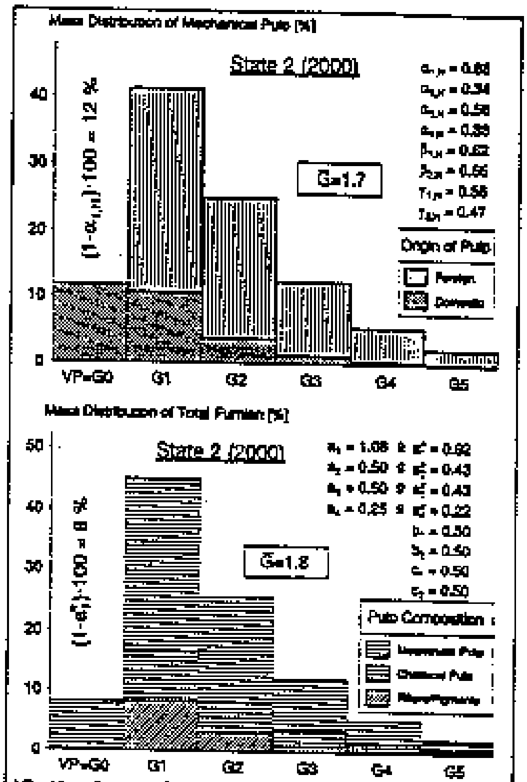
The different parameters of the modified Eight Parameter Model are explained in Fig. 4.2.-11

The results of the refined, reality-oriented calculations are shown in Fig. 4.2.-12 and Fig. 4.2.-13. Now, we are in a position to specify separately the age distribution of the three stock components, such as fillers/pigments, chemical pulp and mechanical pulp.



VP = Virgin Pulp Source: IfP, Darmstadt (1995)

Fig. 4.2.-12	Age Distribution of Total Pulp Components of German Newsprint (Modified Eight Parameter Model)	IfP 1995



VP = Virgin Pulp Source: IfP, Darmstadt (1995)

Fig. 4.2.-13	Age Distribution of Total Pulp Components of German Newsprint (Modified Eight Parameter Model)	IfP 1995

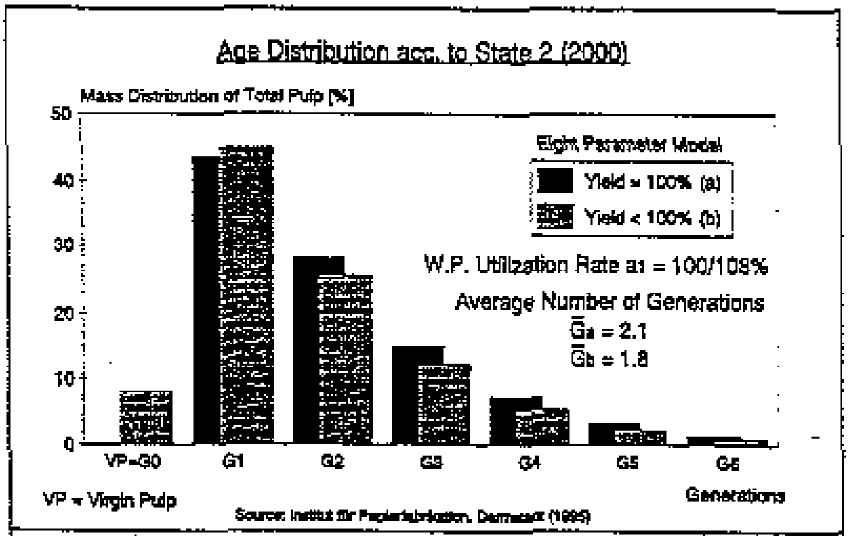
We start with the age distribution of fillers and pigment in Fig. 4.2.-12 referring to newsprint and its forecast waste paper utilization rate of $a_1 = 108$ percent in the year 2000 (which was already achieved in Germany in 1994). First of all, one must be aware that, because the filler content of the newsprint to be produced is in the range of ten percent, there is no need for the application of any additional virgin fillers, which means that the zero-generation G_0 amounts to zero percent. This depends on the fact that the highly filled SC-paper fraction and the coated LWC-paper fraction of magazine papers present in the waste paper mix introduce a sufficient amount of fillers and pigments into the final newsprint stock.

It can be easily seen that only four recycled filler/pigment generations are present in the newsprint stock and the newsprint produced. The youngest recycled filler generation G_1 contributes to the largest amount, whereas the fourth generation G_4 is only marginal. The average number of cycles of fillers and pigments is not more than 1.6. However, one should bear in mind that particularly recycled fillers and pigments are acting as carriers of residual printing particles which will accumulate in the course of each recycling loop because of imperfect deinkability. Such residual inks will affect the brightness of the paper depending on the number of generations of fillers and pigments present in paper based on recycled fibers.

The age distribution of chemical pulp comprises six generations. Because of a high chemical pulp content of SC- and LWC-papers as components of the waste paper mix used, it is common to manufacture newsprint without any addition of virgin chemical pulp. Therefore, the zero-generation G_0 is equivalent to zero percent. The average number of generations is 2.0. The chemical pulp content 'imported' via imported newsprint, SC- and LWC-papers is larger than that which has been used in manufacturing SC- and LWC-paper in Germany.

Fig. 4.2.-13 refers to the age distribution of recycled mechanical pulp fibers. In this case the mass distribution is quite different compared with recycled fillers and recycled chemical pulp because of the addition of a certain amount (12 percent) of virgin mechanical pulp. Bearing in mind that the yield is lower than 100 percent, there is a need for the addition of 12 percent virgin mechanical pulp based on the total amount of mechanical pulp of the furnish. This freshening up of the mechanical pulp composition of the newsprint furnish results in a lowering of the average number of pulp cycles ($G \approx 1.7$).

The lower part of Fig. 4.2.-13 summarizes the age distribution of the three furnish components of the newsprint concerned. The virgin component with its eight percent is only mechanical pulp. The total number of recycled components does not exceed five generations. As expected, with all the five recycled generations mechanical pulp is dominant. Finally, the average number of pulp generations results in 1.8 which is surprisingly small even though the waste paper utilization rate of the newsprint discussed is 108 percent. This underlines the significance of imported paper as potential waste paper with its lower recycled fiber content compared with the recycled fiber content of the newsprint concerned.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.2.-14 Age Distribution of Total Pulp (Eight Parameter Model) IfP 1995

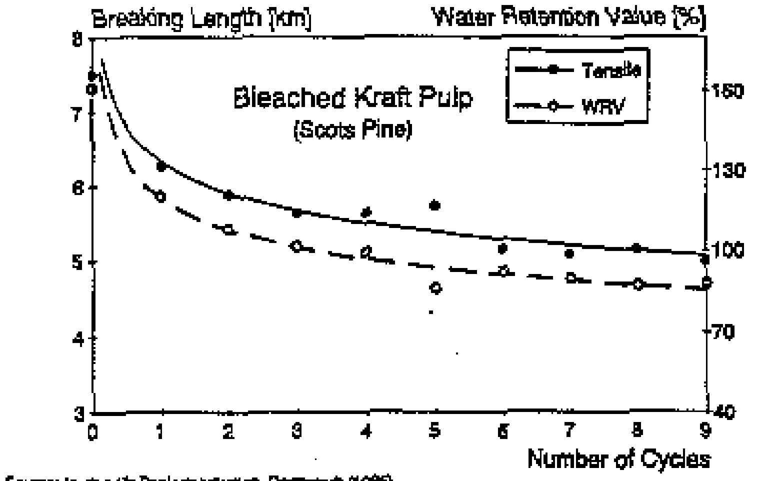
How does a realistic yield of 85 percent affect the number of recycled fiber generations in comparison to the corresponding Multi-Parameter Model, based on a yield of 100 percent? The results of these calculations are shown in Fig. 4.2.-14 with reference to German newsprint, produced in the year 2000 with a waste paper utilization rate of 108 percent. Taking a pulp yield smaller than 100 percent into account, the total number of recycled fiber generations is reduced from six to five, whereas the proportion of virgin pulp (mechanical pulp) is increased from zero percent to eight percent. Due to the loss of fibers and fillers by screening, cleaning and deinking the Modified Eight Parameter Model results in an average number of 1.8 generations, which seems to be rather small, despite the fact that the waste paper utilization rate has been established as high as 108 percent.

4.2.1.2 *Physical Characteristics of Paper Containing Recycled Fibers*

Apart from economic conditions, the quality profile of recycled fibers and of paper made from them affects the level of utilization of waste paper. Most important are strength and optical properties. Strength properties depend mainly on the average fiber length and on the fiber-to-fiber bonding, which is influenced by hornification as a result of drying in previous papermaking. Average fiber length and fiber length distribution are affected by mechanical pulp treatment, particularly by beating and to a lesser extent by deflaking or even by calendering. The hornified fines generated by cutting effects hardly contribute to fiber-to-fiber bonding. Elimination of fines of recycled fibers, besides de-ashing (= controlled removal of fillers/pigments which impair mechanical properties of paper sheets), can thus be rated as an upgrading measure.

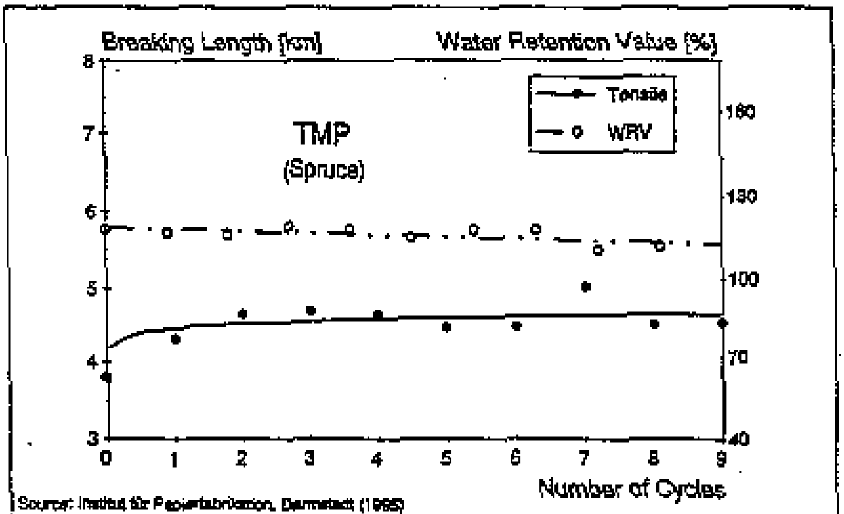
So far, no effective technology is available to improve the bondability without any reduction of the fiber length. An exception is high-consistency beating or refining in an alkaline environment. However, these processes are not yet widely used because of certain disadvantages: an alkaline regime contributes to an increase of the COD of white water and of waste water and to yellowing of wood-containing sheets. According to current knowledge, enzymes used in waste paper processing do not contribute to an improvement of strength and optical properties of recycled fibers. They tend to decrease Schopper-Riegler wetness (or increase Canadian Standard Freeness) which is advantageous in the drainage of paper webs on the paper machine.

Recycling or drying of natural fibers results in differing effects depending on the type of fibers. Fig. 4.2.-15 and Fig. 4.2.-16 prove that multiple recycling, simulated on lab scale by disintegration, refining (only in the first cycle), sheet formation, wet pressing and drying, does not influence water retention value of fibers and tensile strength of mechanical pulp. On the other hand chemical wood fibers deteriorate during recycling by reducing swelling (water retention value) of fibers and tensile strength of the sheet made of recycled fibers. Obviously, high-yield pulp is more resistant against rigors of recycling whereas chemical pulp, with its higher starting point of strength characteristics, suffers significantly, particularly during the first cycle. One has to be aware that deterioration of strength properties of chemical pulps already occurs with market pulps compared with undried pulps converted to paper in integrated mills. The different trends of strength properties of mechanical and chemical pulps after multiple recycling on lab scale were confirmed by researchers in Europe as well as in North America.



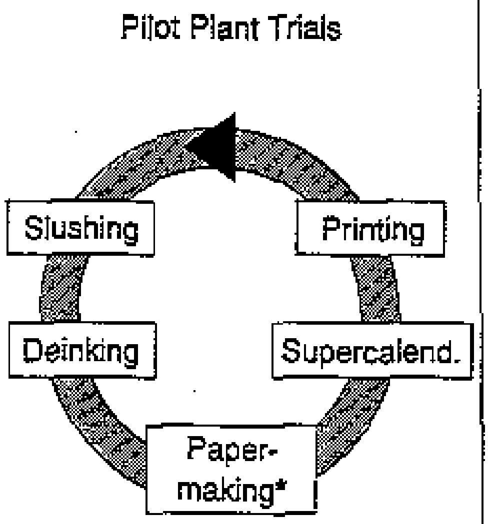
Source: Institut für Papierfabrikation, Darmstadt (1996)

Fig. 4.2.-15 Effect of Recycling (Lab Simulation) IfP 1995



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.2.-16 Effect of Recycling (Lab Simulation) IfP 1995



* Sheet Formation, Wet Pressing and Drying of Paper Web

Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.2.-17 Scheme of Multiple Recycling IfP 1995

- Units of Operation

  - Slushing (5% consistency)
  - Flotation (injector aerated, 5 passes)
  - Papermaking (Fourdrinier machine)
  - Calendering (2 nips)
  - Printing (web offset, black ink)

- Paper

  - Fiber Composition:
    50% bleached Pine Kraft
    50% Stone Groundwood
  - Filler:
    12% China Clay
  - Basis Weight: 80 g/m²
  - ISO-Brightness: 68% (first cycle)
  - Roughness: ≈120/230 ml/min (TS/WS)
    (Bendtsen)

- Recycling Passes
  - 6 Cycles
  - Machine and Technological Parameters kept constant
  - Loss of Filler was compensated at each Cycle

Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.2.-18 Conditions of Multiple Recycling on Pilot Plant Scale IfP 1995

Upscaling multiple recycling trials on pilot plant scale (Fig. 4.2.-17 and Fig. 4.2.-18) have been recently conducted by the Department of Paper Science and Technology at Darmstadt, based on a model paper consisting of

- 44 percent mechanical pulp (spruce stone groundwood)
- 44 percent chemical pulp (bleached pine sulfate pulp)
- 12 percent fillers (China clay).

The same fibers passed the total cycle of papermaking, supercalendering, printing and stock preparation (disintegration, deinking) six times aiming at a minimal loss of material.

After a gentle beating of the chemical pulp component (only prior to the first cycle) paper was manufactured on a Fourdrinier pilot machine (0.6 m trim) followed by rewinding, supercalendering to approximately the same roughness and printing on an offset press (black ink, coverage of 60 percent on one side). The non-aged printed paper was then deinked by an one-stage injector aerated flotation without employing any dispersion or post-flotation. This cycle was repeated five times without any addition of virgin fibers. Small portions of lost fillers (because of flotation losses and a retention less than 100 percent) were added after each cycle to keep the ash content constant at twelve percent. Some of the findings are shown in the Fig. 4.2.-19 to Fig. 4.2.-23.

- The average fiber length (measured with a Kajaani tester) is kept constant which indicates that the retention of short fibers and fines was excellent (Fig. 4.2.-19).

- The classification by a Bauer McNett classifier indicates that the proportions of long fibers (R14 ÷ R30), short fibers (R50 ÷ R100), fines and fillers (D100) are kept constant cycle by cycle (Fig. 4.2.-20).

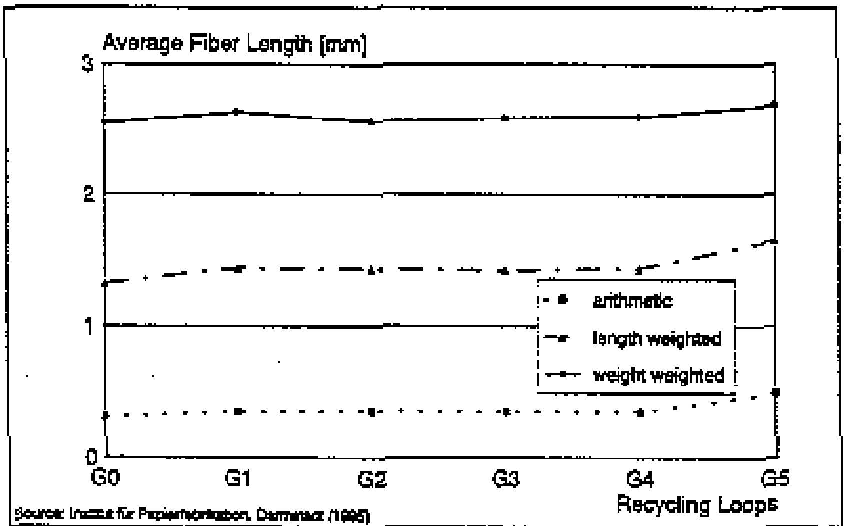
- Apparent density of the uncalendered paper sheets slightly increased with the number of cycles and that of the supercalendered sheets decreased slightly (Fig. 4.2.-21). In the case of calendered paper deviations can be seen at the third and fourth cycles.

- Breaking length of the paper sheet was not impaired by multiple recycling (either in machine direction or in cross direction of the paper sheet) despite the fact that no virgin fibers were added between any cycle and that the pulp was not activated by any beating after the first cycle GO (Fig. 4.2.-22).

- Brightness and luminance dropped significantly after the first cycle of printed paper, whereas the following cycles affect these optical characteristics only to a smaller extent (Fig. 4.2.-23). Considering these findings, one must bear in mind that the pilot plant trials discussed did not comprise any dispersion (nor any disperser bleaching) and any post-flotation, which are both beneficial for the control of optical characteristics.

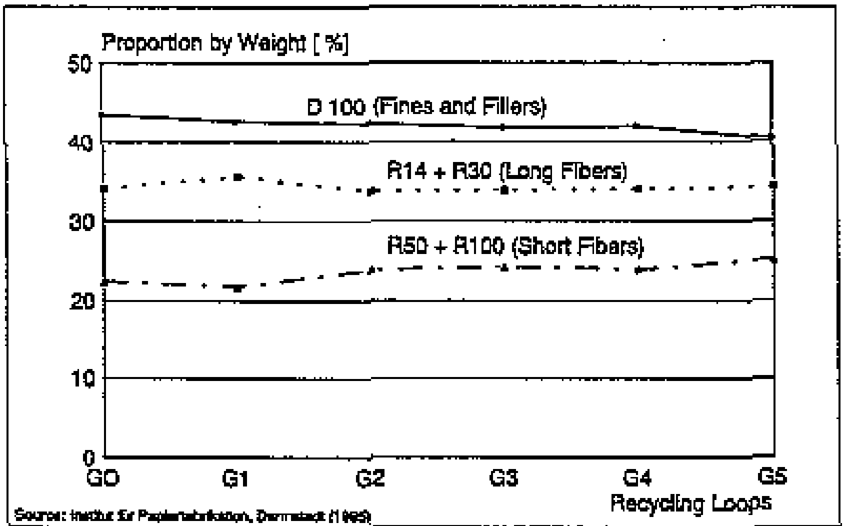
- Printability in terms of coverage, optical density, mottling or the resolution of the printed line pattern was not affected by the increasing number of cycles. Due to minor linting the washing intervals became slightly shorter with the increasing number of cycles.

In conclusion, the findings of these pilot plant trials make evident that fibers are more resistant against multiple recycling than expected even by experts. Taking into account that the average number of cycles fibers pass the recycling system in the case of German newsprint manufacturing (based on 108 percent waste paper) is not more than two, one must not be afraid of that what is called 'recycling fatigue'.



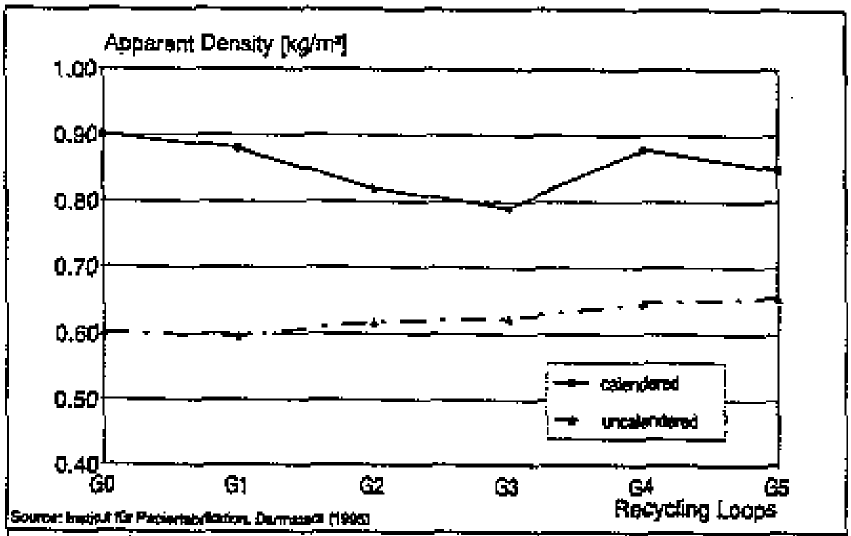
Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.2.-19 Average Fiber Length (Kajaani Tester) (Machine Chest) IfP 1995



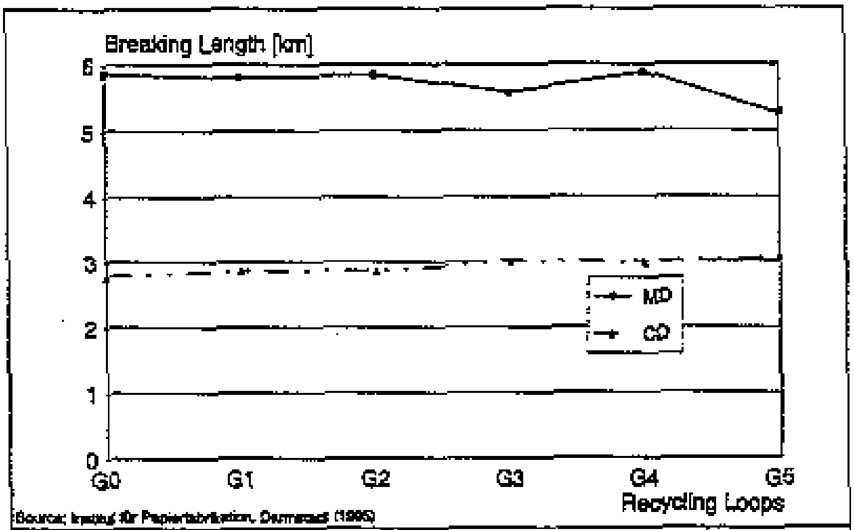
Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.2.-20 Pulp Classification acc. to Bauer McNett (Machine Chest) IfP 1995



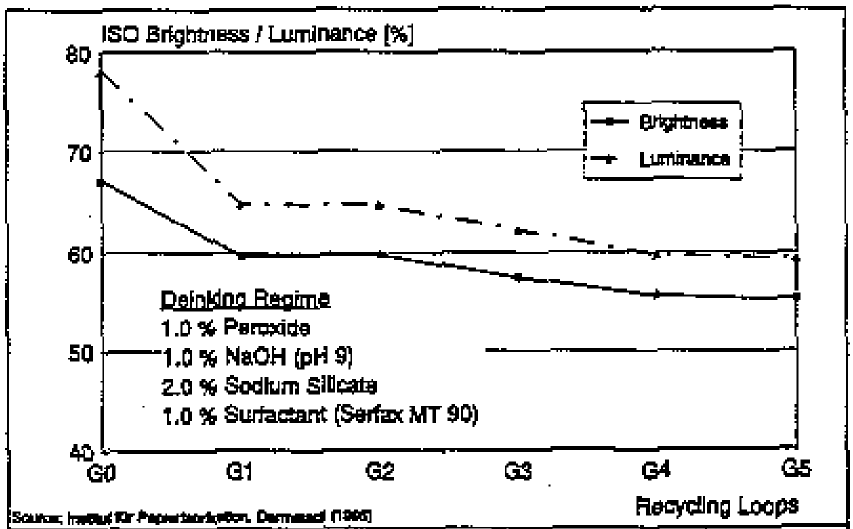
Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.2.-21	Apparent Density of Paper	IfP 1995



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.2.-22	Breaking Length of uncalendered Paper	IfP 1995



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.2.-23	Brightness and Luminance of uncalendered Paper	IfP 1995

4.2.2 Effect of Additives for Papermaking, of Printing Inks and Adhesives in Paper Conversion on the Recyclability of Waste Paper

Additives for Papermaking

The use of inorganic chemicals and organic additives is indispensible for environmentally compatible manufacturing of paper and board as well as for the demanding functions of the various paper grades to be converted, printed and consumed. Apart from fillers and pigments (14 percent by weight related to paper production), on average about four percent of chemicals and organic additives are used in the German paper industry. Native and modified starch is the most prominent additive, followed by others such as, for example, retention or deinking agents. Chemicals and additives must be neither human-toxic nor eco-toxic, which means that the presence of toxic heavy metals or persistent organochlorinated compounds must be avoided or their content must be, at least, negligible, even when analysed with test methods of very low detection limits (e.g. by atomic absorption spectrometry or gas chromatography). Further requirements refer to the following features:

- Organic additives must be biodegradable (in effluent treatment)
- Organic additives must be compostible (in composting of waste)
- Organic additives must be recyclable (in papermaking).

By far most of the additives applied in papermaking fulfil these requirements with the exception of traditional chelating agents (EDTA, DTPA) or optical brighteners which are not biodegradable. In addition, wet-strength additives such as epichlorhydrine based compounds contain chlorine atoms which contribute to a certain AOX content of paper and paper mill effluents to be treated biologically. Pentachlorophenols should not be used as slimicides at all and should be furthermore not present as a contamination of any other organic additive used in papermaking and paper conversion.

Nearly all chemical additives used in papermaking are environmentally compatible, with the exception of the very few additives mentioned above, which should be modified or substituted by environmentally sound substances as soon as possible. However, in some cases, requirements of recyclability are detrimental to the functions which certain paper grades and paper products must fulfil. This is the case, with respect to wet-strength paper, which must resist water and which is therefore more resistant against disintegration in waste paper processing. Regarding optical brighteners, which are not biodegradable, one must bear in mind that they can be decomposed abiotically by UV light and UV containing light. In the case of the traditional, but very effective chelating agents, which are essential in peroxide bleaching (particularly in virgin pulp bleaching), a new generation is under development, being biodegradable, but they are less effective as far as the unwanted decomposition of peroxide by heavy metals, present in fresh water, pulpwood and in consequence in recycled fibers, is concerned. In general, chemicals and organic additives used in papermaking do not affect the recyclability of waste paper.

Printing Inks

Printing inks constitute of pigments, vehicles, additives and in the case of rotogravure inks of an organic solvent (toluene). In the past two decades pigments of printing inks have been significantly improved with respect to their reduced heavy metal content. The dominant pigment is carbon black, which does not cause any environmental problems. Blue pigments contain a certain, but non-critical amount of copper. A substitute of traditional blue pigment has recently been developed. Because of its high price, being more costly than current blue pigments and because of its inferior printability, it is not yet accepted by ink manufacturers and printers. On the other hand, yellow pigments of the diarylazo type are chloro substitutants and might be considered to be hazardous. However, according to very careful investigations, recently carried out by pigment manufacturers, they are not biodegradable either in an aerobic or in an anaerobic environment. This means that they do not contribute to any environmental pollution, not even in the long-term.

The organic solvent toluene of rotogravure printing inks is from time to time discussed because of an assumed possible mutagenicity effect. That is the reason why printing ink manufacturers have made progress in developing water-based rotogravure inks, which, however, do not yet fulfil all printability requirements. The recyclability of toluene-based printing inks does not cause problems, whereas offset printing inks with their mineral oil-based vehicle impair recyclability in terms of deinkability with ageing, which means the period of time between printing and processing of waste paper in the paper industry. Currently, natural ink vehicles such as soya bean oil or rape oil are discussed in Europe as a substitute for mineral oils. However, it became evident that offset printing inks based on such natural vehicles are even more difficult to be deinked than mineral oil based vehicles.

From the point of view of the paper industry, the deinkability of any printing ink must be further improved for the benefit of the optical characteristics of deinked pulp (brightness, luminance, colour shade, freedom of specks) processed at a high yield and for a reduced volume of deinking sludge.

In previous years European newsprint manufacturers processing waste paper for deinked pulp by the flotation process became aware that a new type of printing ink might cause severe problems in respect to recyclability in terms of deinkability. This refers to water-based flexo inks substituting mineral oil-based offset inks. Because of their hydrophilic nature and their very small particle size they are extremely difficult to be deinked by flotation leading to a very poor brightness of the deinked pulp. The alternative to flotation is washing. By washing flexo ink particles can be removed effectively. However, in the case of waste paper with a higher content of fillers and pigments, a good deinkability is then accompanied by a significant loss of these small mineral particles which results in a low pulp yield. This also produces a high sludge volume, which is costly to disposed of. Considering these handicaps there is a need for flexo inks which are resistant against mechanical and chemical forces in deinking in order to achieve larger particles size which can then be effectively flotated, avoiding a poor yield of the deinked pulp.

Adhesives in Paper Conversion

The real challenge with reference to materials applied in paper conversion including printing comes from adhesives because they cause problems in paper manufacturing, based on recycled fibers, when they enter the paper machine and succeeding processes (e.g. coating machine). In waste paper processing adhesives as well as binders of coating layers applied in previous papermaking and paper conversion are broken up in small particles which contaminate the pulp slurry. These adhesive particles, called stickies, can stick to wires, felts or heated cylinders in the paper machine, generating breaks of the paper web, which affect runability and efficiency of the paper machine or coating machine.

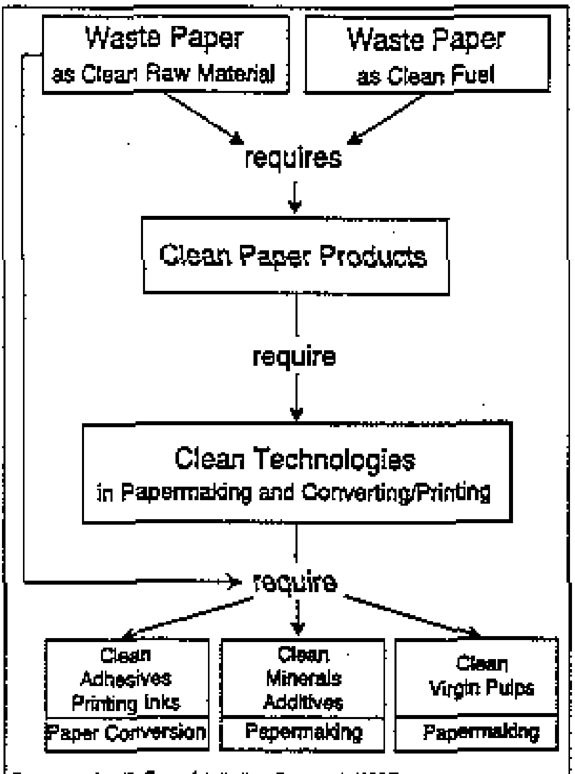
The problem to be solved is characterized by the saying: 'how can one prepare an omelett without breaking eggs'. Adhesives must fulfil various functions (e.g. pressure-sensitive adhesives of labels or envelopes, glueing of book backs or corrugated containers) which are based on their sticky nature, whereas in manufacturing of paper made of recycled fibers they should have lost this behaviour. The manufacturers of adhesives are aware of the demands of the waste paper processing industry and are currently involved in research work to control the problems identified in waste paper processing.

In waste paper, adhesives should not be water-soluble in order to avoid an increase of the COD (chemical oxygen demand) load of white water and waste water to be treated. Furthermore, adhesives should not become collodially dispersed, because this state would prevent their elimination in waste paper processing by screening and/or cleaning. In the case of too intensively dispersed adhesives there might be a risk of re-agglomeration, affected by changes of temperature or pH in various stages of waste paper processing and by additives present in the pulp slurry.

The best solution for sticky prevention is to keep them in a certain particle size of several hundred microns. This ensures their elimination by fine screening and fine cleaning. The first step for the removal of stickies in waste paper processing is to ensure that the disintegration of the waste paper concerned in high-consistency pulpers or rotating drums is gentle enough to produce large pieces of adhesives and paper flakes. Such pieces and flakes can then be easily eliminated in the beginning of waste paper processing plants generating a reject component with no environmental effect.

General Requirements

For the waste paper utilized either in papermaking as a raw material or as a fuel for energy recovery requires the original paper to be clean (Fig. 4.2.-24).



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.2.-24 Requirements in Papermaking and Paper Conversion IfP 1995

- Cleanliness of paper products must be ensured by clean technology including environmentally compatible chemicals and chemical adhesives (in papermaking), clean printing inks and adhesives (in printing and paper conversion).

- This requires at the same time the utilization of clean primary raw materials in terms of pulps and minerals (fillers and pigments).

It is the responsibility of the pulp- and papermakers to work in close cooperation with the chemical industry and manufacturers of printing inks or adhesives as well as with the suppliers of minerals, in order to achieve these challenging targets. In previous years significant progress was made characterized, for example, by chlorine free pulp bleaching, ban of organochlorinated additives (e.g. pentachlorophenols) in many but not all countries, avoidance of printing inks with toxic heavy metals, or development of wet-strength agents with a still lower AOX content. Further research work must concentrate on adhesives in order to avoid the formation of stickies, on AOX-free additives and printing inks and biodegradable organic additives use in papermaking as well as in paper conversion and printing.

4.3 Economic Impacts

4.3.1 Acceptance of the Market Place with Respect to Paper Products based on Recycled Fibers

The acceptance of the different grades of paper and board made of recycled fibers, either partially or totally, cannot be measured or assessed in quantitative terms. Furthermore, acceptance of paper and board, made of recycled fibers, can be evaluated from the possibly differing points of view of private end-consumers or institutional consumers, such as industry and trade e.g. with respect to distribution of packed consumer goods.

In general, German consumers are highly recycling-minded and give therefore a preference to paper products based on recycled fibers, partly affected by the price of products and partly influenced by marketing issues or by the permanent 'education' via the media and green movements, the latter characterized by a high credibility. The following comments refer to the acceptance of various grades of paper which also stand for the corresponding products on the market place:

- Packaging paper and board which have been manufactured almost totally from recycled fibers for many decades in Germany, have achieved a very high and lasting degree of acceptance. To end-consumers it does not matter if, for example, corrugated containers or folding boxes are made of paper or board totally based on recycled fibers as long as the necessary requirements (packaging function and printed information) are fulfilled. Because end-consumers are consumers on the one hand and 'producers' of waste paper as raw material for the paper industry on the other hand, they expect and assume that their used packaging material will be accepted by the recycling system.

- Sanitary papers made of recycled fibers are characterized by a further increasing acceptance, stimulated by the fact that due to permanently improved waste paper processing the quality of such sanitary papers is continuously improved in terms of optical characteristics (brightness, cleanliness, colour shade), softness and absorbancy. Even when certain hygienic products made of recycled fibers are more expensive than products containing virgin fibers, end-consumers give increasingly preference to the product perceived as more environmentally-friendly.

- The acceptance issue in respect to graphic papers is more complicated than with packaging paper and board or sanitary papers.

– Newsprint made of recycled fibers is well-received by the end-consumers, who are generally aware of the fiber furnish used for manufacturing such recycled newsprint in Germany. Thanks to the sophisticated waste paper processing (e.g. two-stage flotation and dispersion), the good runability and optical performance of newsprint made of recycled fibers have convinced the printers to make use of this type of newsprint.

– Wood-containing printing and writing papers made of recycled fibers, called recycled graphic paper (Recyclingpapier), compete with printing and writing papers based on virgin fibers. Apart from economic and marketing issues, the acceptance of recycled graphic papers is also affected by emotions. Furthermore, governmental organizations of various Federal States recommend the utilization of recycled printing and writing papers (e.g. as copy paper or computer printouts). As far as such recycled papers are concerned, one must bear in mind that their volume is not more than five percent of the total volume of graphic papers.

– The manufacturers of SC- and LWC-papers are prepared to use increasing proportions of recycled fibers. As long as printability is not impaired, the institutional consumers and the end-consumers do not mind if magazines or catalogues contain an increasing proportion of recycled fibers. However, the acceptance issue is not yet relevant with respect to these paper grades because the manufacturers have not started any stimulating campaigns.

- A certain segment of the market of woodfree papers requires the utilization of recycled fibers. Therefore, even manufacturers of woodfree (coated and uncoated) graphic papers offer a small volume of their production to the market place because of an increasing acceptance of paper grades with a certain proportion of recycled fibers.

- Because of the heterogeneity of the group of specialty papers and products made of them, it is most difficult to judge their acceptance in the market place. It might be assumed that there is no increasing acceptance because it is fact that a number of such products can only fulfil very high quality demands when they are made of virgin pulp (e.g. filter paper, banknote paper, cigarette tissue).

4.3.2 Costs of Collection and Sorting of Waste Paper

It is a rather difficult task to obtain reliable data on costs of collection and sorting of waste paper, particularly with respect to the collection of waste paper from households. The main reason for that situation is the large variation of collecting costs, arising from the following factors:

- Collection systems which are divided in the first place into pick up and carry systems. In both cases there exist different sub-systems according to their size, design and handling.
- Density of population per area, in the first place divided into urban and rural areas which again differ with respect to their infrastructure.

As far as sorting is concerned, the variations of the costs are affected, amongst others, by the following features:

- Waste paper grades to be sorted
- Origin of the waste paper (waste paper from industry, distribution, small commercial enterprises, households)
- Size and technical equipment of the waste paper dealers, waste management industry or paper industry involved in sorting of waste paper.

The most challenging task refers, however, to the assessment of marginal costs of collection, required to meet different recycling levels. These marginal costs of collection cannot be predicted.

In the following reference is made to collection and sorting costs, generated in a larger scaled enterprise, dealing with collection of household waste paper as well as in sorting, particularly of waste paper for DIP, based on a mixture of news, magazines and other graphic products, delivered unbaled to the paper industry.

Collection Costs

Table 4.3.-1: Costs of Waste Paper Collection [DEM/Tonne]

Collection Area	Container	Household Bin
Urban Area	30 - 50	180
Rural Area	50 - 100	250

Source: Intecus, Berlin, private communication

Table 4.3.-1 shows the large variations of the collection costs between 30 DEM and 250 DEM per tonne, depending on collection area and collection system. The volume of the containers varies between 20 m³ and 36 m³, some equipped with a compactor. The distribution of the collection costs is as follows:

Distribution of Collection Costs

• Calculation Costs	18 percent
• Interest Rate	4 percent
• Tax and Insurance of Trucks	5 percent
• Maintenance	12 percent
• Energy	11 percent
• Labour	50 percent

With respect to the collection costs one must bear in mind that the collectors are able to recover some costs at least for the proportion of packaging material (sales packaging) in the waste paper, which is financed by the Dual System Germany DSD based on the licence fees for the Green Dot.

The following calculations are based on average collection costs of 150 DEM per tonne of waste paper taking into account that Germany is mainly equipped with household bins and to a lesser extent with containers located in public places.

Sorting costs

Reference is made to waste paper collected from households, containing mainly news and magazines for making DIP for manufacturing graphic and sanitary papers, but mainly newsprint. This grade of waste paper for DIP requires a most careful sorting in order to remove quality-impairing components such as packaging material (e.g. corrugated containers, folding boxes) as well as impurities (e.g. plastic, composite material, textiles, metals, glass).

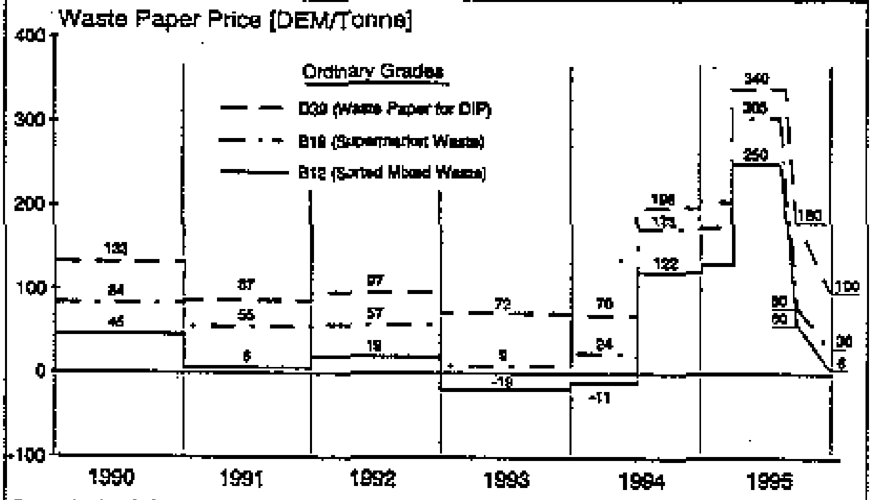
In the first case the waste paper from households is composed of 80 percent news and magazines, 16 percent packaging material and four percent impurities. The sorting costs amount to 60 DEM/tonne. The dominant cost component refers to the sorting system (belt system) which causes 80 percent of the total sorting costs (48 DEM/tonne). Other technical equipment covers about 15 percent of the total sorting costs, whereas the bale press used for the removed packaging material causes about five percent of the total sorting costs. The dominant cost factors are variable costs for labour, energy and maintenance.

The second case is based on a waste paper composition of 90 percent news and magazines, eight percent packaging material and two percent impurities before sorting. Due to that 'cleaner' waste paper composition the total sorting costs are not more than 45 DEM/tonne. About 85 percent of the total sorting costs are generated by the sorting system and not more than ten percent by other technical equipment.

The following evaluations of the sorting costs of any waste paper are averaged at 50 DEM/tonne.

4.3.3 Waste Paper Processing Costs incl. Waste Disposal

Because waste paper processing costs are of a sensitive nature due to competition issues, there are almost no reliable data published in literature. Reliable data are generally confidential and therefore not permitted to be distributed to other parties. It is, however, evident that in Germany waste paper processing costs are generally lower than the costs of pulping wood or of using virgin pulps as long as waste paper prices are not at a peak level exceeding the long-term averages as was the case in the middle of 1995 (Fig. 4.3.-1). It is supposed that waste paper for DIP (category D 39: 50 percent news and 50 percent magazines) will cost at the mill gate 150 DEM to 200 DEM per air-dry tonne in the longer term due to the increasing demand of the paper mills manufacturing newsprint and high-grade wood-containing printing papers.



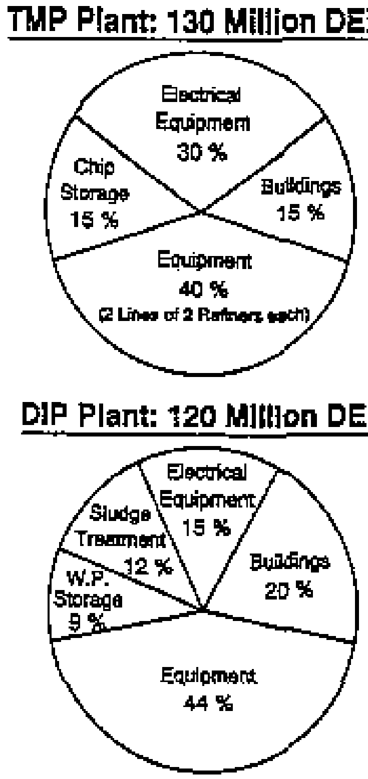
Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.3.-1 Price of Important Waste Paper Grades IfP 1995

In the following a cost comparison is discussed with reference to pulping of TMP made of sawmill residues and processing of DIP made of manually sorted household waste paper, both used as a raw material for manufacturing newsprint.

The furnish for newsprint is based either on 100 percent TMP or on 100 percent DIP. The capacity of the DIP plant as well as of the TMP plant amounts to about 850 tonnes/day (air-dry substance). Because of a yield of 85 percent in the case of waste paper processing a daily volume of 1,000 tonnes of waste paper must be processed. At the machine chest the double-flotated and dispersed DIP contains 15 percent fillers and pigments introduced by the waste paper components, namely ash-containing news and filled or coated magazine papers.

The investment costs for a DIP plant totals approx. 120 million DEM, whereas the TMP plant requires investment costs of about 130 million DM (Fig. 4.3.-2). Energy supply, waste water treatment and waste incineration are not included in the above mentioned investment costs. In the case of the DIP plant, however, equipment for sludge dewatering is included. This sludge treatment guarantees a dry content of about 50 percent for the benefit of cost saving in landfilling or alternatively of a reasonable heating value used in co-generation.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.3.-2 Investment Costs of TMP and DIP Plants (Capacities: 850 ADTPD each)

IP 1995

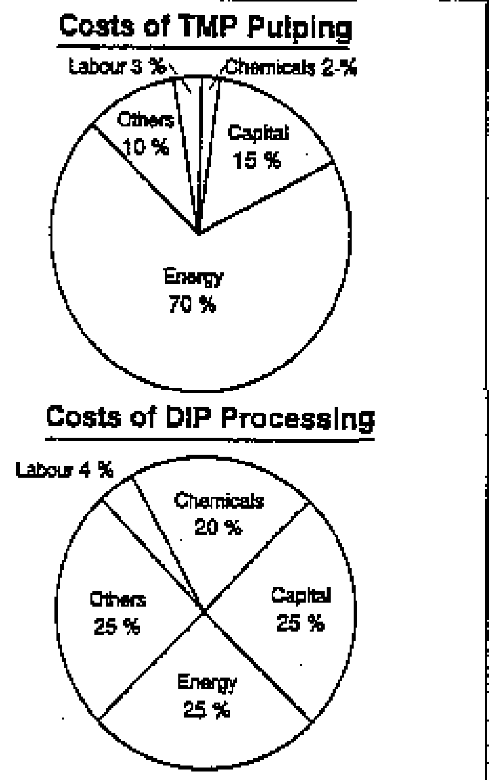
Depreciation is set at six percent per annum (4.8 percent for equipment and 1.2 percent for buildings) and the interest rate amounts to four percent per annum which results then in ten percent capital costs.

Besides the costs for raw materials (sawmill residues for TMP and waste paper for DIP) the operation costs comprise the following positions:

- Energy costs (power, process steam including steam recovery)
- Chemical costs (mainly deinking agents and flocculants for sludge treatment)
- Personnel costs
- Other costs (maintenance, auxiliary material)
- Waste disposal costs (landfilling of waste material from waste paper processing)

The most significant variables of these individual costs refer to raw materials (in the first place to waste paper according to Fig. 4.3.-1 and furthermore to waste disposal costs with their big range depending on the location of the landfill site. In many cases it is more economical to treat the sludge of waste paper processing by burning, making use of energy recovery.

Fig. 4.3.-3 shows the distribution of capital and operation costs with the exception of the costs of raw material and of disposal of deinking sludge. Due to extremely high costs for energy generation and purchased power in Germany and because of the high power demand (of about two MWh per tonne of TMP compared with 0.4 MWh per tonne of DIP), pulping of TMP requires very high costs for energy despite the fact that steam recovery is taken into account.



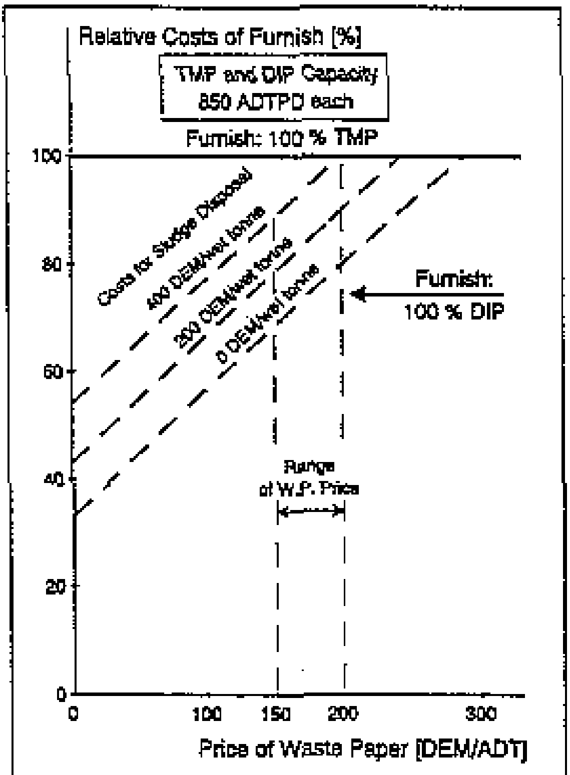
Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.3.-3	Distribution of Different Costs for TMP Pulping and DIP Processing (Costs at Machine Chest)	IfP 1995

In the case of DIP processing, capital and other costs are of the same order as energy costs, followed by chemical costs which are, of course, much higher compared with the corresponding costs for TMP pulping. The costs for personnel are of marginal importance in both cases. However, this comparison refers only to the distribution of costs as percentages and one must be aware that the actual costs of DIP processing are less, related to the corresponding costs of TMP pulping.

Fig. 4.3.-4 illustrates the total costs of both furnishes, based on 100 percent TMP and on 100 percent DIP, now including the costs of raw materials. In the case of TMP pulping the assumption is made that the price of sawmill residues is constant. The total costs of the TMP furnish are set 100 percent. Because of the significant variations of waste paper prices, the costs of a DIP furnish is shown versus the price

of waste paper which varied between 70 DEM and 350 DEM per air-dry tonne between 1991 and 1995.



Source: Institut für Papierfabrikation, Darmstadt (1996)

Fig. 4.3.-4 Capital, Raw Material and further Operation Costs for TMP and DIP (at Machine Chest) IfP 1995

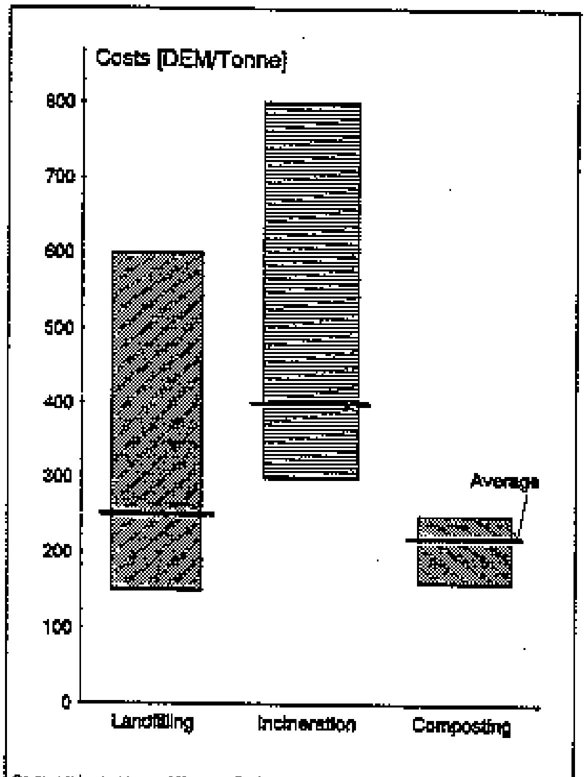
The other variable documented in Fig. 4.3.-4 refers to the costs for sludge disposal, starting with the unrealistic presentation of the costs for DIP processing without any costs for sludge disposal, followed by more realistic costs for sludge disposal in the range between 200 DEM and 400 DEM per wet tonne (dry content: 50 percent). At a waste paper price of 100 DEM/tonne and minimum costs for sludge disposal of 200 DEM per wet tonne of deinking sludge, the costs of a processed DIP correspond to about two thirds of TMP costs at the machine chest. At a waste paper price of 200 DEM/tonne and costs for sludge disposal of 400 DEM per wet tonne DIP processing is not at all competitive in comparison with TMP pulping.

Sludge disposal by landfilling will become unrealistic in the medium-term due to costs as well as to legislation (Municipal Waste Management Provision). Therefore, priorities are given to combustion of the sludge or its utilization as raw material. The approximate costs for these alternatives are in the order of 100 DEM per wet tonne. Considering this and an average waste paper price of 175 DEM per tonne, then DIP processing costs about three quarters of TMP pulping.

4.3.4 Impacts on Waste Management Authorities

4.3.4.1 Costs of Disposal and Utilization of Municipal Waste

Fig. 4.3.-5 shows the costs of incineration and landfilling of household waste as well as for composting of biowaste from households referring to Germany in 1994. The data presented are based partly on literature and partly on present-day information of waste management experts. It becomes evident that the variations of the costs are very significant with respect to landfilling and to incineration. These variations are partly affected by the capacities of municipal incineration plants but also to a large extent by the number of landfilling sites and incineration plants in certain areas of the country.



Source: Infrastruktur und Umwelt, Prof. Böhme + Partner, Darmstadt (1995)

Fig. 4.3.-5 Costs of Utilization and Disposal of Municipal Waste in Germany (1994) ifP 1995

The average landfilling costs of 250 DEM per tonne of waste are lower than the average incineration costs of 400 DEM per tonne of municipal waste. Most competitive are the costs of composting of biowaste (220 DEM per tonne). In this case the price of compost (30 DEM/tonne) is not taken into account because it is uncertain if this compost can be totally sold on the market place.

Table 4.3.-2 refers to the collection costs of residual household waste, biowaste and waste paper (from households). For collection of residual household waste and

biowaste, the costs amount to about 90 DEM per tonne in densely populated areas and to 150 DEM per tonne in rural areas. On average, it is supposed that the collection costs for residual waste and biowaste total 130 DEM/tonne. On the other hand, the costs for waste paper collection amount to 50 DEM to 250 DEM per tonne (average: 150 DEM/tonne) affected by the collection system (pick-up or carry system) and the density of population in urban and rural areas.

The sorting costs are averaged at 50 DEM/tonne of waste paper with reference to the main waste paper grades for manufacturing graphic papers as well as packaging paper and board.

Table 4.3.-2: Costs for Collection of Household Waste and Waste Paper (from Households)

Material	Collection Costs [DEM/Tonne]	Sorting Costs [DEM/Tonne]
Residual Household Waste	90 - 150	
Biowaste from Households	90 - 150	
Waste Paper	50 - 250	30 - 60

Source: Infrastruktur und Umwelt, Prof. Böhme + Partner/Darmstadt (1995)

4.3.4.2 *Current Situation and Scenarios*

According to Table 4.3.-3 the total disposal and treatment costs of waste paper being a part of municipal waste do not change significantly in comparison between scenario 1 and 2 of chapter 3. Scenario 1 results in additional costs of 54 million DEM compared with the current situation, whereas with scenario 2 the total costs are reduced by 255 million DEM related to the current situation. This means for scenario 2 a cost saving of approx. three DEM per year per head of population in Germany compared with the current situation. (Sales of separately collected and sorted waste paper is not taken into account.)

In view of the relatively small cost difference between the current situation and scenario 2, it must be emphasized that, in the framework of waste management, economic factors are hardly involved and will not affect political decisions how the waste management strategy will be realized in a region. Anyhow, the long-term strategy on disposal of waste is already prescribed by the Municipal Waste

Table 4.3.-3: **Costs for Disposal of Waste Paper and Utilization for Energy Recovery and Composting - Current Situation and Scenarios -**

Treatment Method	Specific Costs [DEM/Tonne]	Current State [M Tonnes]	[M DEM]	Scenario 1 [M Tonnes]	[M DEM]	Scenario 2 [M Tonnes]	[M DEM]
Collection with Household Waste	130	4.2	546	2.5	325	2.5	325
Separate Collection	150	--	--	1.7	225	1.7	255
Sorting (for Recycling incl. Export)	50	--	--	--	--	1.7	85
Incineration in Municipal Incineration Plants	400	1.2	480	2.5	1,000	1.7	680
Incineration in Industrial Incineration Plants*	150	--	--	1.7	250	--	--
Composting**	220	--	--	--	--	0.8	176
Landfilling	250	3.0	750	--	--	--	--
Total Costs [M DEM]			1,776		1,830		1,521

* Including Pelletizing of Waste Paper and Savings from Energy Recovery
** Not included possible Savings from Sale of Compost

Management Provision. In order to avoid air and water pollution by landfill sites it is permitted to dump nothing else than inorganic material in the future, at the latest by 2005. To fulfil this requirement, waste material based on organic components must be first burnt. This thermal treatment also applies for non-recoverable/non-recyclable waste paper and waste material from waste paper processing paper mills.

The local authorities responsible for waste management will agree to an intensified separate collection of waste paper from households as long as no additional costs are generated for the local governments. With reference to the comprehensive product responsibility of the German industries required by the recently issued Recycling and Waste Management Act (to be in force 1996), the paper chain will be urged to pay for any additional costs in order to utilize excess waste paper for recycling or energy recovery.

An additional potential for waste paper composting (scenario 2: 0.8 million tonnes) is unlikely to be realized. According to the Municipal Waste Management Provision, the establishment of further composting capacities will be only permitted if the compost to be produced can be sold on the market place. Already today, bottlenecks on the market place for compost occur locally. These bottlenecks can be surmounted only if the acceptance of that compost as a substitute for peat is improved.

4.3.5 Adaptation of Industrial Combustion and Power Plants

Waste paper can be only burnt in industrial plants which are suitable for the combustion of solid fuel such as hard or brown coal or solid waste from paper manufacturing. Fuel oil - or natural gas - fired power plants are not suitable for burning waste paper, because of the following reasons:

- The firing chambers are generally too small.
- Combustion takes place with an air surplus which is too small for optimal waste paper incineration.
- The boilers are not designed for dealing with the large ash volume generated by waste paper incineration.

Against this background, it is evident that waste paper must be burnt in power plants designed for hard or brown coal or in combustion plants employed for the incineration of waste material.

When non-densified, loose waste paper is burnt, the resulting heating value per unit of volume corresponds to less than ten percent of the heating value of hard coal at the same unit of volume. In order to achieve the identical energy output by substituting, for example, one third of hard coal by non-densified waste paper, the total fuel input by volume must be increased by 33 percent related to the former input of hard coal. The height of the fuel layer (coal and waste paper) on the firing grate has then to be increased by about ten times. Such a change of the burning conditions cannot be managed. Furthermore, this would result in changes of the flue gas volume and of the temperature in the firing chamber. Finally, the thermal efficiency of the boiler would be impaired.

According to an inquiry of the German Federation of the Pulp and Paper Industry focusing on energy issues, the following information was received:

- Present combustion plants for waste material (from paper manufacturing) have a capacity equivalent to the amount of the waste volume generated. Additional energy recovery using waste paper would be only possible to a limited extent. This is also the case with the capacity of planned combustion plants for waste material.

- Related to the total amount of fossil fuel for energy generation, the proportions of hard coal (23 percent) and brown coal (6 percent) in terms of energy output are smaller in the German paper industry, compared with those of natural gas (55 percent) and fuel oil (16 percent). Three percent is based on other sources (e. g. residues, hydropower).

In the case of co-combustion of waste paper in existing boilers based on hard coal, it must be realized that the heating value of waste paper is not more than 50 percent of that of hard coal at the same unit of mass. By substituting a proportion of hard coal with waste paper, the previous energy output (in terms of steam and power) could then not be achieved. To overcome this problem, it would be necessary to increase the boiler capacity including the extension of the capacity of the stack gas purification.

The substitution of solid fossil fuel by waste paper would only make sense in combustion plants based on brown coal. In the German paper industry the input of brown coal is not more than 352,000 tonnes, which corresponds to an energy input of 6,370 TJ. Not more than 25 percent of the energy input of power plants is permitted to be realized by waste paper to avoid the application of the very stringent 17th Regulation of the Federal Emission Control Act. Therefore, only 100,000 tonnes waste paper could be burnt annually in existing combustion plants of the German paper industry based on brown coal.

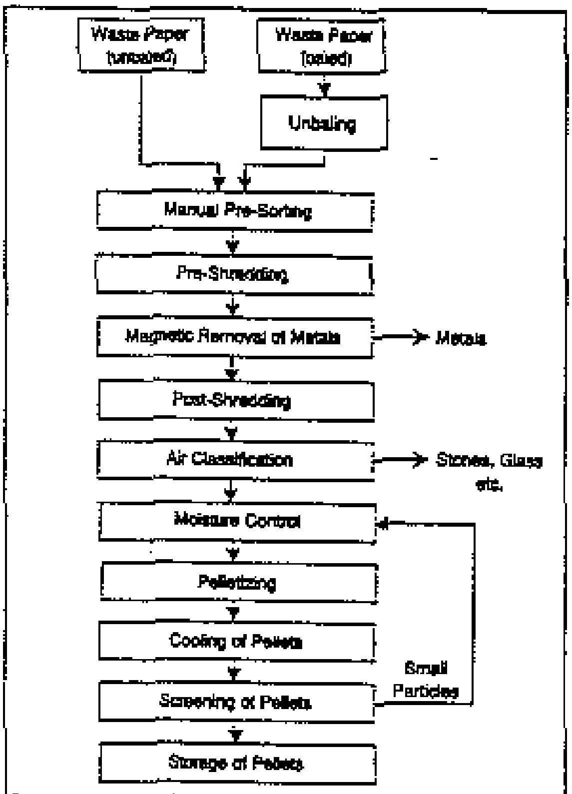
4.3.6 Costs of Collection and Processing of Waste Paper for Energy Recovery in Industrial Combustion Facilities

Waste paper as a substitute of solid fossil fuel (hard and brown coal) has to fulfil the following requirements when used in industrial combustion plants:

- Smooth flowing characteristics as a prerequisite for an automatic feeding of the firing chamber
- Minimal dusting with handling of waste paper
- Constant characteristics (e. g. heavy metal content, heating value, density)
- Low emissions of harmful substances during incineration.

To contribute to the uniformity of these characteristics, waste paper requires a pre-treatment. This pre-treatment comprises shredding and the removal of impurities (e. g. stones, metals) as well as densification in the form of pelletizing. The various stages of waste paper pre-treatment are shown in Fig. 4.3.-6.

Waste paper must be pelletized in order to increase its volume-related heating value. The pellets produced can have a diameter of 1 cm to 3 cm and a length of 2 cm to 5 cm. It is considered that a diameter range between 1 cm and 2 cm and a length of 5 cm is optimal.



Source: Institut für Papierfabrikation, Darmstadt (1995)

Fig. 4.3.-6 Treatment of Waste Paper producing Fuel Pellets

IfP 1996

The density of loose waste paper ranges between 50 kg/m³ and 150 kg/m³. By compacting, the density of waste paper is increased to about 600 kg/m³ which corresponds to the density of brown coal (500 kg/m³ to 800 kg/m³) and approaches almost the density of hard coal (700 kg/m³ to 850 kg/m³).

The heating value of waste paper pellets ranges between 14 GJ/tonne and 18 GJ/tonne at a moisture content of five percent to ten percent. This is almost the same heating value of that of brown coal (16 GJ/tonne to 20 GJ/tonne) and half of that of hard coal (29 GJ/tonne to 31 GJ/tonne).

So far, waste paper pelletizing is not performed in Germany in a commercial scale. According to information on waste paper combustion practised in the paper industry of the USA, the costs for pelletizing are estimated at 40 DEM/tonne to 50 DEM/tonne.

When comparing the costs for waste paper pelletizing and the costs of fossil fuel, it is more useful to refer to heating value-related costs rather than to mass-related costs. At an average heating value of waste paper pellets of 16 GJ/tonne the specific costs for pelletizing ranges between 2.50 DEM/GJ and 3.10 DEM/GJ. The mass-related and the heating value-related costs of fossil fuels are shown in Table 4.3.-4 (Germany 1994).

Table 4.3.-4: Mass-related and Heating Value-related Costs of Different Fossil Fuels

Fossil Fuel	Price	Heating Value	Heating Value-related
Hard coal (imported)	75 DEM/tonne	30.0 GJ/tonne	2.50 DEM/GJ
Hard coal (German)	155 DEM/tonne	30.0 GJ/tonne	5.20 DEM/GJ
Brown coal	85 DEM/tonne	18.0 GJ/tonne	4.70 DEM/GJ
Natural gas	21 DEM/m³	31.7 MJ/m³	5.90 DEM/GJ
Fuel oil	205 DEM/tonne	42.4 GJ/tonne	4.80 DEM/GJ

Source: DEBRIV (1995)
Ruhrgas AG (1995)
BP Oil Deutschland GmbH (1995)

The difference between the costs of the different fossil fuels and the costs for pelletizing of waste paper indicates that the price of waste paper should be aimed at identical costs with reference to the same unit of heating value. At costs of 50 DEM/tonne (3.10 DEM/GJ) for pelletizing of waste paper, the price of waste paper should not exceed 34 DEM/tonne compared with German hard coal. In comparison with imported hard coal the waste paper price becomes even negative (-10 DEM/tonne) at the same costs for pelletizing as in the previous case.

Taking the collection costs of waste paper into account (50 DEM/tonne to 250 DEM/tonne) then it becomes evident that waste paper as a fuel is not cost-competitive at all with fossil fuels, either with the expensive German hard coal or brown coal or with the cheaper imported hard coal. Nor is this use of waste paper economically attractive compared with the sales price of waste paper as a raw material for papermaking.

5 Summary

Waste paper is an indispensible raw material for the German paper industry as the source for recycled fibers becoming increasingly important as a result of economic and legal forces. Current legislation requires an intensified waste paper recycling, characterized by collection and recycling rates of 80 percent in the case of used packaging material and of 60 percent in the case of used products made of graphic papers (news, magazines, catalogues, office paper etc.) to be achieved at the latest by the end of this decade. In fact, these targetted collection and recycling rates have been already realized in 1994. This resulted in an average waste paper utilization rate of 56 percent. (The utilization rate refers to the waste paper volume recycled in Germany related to the total paper production.)

The waste paper collection rate was actually 59 percent. (The collection rate refers to the waste paper volume collected, related to the total paper consumption in Germany.) A certain amount of the collected waste paper was exported, mainly to neighbouring countries of the European Union, but also to the Far East. The exported waste paper volume (2.2 million tonnes) is globally the second-largest, following the USA. On the other hand, superior and medium waste paper grades must be imported (0.7 million tonnes) because of their shortage in the local market place.

The waste paper utilization rates of packaging papers and board as well as of specialty papers have already reached their saturation point, whereas graphic papers (waste paper utilization rate: 28 percent) will further increase their content of recycled fibers, approaching a rate of about 40 percent in the medium-term. A certain increase of the waste paper utilization rate will occur in the case of sanitary papers, too.

It is supposed that the average waste paper utilization rate of the German paper industry will approach 65 percent in the next decade. Furthermore, it is assumed that the waste paper collection rate will not exceed 70 percent in the longer term. Germany is already today covered with a dense network of waste collection systems aiming at a separate collection of waste paper (post-consumer waste) in private households and small commercial enterprises, whereas waste paper from industry and commercial enterprises (e.g. print houses and department stores) is recovered by almost 100 percent. A not yet completely exploited resource can be found in offices, apart from households.

The higher the waste paper utilization rate the higher is the number recycled fibers passing the recycling loops. It is anticipated that each recycling loop contributes to a deterioration of mechanical and optical characteristics of the fiber material. With respect to brown waste paper grades (e.g. mixed waste, department store waste), which comprise about 50 percent of the total waste paper volume, it was confirmed by systematically performed investigations that mechanical properties of recycled fibers were not deteriorated between 1984 and 1994. As far as wood-containing waste paper for DIP is concerned, pilot plant trials made evident that mechanical properties of printing paper made of recycled fibers (50 percent mechanical pulp and 50 percent chemical pulp) are not impaired when being recycled for several times. This is due to the resistance of high-yield pulp (TMP) against multiple effects of drying and calendering of paper or printing of paper. On the other hand optical characteristics such as brightness or luminance are impaired to a certain extent as far as no additional upgrading measures such as double flotation and dispersion are applied in waste paper processing.

The collection costs of waste paper vary between 30 DEM/tonne waste paper and 250 DEM/tonne waste paper, depending on the collection area and the collection system. This would lead, together with the costs for manual sorting (40 DEM to 60 DEM/tonne of waste paper for DIP), to waste paper prices for the majority of the waste paper volume which would exceed the prices to be economic for papermaking. To compensate, waste paper from households is subsidized either by licence fees paid by the paper chain (Green Dot fee) in the case of packaging material or by communities in the case of graphic products. Subsidizing is, however, less expensive than the costs for disposal of waste paper by landfilling (average costs: 250 DEM/tonne) or municipal waste incineration (average costs: 400 DEM/tonne). Furthermore, one has to take into account that landfilling of organic waste such as non-recycled waste paper, will not be permitted at the latest by 2005 according to the Municipal Waste Management Provision, already in force since 1993.

Further intensified waste paper recycling and disposal options are limited in Germany because the legal requirements already force the paper industry today to use a large volume of waste paper and to dispose of the non-recycled fraction in an environmentally-friendly way. In fact, suitable waste paper grades required for manufacturing of graphic and sanitary papers are not sufficiently available. Further increased waste paper collection rates will mainly generate ordinary brown grades such as mixed waste and supermarket waste, which cannot be used for deinked pulp but only for packaging paper and board which have already achieved their saturation point in terms of waste paper utilization.

Disposal of excess waste paper by landfilling will not be possible in the near future. Overcollected ordinary waste paper which cannot be exported must be burnt in industrial power plants as well as in municipal incineration plants. Combustion of excess waste paper for energy generation makes sense only by co-generation of electricity and heat beneficial for a high thermal efficiency.

However, most industrial power plants of the German paper industry are fired by natural gas and fuel oil and are therefore not suitable for the combustion of waste paper. Existing power plants fired with brown coal could burn pelletized waste paper but only with a proportion of 25 percent, with reference to the energy input, in order to avoid the application of the 17th Regulation of the Federal Emission Control Act which sets very stringent standards for the emission of different air pollutants present in the purified flue gas. Taking into account that the total capacity of the brown coal-fired boilers is not more than about 400,000 tonnes/year, the volume of co-burnt waste paper could not exceed 100,000 tonnes/year. This is only a small fraction of the excess waste paper which could be used for energy recovery. Another option could be the combustion of waste paper in boilers suitable for the incineration of waste material from waste paper processing (e.g. fluidized bed boilers). So far, the capacity of boilers incinerating waste material from waste paper processing is not sufficient for burning an additional volume in terms of non-recyclable waste paper.

If an assumed excess of waste paper (1.7 million tonnes) - as taken into account in one of the scenarios - was burnt in incineration plants of the paper industry, an equivalent of 0.7 million tonnes of hard coal (energy content: 21,000 Terajoule) could be substituted which corresponds to about 18 percent of the fossil energy (116.500 Terajoule) consumed by the German paper industry. Because of the costs of pelletizing of waste paper (50 DEM/tonne waste paper), the heating value-related price of waste paper as a fuel would have to be negative (minus 10 DEM/tonne waste paper) at the same heating value of imported hard coal, which costs only 75 DEM/tonne. The subsidized price of German hard coal is about 155 DEM/tonne, so with reference to this, the waste paper price could be 34 DEM /tonne waste paper. In either case, it is obviously more attractive for the waste management industry and traditional waste paper dealers to sell the waste paper as a raw material to the paper industry.

Waste paper is nowadays a rather clean material with respect to its heavy metal content and the content of chlorinated compounds compared with brown and hard coal. Modern combustion technologies including stack gas purification, guarantee flue gas emissions which fulfil the most stringent requirements of the 17th Regulation of the Emission Control Act, including negligible emissions of dioxins and furans.

Because of its high degree of cleanness as far as harmful substances are concerned, non-recycled waste paper can be alternatively used as a co-substrate for composting, but it will compete with the increasing volume of biowaste from households which must be composted. Therefore, the amount of waste paper used as a compost substrate will not increase to any great extent.

A major concern in waste paper processing refers to disposal or utilization of rejects and sludges (deinking and waste water treatment sludges). Apart from a certain fraction of rejects from pre-screening (generated by rotating drums or pulpers for waste paper defibration) which might contain a proportion of chlorinated plastic, nearly all the waste material could be burnt in the paper industry in an environmentally compatible manner without additional fuel, thereby recovering energy. In the future, the current proportion of 40 percent of rejects and sludges burnt will be increased to at least 60 percent.

The remaining proportion of industrial waste material will be used as biological raw material (composting and soil spreading) and for construction material (e.g. cement, bricks). Despite the fact that deinking sludge is a repository of potentially harmful substances possibly present in waste paper, it can be burnt or composted without any environmental concerns. As far as any remarkable pollution of sludges by heavy metals is concerned, one must bear in mind that their most significant source are fillers and pigments used in previous papermaking. The heavy metal contaminations of these compounds are, however, strongly fixed in the crystal lattice and are therefore almost insoluble in water. The former problem of organochlorinated compounds present in waste paper as well as in sludges has become increasingly irrelevant thanks to the preferential use of ECF and TCF bleached chemical pulps by the German paper industry. Additives used for papermaking are generally free of AOX generating compounds, with the exception of wet-strength agents or defoamers.

The environmental effects of two scenarios were compared with the current situation of pulp and papermaking including waste paper processing, utilization and disposal of waste material generated by waste paper processing and disposal of non-recycled waste paper (landfilling, incineration and composting). They did not differ significantly. This is particularly the case with respect to energy consumption which is identical with both scenarios and the current situation. With reference to the reduction of fossil CO_2 emissions, it is advantageous to burn biomass in terms of (non-recyclable) waste paper as well as waste material from waste paper processing. However, one must be aware that the combustion of waste paper by co-generation (in the paper industry) requires its separate collection. If this 'overcollected' proportion of waste paper can be used abroad for papermaking, it will contribute to fiber supply, which is assumed to be characterized by a medium-term shortage.

The German public is recycling-minded. It is prepared to intensify measures which aim at separate collection of waste paper classified into brown and printing grades either used for manufacturing of packaging paper and board or of graphic and sanitary papers. Requirements of NGOs for intensified waste paper recycling are supported by politicians and are taken into account by legislation. There are indications that incineration of excess (non-recyclable) waste paper would be accepted by the NGOs if co-generation of electricity and heat will be performed, particularly by the paper industry. In general, environmentally-sound technologies of incineration (of waste in industrial and municipal plants) and landfilling are most advanced in Germany. This results, however, in high disposal costs to be paid by the industry as well as by communities and private households, respectively. Considering the avoided costs for disposal in terms of landfilling or incineration, it is more economic to use waste paper as a raw material as long as the quality of paper made of recycled fibers fulfils the market requirements.

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Appendix 1

Tab. 1: Waste Paper Grade List according to VDP and DIN EN 643

(VDP = Federation of the German Pulp and Paper Industry)
(DIN EN = European Standard (EN) issued by the German Standardisation Organisation DIN)

VDP Specifications (valid by 15.04.1993)	VDP Code	DIN Code	Specifications
Group 1: Ordinary Grades			**Group A: Ordinary Grades**
Original mixed waste paper (incl. original mixtures from private households) no guarantee of absence of unusable material	A 00	A 0	**Unsorted mixed waste paper** Including unsorted consolidated material from households, no guarantee of absence of unusable materials
Sorted collecting-waste *Mixture of various paper and board grades* Unusable material: max. 1 %	B 10	A1	**Mixed papers and boards (unsorted)** Mixture of various paper and board grades, without restriction on short fiber content
Sorted mixed waste paper Mixture of various paper and board grades containing less than 40 % news and magazines Unusable material: max. 1 %	B 12	A 2	**Mixed papers and boards (sorted)** Mixture of various paper and board grades containing less than 40 % news and magazines
Supermarket waste Used paper and board packaging containing at least 70 % corrugated board, the rest being solid board and wrapping paper. Unusable material: max. 1 %	B 19	A 4	**Supermarket waste** Used paper and board packaging containing at least 60 % corrugated board, the rest solid board and wrapping paper

		A 6	**New shavings of corrugated board** New shaving of corrugated board free of any other paper and any trace of unusable material. They are crushed or shredded and guaranteed to be free of any other product
		A 12	**Shredded office waste paper (unsorted)** Shredded office waste paper, unsorted
<u>Group II: Medium Grades</u>			**<u>Group B: Medium Grades</u>**
		B 1	**Once-read news** Old news, with less than 5 % colour inserts or advertisements
Original news (sorted) Sorted news (incl. unsold newspaper)	E 12	B 2	**Over-issue news** Unsold daily news, printed on white newsprint and free of additional colour inserts or illustrated material, strings allowed
Continuous stationery, wood-containing Sorted by colours	F 12	---	
Carbonless copying paper	G 12	—	
Board Without grey and mixed board of grade B 42, not free of staples	H 12	B 3	**White lined board cuttings** New cuttings of multi-ply board with at least one white liner over a grey interior or back
Coated board From production of liquid board packaging	H 22	---	

---	---	B 10	**Coloured best pamphlets** White or coloured coated or uncoated periodicals and brochures, free of non-flexible covers, bindings, varnishes, non-dispersable inks and adhesives, poster papers, labels or label trim. May include heavily printed circulars and coloured shavings. Mechanical content less than 10 %
---	---	B 11	**White carbonless copy papers**
---	---	B 12	**Coloured carbonless copy papers**
---	---	B 13	**Bleached PE coated board** Bleached, polyethylene coated board from liquid packaging board manufacturers
---	---	B 14	**PE coated board** Polyethylene coated board, may include unbleached board from liquid packaging board manufacturers
---	---	B 15	**Woody continuous stationary** Woody continuous stationary may include recycled fibers
<u>**Group III: High Grades**</u>			<u>**Group C: High Grades**</u>
Multi printing Woodfree, coated, printed, not wet-strength papers, free of dyed papers	K 02	C 2	**Light coloured woodfree shavings** Mixed light coloured shavings of printing and writing papers containing at least 90 % woodfree paper

White magazine broke Free of cores	P 23	C 13	**White magazine paper** Shavings and sheets of white unprinted magazine paper, free of newsprint
White wood-containing shavings Free of newsprint and magazine paper	P 32	C 16	**White woody shavings** Shavings and sheets of white unprinted paper, free of newsprint and magazine paper with at least 60 % of woodfree paper, may contain not more than 1 % coated paper
White woodfree shavings, slightly printed	Q 14	C 18	**White woodfree shavings** Shavings and sheets of white unprinted woodfree paper; may contain not more than 5 % coated paper
White woodfree shavings, unprinted, uncoated	R 12	C 19	**White woodfree shavings (uncoated)** Shavings and sheets of white unprinted woodfree paper; free of coated paper
White woodfree shavings, unprinted, coated	S 12	C 15	**White woodfree coated paper** Shavings and sheets of white unprinted woodfree coated paper
---	---	C 14	**White woody coated paper** Shavings and sheets of white unprinted woody coated paper
High gloss board Slightly printed or unprinted white and coloured	T 14	C 10	**Printed white multi-ply board** New cuttings of lightly printed white multi-ply board, without grey plies

Used kraft, natural coloured	W 12	D 5	**Used kraft** Used kraft paper and board of a natural or white shade
New kraft, natural coloured	W 13	D 6	**New kraft** Shavings and other new kraft paper and board waste of a natural shade
Original corrugated board From corrugated board production or converting, free of cores	W 41	---	
Corrugated kraft II Two liner plies of kraftliner or testliner	W 52	D 1	**Corrugated kraft II** Cases, sheets and shavings of corrugated board, with liners of kraftliner or testliner, but having at least one liner made of kraft
Corrugated kraft I Liner from kraftliner, fluting made of semichemical or chemical pulp	W 62	D 2	**Corrugated kraft I** Cases, sheets and shavings of corrugated board, with kraftliners only, the fluting made of chemical or semichemical pulp
---	---	D 0	**Brown corrugated** Cases, sheets and shavings of corrugated board, with liners of kraftliner or testliner
<u>Group V: Special Grades</u>			**<u>Group V: Special Grades</u>**
Unsorted waste paper from multi-component collection	X 09	---	