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PULP AND PAPER

Case study No. 1

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EXPLANATORY NOTES

AOX	absorbable organic halides, chlorine is the main halide present in the effluent is also called absorbable organic chlorine
ADT or adt	air dried tonne (pulp or paper with nearly 10 % moisture)
BAT	best available technology economically achievable
BCT	Best conventional control technology
BOD	biological oxygen demand
BPT	best practicable control technology currently available
C	Chlorination stage in pulp bleaching (Cl_2)
COD	Chemical oxygen demand
CTMP	Chemithermomechanical pulp
D	Chlorine dioxide stage in pulp bleaching (ClO_2)
E	Alkaline extraction, normally with sodium hydroxide (NaOH)
EO	Oxidative alkaline extraction stage
EPA	Environmental Protection Agency
GJ	Giga-joules
H	hypochlorination stage in pulp bleaching (ClO)
kgPt/t	kg platinum per tonne of pulp
kg/t/90	kilogram per tonne with 10 % moisture, air dry pulp
MPa	Mega Pascal
NSPS	New source performance standards
O_2 or O	oxygen stage
odt	oven dry tonne
ppm	parts per million ($1:10^6$)
ppt	parts per trillion ($1:10^{12}$)
ROI	return on investment
TCDD	tetra chloro dibenzo dioxin
TCDF	tetra chloro dibenzo furan
TMP	thermomechanical pulp
TOCl	total organic chlorine
TRS	total reduced sulphur
TS	total solids
TSS	total suspended solids
w/w	weight/weight

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ABSTRACT

The total world production of paper and board in 1989 was 233 million tonnes and of pulp nearly 164 million tonnes. Out of this about 85 per cent of paper and board and 87 per cent of pulp was manufactured in developed countries. The expected increase in the consumption of paper and board will be 3.4, to 3.6 per cent in developed countries and 5.8 to 5.9 per cent in developing countries. The expected annual growth in the pulp production will be 2.9 to 3.1 per cent in developed countries and 4.4 to 4.5 per cent in developing countries.

The basic raw materials used in pulp manufacture are renewable lignocellulosic fibrous materials. In developed countries mainly woods are used for pulping. In many developing countries, wood is in short supply and more than 45 per cent of the pulp is manufactured from other fibrous materials, mainly agricultural residues such as straw and bagasse and also bamboo. About 55 per cent of the other fibre pulp is manufactured from straw. Bagasse is used as fuel in sugar mills and surplus bagasse is used for pulp and papermaking. But in some cases bagasse as fuel is replaced by fossil fuels to increase pulp production. Wood supply in developed countries is based on the method of sustained yield. Plantations especially in tropical countries are an important source of wood.

In the pulping process about 50 per cent of the lignocellulosic material is dissolved by action of inorganic chemicals generating a biological oxygen demand (BOD) load of about 330 to 390 kg per tonne of pulp. In modern pulp mills these dissolved substances are collected by washing of pulp, evaporated, incinerated in a recovery furnace and the inorganic chemicals recovered and recycled. The BOD load can be reduced to a value of 10 to 20 kg/t of unbleached pulp before biological treatment.

The current best practicable technology standards in the USA for BOD are 8.05 kg/t of bleached pulp and new source performance standards (NSPS) are 5.5 kg/t of bleached pulp. Old wood-based pulp mills with recovery in developing countries still emit up to 40 to 60 kg/t BOD. Activated sludge or areated lagoon treatment considerably reduces BOD (70 to 90 per cent) but is expensive. In bleaching the BOD load is increased and in addition chlorinated organic compounds are generated.

The absorbable organic halides (AOX) load from a conventional bleaching using elementary chlorine and chlorine dioxide is 5 to 8 kg per tonne of pulp. This can be considerably reduced by using oxygen pre-bleaching and substituting chlorine by chlorine dioxide. The AOX load in bleaching of softwood pulp can be reduced to 2 kg per tonne and in bleaching of softwood to 1 kg per tonne taking into consideration that biological treatment reduces AOX by about 40 per cent. The target in the future in developed countries is further replacement of chlorine and reduction of AOX in the range of 0.5 to 1 kg (1995 to 1998) and later from 0.3 to 0.5 kg (2000) per tonne.

Wood pulp mills are using the sulphate process in which odorous gases such as hydrogen sulphide and methylmercaptan are emitted. The amount can be reduced by collecting and burning the gases. Non-wood mills using agricultural residues use the soda process, which is sulphur free and does not emit odorous gases. These mills are facing difficulties in washing of pulp (low capacity of washers) and in recovery of chemicals due to high silica content resulting in scaling which prevents lime re-burning. Consequently the recovery efficiency is low and BOD discharges are considerably higher than in modern wood-based mills. Small pulp mills (5 to 30 t/d) do not have a recovery programme as capital investment for recovery is about 30 per cent of total investment.

These mills discharge the total BOD and chemical oxygen demand (COD) load to recipient (about 250 to 300 kg BOD/t). However, as these mills are small, the total load on a locality is higher than that of a large capacity modern mill.

Waste paper is an important component of the papermaking furnish. The world utilization rate of waste paper is about 34 per cent but in some countries it is up to 50 to 60 per cent. Utilization of wastepaper prevents over-cutting of forests. The BOD discharge in waste paper processing is about 15 to 20 kg/t.

Papermaking is mainly a physical and hydromechanical process using raw materials which are nearly insoluble in water. The BOD load is low, but total suspended solid losses (TSS) are higher than in pulping. On a medium level paper machine, the BOD discharge is 2 to 3 kg/t and TSS is 5 to 6 kg/t. On paper machines using waste paper or mechanical pulp the BOD discharges are higher.

Old or second-hand paper machines frequently used in developing countries have a BOD discharge of 7 to 15 kg/t and TSS and from 35 to 75 kg/t. This is due to high water consumption (up to 160 to 200 m^3/t of paper) which is conversely very low on new paper machines (10 to 20 m^3/t).

Pulp manufacture is a thermal-energy consuming process (about 16 to 20 GJ/t), but in a modern mill the energy is generated by incinerating pulping waste liquor and bark. Thermal efficiency can be improved by displacement cooking, increasing black liquor concentration etc. to about 9 GJ/t. Energy consumption in papermaking is mainly for drying of paper. The energy consumption on modern paper machines has been reduced in the past 10 to 15 years by about 20 per cent in the range of 6 GJ/t to 9 GJ/t of paper. The main development is increasing dryness by better pressing.

There are still some technical and economical barriers to overcome to meet environmental requirements and this is mainly for small mills based on non-wood fibrous raw materials such as bagasse, straws. The high silica and hemicellulose content of these materials creates some problems in the pulping and papermaking process and not all clean production options developed for wood are applicable to pulping residues. The economic barriers are also important. A modern 'greenfield' mill spent about 20 per cent of the total investment for cost environmental protection. These clean production options developed for large scale mills when scaled down would result in lower efficiency. Heat consumption and lower chemical recovery efficiency increases the relative investment cost per tonne of pulp. Import duty on equipment in some countries is another economic barrier. International lending institutions would finance only projects which meet environmental guidelines. This also could be a barrier for funding of small mills. Closing a mill because of poor environmental performance could be a social problem for developing countries. This option should be carefully evaluated by Governments.

Despite financial and technical difficulties in implementing clean production options, the industry in many developing countries has improved and the valuable experience gained should be disseminated.

Government can play an important role in the environmental protection and can bring about changes by issuing environmental guidelines and standards, supporting environmental measures and by tax incentives or direct subsidies.

The environmental guidelines should be realistically attainable to avoid closing down mills and generating social problems. The Government programme should provide a progressive approach for existing mills giving them time to attain the limits. Furthermore assistance and support to research institutions in their search for appropriate effluent disposal technologies should be an integrated part of the government programme.

SECTION I

1. INTRODUCTION

The total world production of paper and board in 1988 was 224,329,000 t of which developed countries accounted for 189,604,000 t and developing countries 34,725,000 t [1]. The total world production in 1989 was about 233,000,000 t [2]. A further steady growth is expected in the next 20 years. The Food and Agricultural Organization of the United Nations (FAO) forecasts that by the year 2000 consumption in developed countries will grow by 3.4 to 3.6 per cent per annum and in developing countries by 5.8 to 5.9 per cent. The expected world consumption in the year 2000 will be 303 million tonnes [1].

Industry is using virgin fibres produced by pulping of lignocellulosic fibrous raw materials (wood, agricultural residues, grasses) but also a considerable amount of recycled fibres (waste paper) besides non-fibrous materials (chemicals, minerals e.g. china clay). The global mass balance of paper and paper board production in 1988 is presented in figure I [2].

World production of pulp in 1988 was 162 million tonnes and nearly 164 million tonnes in 1989 [3]. About 87 per cent was manufactured in developed countries. The expected annual growth in the next decade according to an FAO forecast will be 2.9 to 3.1 per cent in developed countries and 4.4 to 4.5 per cent in developing countries. The expected total world consumption of pulp in the year 2000 will be in the range of 200 to 220 million tonnes [1].

In 1989 there were 1,393 pulp mills and 4,390 paper mills in the world [3]. However, this number includes only the larger mills. There are many small mills in developing countries which are not included in the above mentioned statistics. In China alone there are approx. 5,400 pulp mills but only 189 have an output exceeding 10,000 t/a [4,5]. In India there are about 250 small pulp and paper mills having capacity up to 10,000 t/a [6]. Pulp is manufactured mainly from wood but also from other fibrous raw materials as shown in table 1.

TABLE 1. WORLD PRODUCTION IN 1988 (1000 t)

	Wood pulp	Other fibre pulp	Total pulp
Developed countries	140,904	1,346	141,450
Developing countries	11,078	9,698	20,775
Total	151,183	11,044	162,225

Source: FAO Yearbook Forest Products 1988 [1].

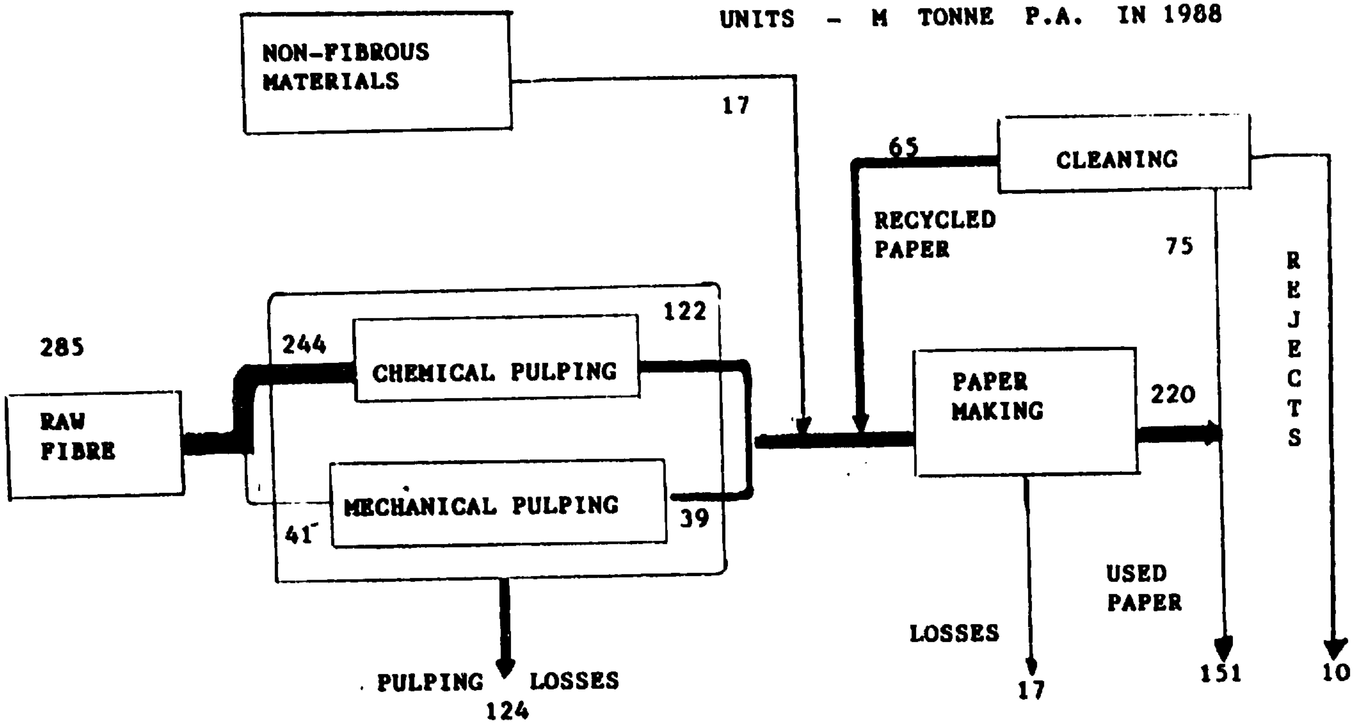

Figure I. Global mass balance [2]

More than 55 per cent of the other fibre pulp is straw pulp. Bagasse and bamboo pulp each represent about 15 per cent and various grasses, such as reeds, represent less than 15 per cent of other fibre pulp production [7].

The industry has an impact on air, water and land as shown in figure II [2].

The extent of this impact can be controlled by appropriate technology. There are still technical and economical difficulties to collect and to burn black liquor and to recover chemicals in small pulp mills.

About 75 per cent of the pulp production is chemical pulp manufactured by processing lignocellulosic fibrous materials with inorganic chemicals. During this process approx. from 50 to 55 per cent of the lignocellulosic material is dissolved thereby generating polluting substances. In a modern mill these are, to a large extent, collected and incinerated and the inorganic chemicals recovered. Possible emission points in alkaline wood pulp manufacture are shown in figure III.

Paper production is basically a physical (hydromechanical) process using materials which are almost insoluble in this process. Only a small amount of polluting substance is dissolved in this process but more suspended solids are discharged than in pulp manufacture.

2. ENVIRONMENTAL IMPACT OF PULP MANUFACTURE

2.1. IMPACT OF FIBROUS RAW MATERIAL EXTRACTION FROM NATURAL RESOURCES

The basic fibrous raw material in pulp manufacture are renewable lignocellulosic fibrous raw materials (wood, straw, bagasse, bamboo) accounting for 85 to 95 per cent weight/weight (w/w) of all raw materials (except fossil fuels). The world consumption of fibrous raw materials in pulp manufacture is nearly 300 million t/a on an oven dry basis. Most of the fibrous materials are woods, both softwoods and hardwoods. The total world consumption of pulp wood including chips from industrial waste was more than 500 million cubic metres in 1984 and is expected to exceed 700 million cubic metres in 1995 [8]. Most of the pulpwood is cut and used in developed countries as shown in table 2.

TABLE 2. ROUNDWOOD PRODUCTION AND UTILIZATION (1988)

	Developed countries	Developing countries
-Total roundwood production (1 million m^3/a)	1547	1883
-Total industrial roundwood (%)	82.0	20.0
Pulpwood (%) (including industrial waste)	24.6	2.56
other industrial uses (%)	57.4	17.5
-Fuelwood and charcoal (%)	18.0	80.0

Source: FAO Yearbook Forest Products 1988 [1].

Wood is the most frequently used fibrous raw material in developed countries and pulpwood production is an important part of forestry.

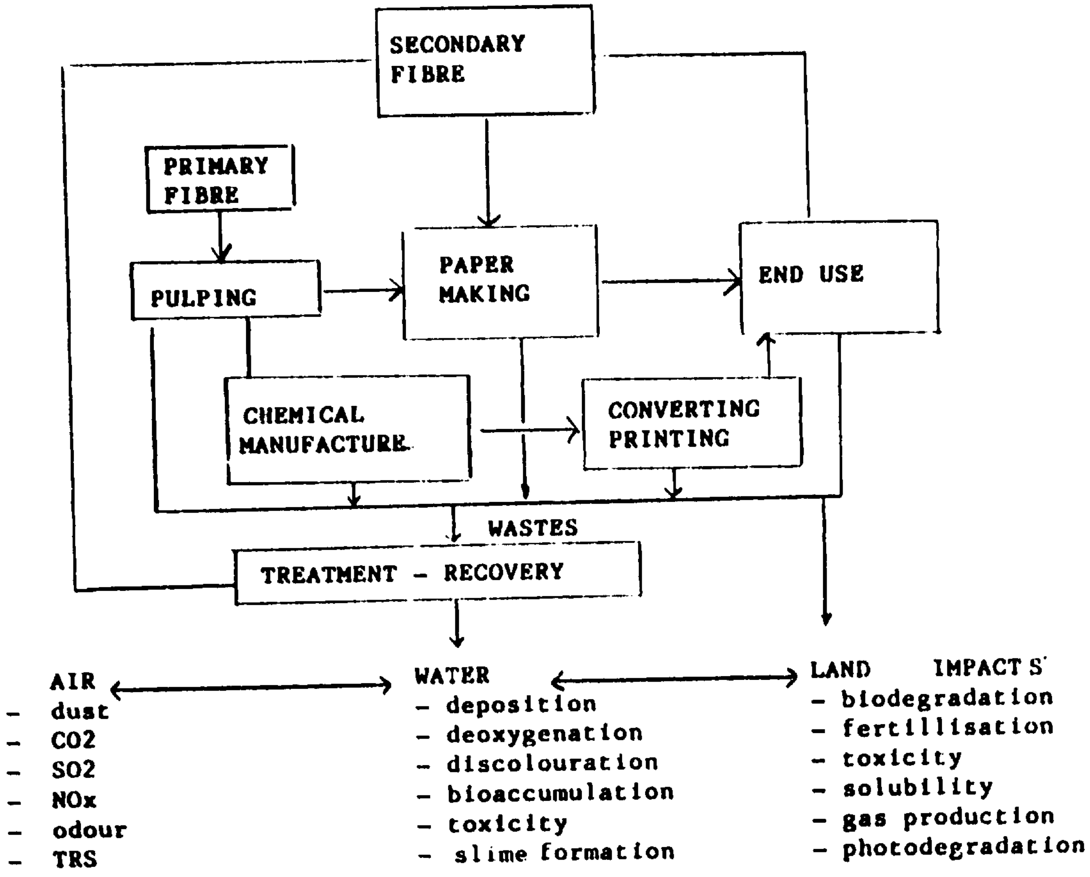

Figure II. The pulp and paper cycle [2]

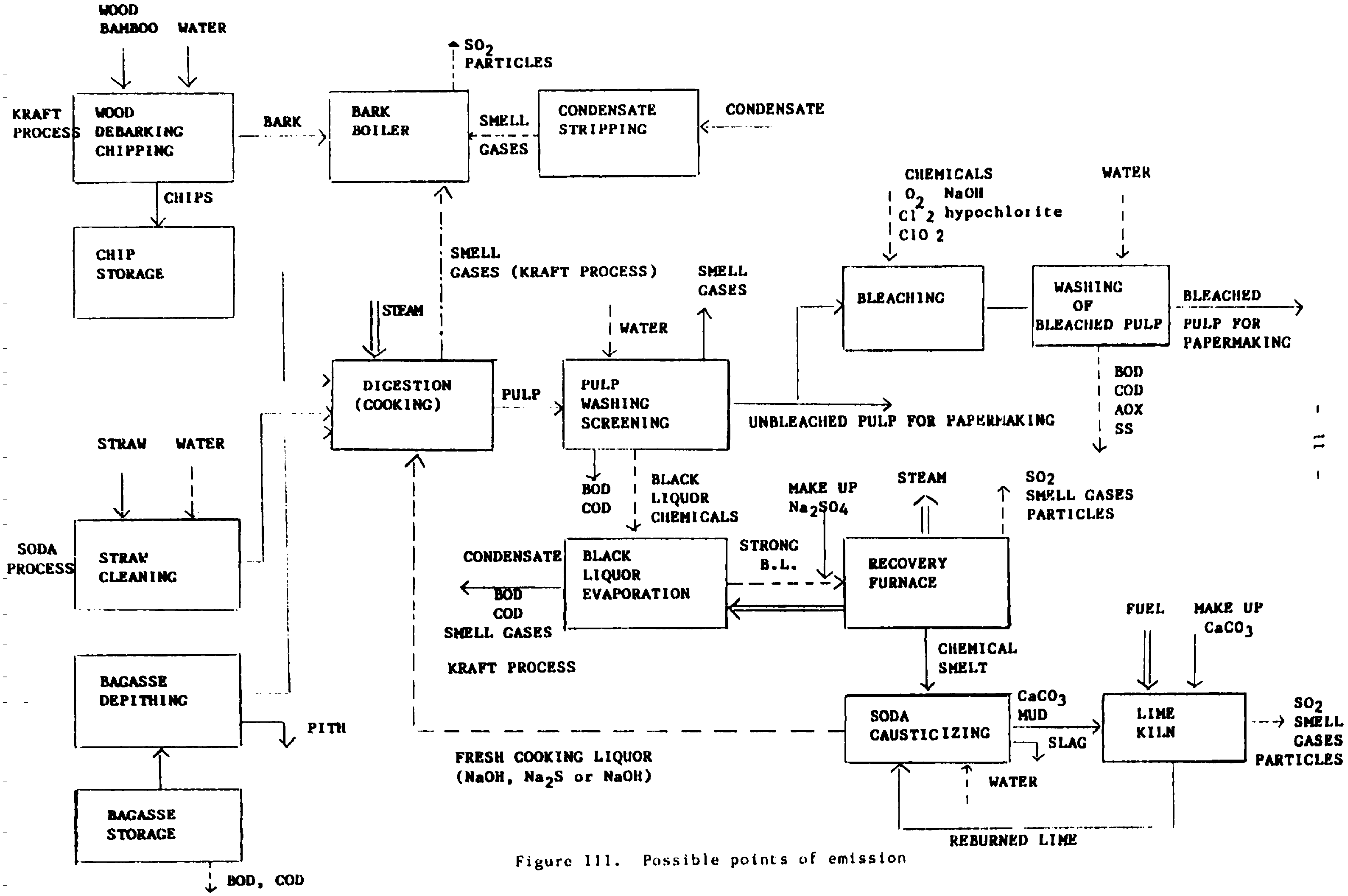

Figure III. Possible points of emission

Forestry management in most developed countries is based on the method of sustained yield. It is ensured that annual growth is at least equal to cut volumes. In some countries e.g. Germany [9] it is general practice to make almost exclusive use of thinning material and industrial wood residues for pulp production. Such exploitation of the forests are harmonized with environmental protection techniques. However, the European forest is more homogenous and, therefore, more readily lends itself to efficient exploitation. There are still large resources of wood in North America, the USSR and minor resources in Central Europe.

In developing countries fuel and charcoal wood are the main forest commodities. Pulpwood production is negligible except in some countries, e.g. Argentina, Brazil, Indonesia, Swaziland, Tanzania. The area of natural forest in developing countries is decreasing as a result of overcutting for fuelwood, shifting cultivation and conversion of land to agriculture and pasture. In some countries, e.g. Nigeria, mixed tropical hardwoods consisting of many species are used for pulp manufacture even though they are not suitable. There is a tendency to replace the natural forest by plantation species (e.g. Pinus, Gmelina, Eucalyptus etc), and to establish plantations on unused land and degraded forest areas. Annual yield of plantations in tropical and subtropical areas is considerably higher, than in a temperate zone forest [10]. In 1985 the area of plantations was a little more than 1 per cent of the total world area of closed forest but the industrial wood supply from plantations accounted for 14 per cent. The area of plantations is expanding and the share of industrial wood in the year 2000 is expected to be in the range of 19 to 22 per cent [11]. Very successful is the plantation programme e.g. in Brazil, supported by an efficient tax-incentive mechanism [12]. In 20 years 6.3 million hectares of forest have been planted. Such plantations reduce CO_2 content in the atmosphere. An approx. 300,000 t/a pulp mill based on Eucalyptus that needs 1.5 million cubic metres of wood per year would need a standing timber volume that corresponds to about 5 million tonnes of oil in terms of carbon content [11].

In developing countries, such as China and India, the natural forest or plantation cannot satisfactorily supply the needs of the pulp industry. Non-wood materials, mainly agricultural residues (wheat and rice straw, bagasse) and bamboos are used for pulp manufacture.

Although non-wood bamboos are actually considered a forest raw material. Wheat and rice straw are used mainly in China and India. There are still large quantities of unexploited wheat and rice straw of the magnitude of several hundred million t/a (moisture-free) which are lost and partially burned on fields. Utilization in pulp manufacture is desirable as it holds carbon in cellulosic fibres for a longer time. The world production of sugar-cane bagasse is 60 to 70 million tonnes (moisture free) per year. Bagasse is used as fuel in sugar mills and only surplus bagasse can be used for pulping. In old type boilers the bagasse surplus is about 5 per cent only. With improved thermal efficiency of the sugar mill evaporators and boilers this amount could be increased from 10 to 20 per cent. In some mills, bagasse as fuel is replaced by fossil fuel.

Utilization of lignocellulosic fibrous raw materials for pulp manufacture is ecologically sustainable provided wood supply is based on the method of sustained wood yield and if otherwise unused wheat and rice straw and surplus bagasse is used. Replacement of bagasse as fuel by fossil fuels, in order to deliver more bagasse for pulp production, is normally less favourable economically as it depends heavily on the equivalent caloric value of the bagasse and oil at the time.

2.2. PREPARING OF FIBROUS RAW MATERIALS

Prior to pulping, wood has to be debarked. The bark content depends on the species of wood and diameter of logs and is usually about 10 per cent but can be as high as 17 per cent w/w. The logs are debarked either in wet debarking drums or by dry debarking methods (dry drums, knife-debarkers or manually). In wet debarking a part of soluble substances is dissolved resulting in BOD discharges of 4 to 12 kg and COD discharges of 20 to 40 kg per tonne of dry wood. Suspended solid discharges are about 5 to 20 kg per tonne (fine particles). In dry debarking BOD discharges are 0 to 3 kg/t of wood. The reduction of BOD by biological treatment is from 60 to 80 per cent of COD about 50 per cent [13]. Bark has a considerable value as a fuel. If a mill is using only unbarked roundwood it would be able to recover 3.5 to 4.0 GJ/t in fuel. If the mill receives a considerable part of the wood as chips the recovered heat will be less [14]. In the chipping operation some fines are screened out and usually burned.

Bagasse has to be stored to supply the pulp mill even if sugar cane is not crushed. The storage is dry in bale form or wet in bulk form and sprinkled. The discharges of BOD are 20 to 40 and COD 80 to 240 kg/t of bagasse pulp.

The next operation is moist or wet depithing removing from 20 to 25 per cent of bagasse substance. The pith is usually burned as fuel.

In some mills wood chips and bamboo chips are cleaned by water and in some cases straw as well. Mainly dust and inorganic substances such as silica are removed through such a treatment.

2.3. COMPOSITION OF LIGNOCELLULOSIC FIBROUS RAW MATERIALS

There are three main organic components in lignocellulosic materials: cellulose, hemicellulose and lignin besides smaller amounts of extracts. Cellulose has a fibrous character and pulping is used to separate the cellulosic fibres from the lignocellulosic structure. Woods contain a small amount of ash, generally below 1 per cent. The ash content in annual plants (straw, bagasse) is higher and is composed mainly of silica as presented in table 3.

TABLE 3. ASH AND SILICA IN NON-WOOD PLANT FIBRES

Raw material	Ash %	SiO_2
Bamboo	3 - 5	1.5 - 3.5
Wheat straw	4 - 7	1.5 - 3.5
Rice straw	7 - 22	4 - 14
Bagasse	4 - 8	1.5 - 4

Source: A. Kulkarni, UNIDO Workshop on Non-wood Fibre Pulping and Papermaking, Beijing 1988.

Softwoods have longer fibres than hardwoods and residues as well as some annual plants. Bagasse contains up to 40 per cent pith, which has a non-fibre character. Straw, expecially rice straw, contains a portion of very short fibres and therefore fibre losses in processing straw are higher than in processing of wood.

2.4. CHEMICAL PULPING

Review of most important processes

In chemical pulping, cellulose fibres are separated by dissolving lignin and hemicellulose in an aqueous solution of chemicals at elevated temperature and pressure. There are basically two main established technologies:

In **sulphite pulping** wood chips or other lignocellulosic material (e.g. bamboo) is digested at 130 to 140°C in a solution of calcium bisulphite containing excess sulphur dioxide or in a solution of sodium, magnesium or ammonium bisulphite with or without excess sulphur dioxide. The advantage of sulphite pulping is the higher brightness and better bleachability of the unbleached pulp when compared with alkaline pulping and the possibility of by-product manufacture from the pulping waste liquor. However, not all fibrous raw materials can be processed by this method (e.g. some hardwoods). The recovery of chemicals is either not possible or too complicated except in magnesiumbisulphite. Only 10 per cent of the world chemical pulp production and only 5 per cent of the chemical pulp production in developing countries are manufactured by the sulphite processes.

In **alkaline pulping** lignocellulosic materials are digested with aqueous solutions of caustic soda (soda pulping) or caustic soda and sodium sulphide (kraft or sulphate pulping) at 160 to 170 °C. All lignocellulosic materials can be processed by alkaline pulping. The soda process is especially suitable for agricultural residues and grasses. The recovery of caustic soda and sodium sulphide is a well established process. However, when fibrous raw materials with extremely high silica content are used for pulping, chemical recovery is made difficult.

Alkaline pulping, washing and screening

Wood is usually digested by the sulphate process. The chemical charge is usually from 16 to 20 per cent Na_2O on o.d. wood at 20 to 30 per cent sulphidity (ratio of Na_2 to active alkalies expressed as Na_2O). The yield of unbleached pulp is usually from 48 to 52 per cent. The total weight of inorganic chemicals is 420 to 600 kg/t of pulp. About 1000 to 1200 kg of oxygen consuming organic substances are dissolved in the black liquor resulting in a BOD value of 330 to 390 and COD 1300 to 1500 kg/t of oven dry pulp. The dissolved substances are deeply coloured resulting in a colour load about 1100 to 1200 kgPt/t of pulp and contain also small amounts of toxic substances such as resin acids and unsaturated fatty acids [15]. Some organic substances are volatile and are contained in the digester and evaporator condensates contributing to the BOD load by 12 to 20 kg BOD per tonne of pulp. During the digestion metoxyl groups are split off producing methanol and also reacting with sodium sulphide forming odorous compounds such as methylmercaptan, methylsulphide, dimethylsulphide and dimethyldisulphide. The amount of total reduced sulphur (TRS) is about 3.5 to 5 kg per tonne of pulp, the higher value related to hardwoods. Bamboo is usually pulped by the sulphate process.

Agricultural residues are usually digested by the soda process (without sodium sulphide). The chemical charge is lower, usually 10 to 12.5 per cent on o.d. material. In some cases, without chemical recovery the chemical charge is even lower. The yield is about 50 per cent and in the case of rice straw it is sometimes as low as 40 per cent and this increases the BOD load considerably. The discharge of TRS (odorous compounds) is negligible as only traces of sulphur are present from water and raw materials.

An important operation is washing of the pulp and extraction of the black liquor containing the dissolved organic substances. Vacuum and pressure drum washer are commonly used for pulp washing mostly in three stages. The loading capacity of drum washers for wood pulp is from 5 to 8 $t/m^3/24$ h. Black liquor washing efficiency is from 96 to 97 per cent. The efficiency of modern belt washers is as high as 99 per cent. With this development the technological limits are most probably reached and in future efforts will be directed to increase capacity and energy saving for drives and vacuum systems.

In old mills, the pulp is screened after washing, leaving shives and knots only partially washed and discharging BOD load in the screening system. By a closed hot screening the effluent can be reduced by 12 to 15 m^3/t of pulp with a corresponding decrease of BOD load. The carry-over to bleach plant should not increase, as it may increase AOX formation. By a closed system and good spill collection system discharges of suspended solids can be decreased from 25 to 35 kg/t to 15 kg/t of pulp.

Washing of agricultural residue pulp is less effective and more capital intensive as drainage properties of these are poor and the loading capacity of drum filters low (bagasse pulp about 3 $t/m^2/d$, wheat straw 1 - 1.5 $t/m^2/d$ and for rice straw even less). The washing efficiency for bagasse is about 94 to 95 per cent calculated on NaOH recovery but is very low for straw as shown in table 4 [3].

TABLE 4. COMPARISON OF PULP WASHERS (Straw pulp washing in China)

Washer type		No. of washers	Total wash area	Capacity odt/m^2/d	BL extraction %
15 m^2	Press washer	3	45	0.86	75-85
10 m^2	Vacuum washer	4	40	0.65	83
10 m^2	Belt washer	1	10	1.66	96.5

Source: C.Pu and S. Hu, Pulp Paper Can., 91 (12):163 (1990) [4].

The table indicates that a belt washer may be the solution for straw pulp washing. The black liquor from agricultural residues is less concentrated e.g. bagasse or wheat straw black liquor is from 8 to 9 per cent of total solids, and in the case of rice straw it is considerably lower.

2.5. INCINERATION OF BLACK LIQUOR AND RECOVERY OF CHEMICALS

The recovery of the chemicals from the black liquor of sulphate (kraft) and soda digestion process is a vital part of the pulping operation as it regenerates chemicals to form fresh digestion liquor. It is also a most important environmental protection process. It supplies heat for the pulp mill by incineration and is a renewable fuel once considered waste. Simultaneously it minimizes discharge of water polluting substances. In a modern mill reductions are from 1 to 3 per cent. In the recovery process, the black liquor is concentrated in multiple effect evaporators followed frequently by a direct-contact evaporator using flue gases and incinerated in a recovery furnace with addition of sodium sulphate to make up for loss. The resulting smelt of inorganic chemicals (Na_2CO_3, Na_2S) is dissolved in water and caustic soda regenerated by causticizing with lime.

The tendency today is to improve evaporator heat economy. An important step is pre-evaporation of black liquor by using flash steam from a continuous digester. It is possible to increase dry solids in black liquor to 30 per cent from originally about 14 to 15 per cent without direct heat consumption [10]. There are attempts to apply this also for batch pulping by conserving flash steam in an accumulator. By increasing the number of evaporator effects from 5 to 6 to 7 the live steam demand will decrease from 0.24 to 0.20 and even 0.17 t of live steam per tonne of evaporated water, corresponding to a live steam saving of 0.23 and 0.56 adt of pulp.

To improve heat efficiency it is advisable to increase black liquor concentration to over 62 per cent. A new development is super-concentration of over 75 per cent using a falling film evaporator [16]. By using such a super-concentrated black liquor the total system energy recovery increases by 9 to 12 per cent. The effect is a drop in SO_2 emissions to zero and H_2S emissions near to zero and showing a positive environmental impact.

Evidently recovery of chemicals from wood black liquors can be substantially improved especially in terms of heat economy. Recovery of chemicals from agricultural black liquors is more difficult and less efficient. Black liquors from agricultural residues are less concentrated, (usually from 9 to 11 per cent, wood black liquors from 14 to 15 per cent). Black liquors from rice straw pulping are even less concentrated [16] and evaporation is more difficult.

High silica content in black liquor increases the melting point of recovery furnace smelt by approx. 30°C making the smelt easy to freeze [4]. High silica content makes calcium oxide recovery from causticizing unusable as calcium silicate is formed by inactivating lime and causing build-up of silicate in the lime kiln. For a successful recovery of high silica containing black liquors desilication is required. There have been many attempts to develop a commercially viable desilication process. A pilot plant has been installed in the Rakta mill in Egypt [17]. A successful process has been jointly developed by UNIDO/SIDA, by the Central Pulp and Paper Research Institute in India and a demonstration-production plant has been installed in a South Indian mill using bamboo and reed.(Hindustan Newsprint Ltd, Kerala) [17].

The submerse reactor capacity is nearly 40 m^3/h of black liquor. The semi-concentrated black liquor (from 14 to 18 per cent total solids w/w and silica from 3 to 6 g/l) is carbonated using recovery furnace hot flue gas. Carbonation is carried out gradually in three reaction tanks in series. The desilication efficiency is 90 per cent to about 0.6 g/l of silica. The process is unsophisticated and operates with a low level of instrumentation. The investment cost of a desilication plant for a 50 t pulp/d mill is estimated to be about $US 500,000 to $US 600,000.

A recovery system with especially high-efficiency and a sophisticated furnace is very expensive and hardly accessible to small mills. A simplified version called a Broby smelter was successfully installed in a Brazilian mill using bagasse. In China recovery furnaces suitable for non-wood black liquor have been developed and installed in several mills producing 10,000 to 15,000 t/a of pulp [4,18]. The recovery efficiency is in the range of 65 to 85 per cent. Recently a furnace for a 25 t/d straw pulp mill has been developed in China [4]. The furnace reportedly is operated without auxiliary fuel.

Condensates from evaporation together with condensates from a digester contribute substantially to the BOD load. In the case of hardwoods it is up to 20 kg BOD_5 per tonne of pulp. Condensates contain methanol and also malodorous substances (TRS). It is necessary to clean the condensates by stripping and to incinerate in a suitable furnace e.g. in the bark furnace or lime kiln.

2.6. BLEACHING OF CHEMICAL PULPS

The residual lignin, which was not removed during digestion (cooking), is responsible for the low brightness of unbleached pulp. Especially sulphate (kraft) and soda pulps are of dark colour. To achieve the required brightness the residual lignin is removed by bleaching. The residual lignin in sulphite pulps is of lighter colour and easier to remove than lignin from sulphate or soda pulps. Hardwood and annual plants (straw, bagasse) based sulphate and soda pulps are easier to bleach as these usually contain less lignin than softwood pulp. Bagasse and straw pulps are bleached by chlorination with elementary chlorine (C stage followed by alkaline extraction of chlorinated lignin (E stage) and by hypochlorite bleaching (H stage) in one or two stages. Sometimes only hypochlorite is used. With the introduction of sulphate bleached pulp and a requirement for higher brightnes chlorine dioxide (D) as bleaching agent is introduced. The conventional sulphate softwood bleaching sequence is C-E-D-E-D, usually with some replacement of chlorine by chlorine dioxide (C/D stage).

Most of the lignin is dissolved in the first two bleaching stages (C-E) and some of the dissolved lignin has covalently bonded chlorine. Such compounds are not common in nature and are actually "man-made". A part of chlorinated lignin is difficult to decompose and may have harmful environmental effects. The bleach effluent has high COD value and is heavily coloured. In conventional bleaching approx. 5 to 7 kg of organically bound chlorine expressed as AOX or TOCl is discharged per tonne of pulp. World wide approx. 250,000 t of organically bound chlorine are discharged from pulp bleaching [19]. Traces of dioxins are also formed in the chlorination stage.

However, it should be mentioned that about 40 per cent of AOX is decomposed in biological treatment of effluent.

Even if the toxicity of bleach effluent is frequently overestimated the tendency is to reduce discharges substantially. Also there have been attempts to reduce discharges by precipitation of chlorinated lignin or by ultra filtration. The generally accepted method is to reduce residual lignin content in unbleached pulp by oxygen pre-bleaching or by modified cooking or by a combination of both methods. In modified cooking or extended delignification the alkali charge is made more uniform during digestion and the concentration of the dissolved lignin in the pulping liquor must be lowered during the latter part of the digestion. In oxygen pre-bleaching the unbleached pulp is treated with oxygen and NaOH at about 100 °C and 0.8 MPa pressure. About 40 per cent of the residual lignin is dissolved. Oxygen bleaching is now introduced in about 40 mills worldwide.

By oxygen pre-bleaching and oxygen delignification the Kappa number i.e. the lignin content of softwood pulp prior to bleaching can be reduced substantially and consequently the AOX, COD, BOD and colour discharge is significantly reduced. If the mill has activated sludge waste water treatment, the final emissions are further reduced.

Further reduction of AOX can be achieved by a high degree of substitution of elementary chlorine by chlorine dioxide. Chlorinated compounds are produced by chlorine dioxide to a limited extent. By a high degree of substitution the AOX discharges from bleaching of softwood pulp can be reduced to 3 kg AOX/t pulp. In the case of hardwood pulp a full substitution of chlorine by chlorine dioxide is possible reducing the AOX discharge to about 1 kg AOX/t pulp. This can be further reduced by activated sludge treatment. A high substitution is also beneficial to reduction of dioxin content in pulp from about 25 ppt to 0 - 5 ppt.

A further reduction takes place in activated sludge treatment (see table 5) reducing the AOX final emission of softwood bleached pulps to about 1.7 to 2 kg AOX/t of pulp, the limit anticipated in the next 2 to 3 years. The AOX emission of hardwood pulp bleaching will be even less.

TABLE 5. COMPARISON OF SOME PREBLEACHING DELIGNIFICATION OPTIONS-SCANDINAVIAN SOFTWOOD

Process		Kraft	Kraft $+O_2$	Mod.Kraft	Mod.Kraft $+O_2$
INITIAL LOADS					
BOD.	kg 02/adt				
- bleaching		16	12	14	9
- other. spills		8	8	8	8
- total		24	20	22	17
COD (Cr)	kg 02/adt				
- bleaching		80	50	60	39
- other. spills		20	20	20	20
- total		100	70	80	59
SUSPENDED SOLIDS	kg/adt	8	8	8	8
COLOUR.	kg Pt/adt	200	120	150	100
TOT.ORG. Cl2.	kg AOX/adt	7.0	3.5	4.8	2.8
AFTER TREATMENT					
BOD	kg 02/adt	2.4	2.0	2.2	1.7
COD (Cr)	kg 02/adt	45	31	36	27
SUSPENDED SOLIDS.	kg/adt	1	1	1	1
COLOUR	kg Pt/adt	180	100	130	85
TOT.ORG. Cl2.	kg AOX/adt	3.9	1.9	2.2	1.3

Source: J.Gullichsen, The Paper Industry and Its Environment Proceedings, OEZEPA, Vienna, 1989 [20].

Implementation of modified cooking and oxygen bleaching has an impact on the entire pulping process. Yield is lower in both cases resulting in a higher loading of recovery as the effluent from oxygen bleaching is recycled and burned. More steam and electricity is produced, but in oxygen pre-bleaching the heat demand is higher as compared with conventional pulping and bleaching. The additional investment for a new mill or a mill undergoing a major rebuild is modest. Oxygen bleaching requires a pressurized reactor and additional washing equipment. It is easier to add on to an existing mill, but it will lead to production losses if the recovery boiler or the recausticizing plant are capacity bottlenecks. The overall economy of a 1000 adt/d pulp mill variations is presented in the following table 6:

TABLE 6. ESTIMATED COST OF ALTERNATIVES
(production 1.000 adt/d) (softwood)

Alternative		Sulphate + O_2	Modified sulphate	Modified sulphate + O_2
Operating cost saving*	$US 1.000 per year	633	2,987	1,769
Required capital	$US 1,000	12,175	6,477	17,532
Marginal ROI	(%)	5.2	46.1	10.1
Payback time**	(years)	indef.	2.4	40

Source: J. Gullichsen, The Paper Industry and Its Environment Proceedings, OEZEPA, Vienna, 1989 [20].

Note: All in Fmk in 1985
converted to $US according to exchange rate in 1985
* 350 operating days
** 10 per cent interest, constant annuity

The investment costs will be affected by local mill conditions. In a new mill, bleaching can be reduced to three stages instead of five. If enough washing filters are available costs can be also reduced. Some authors are therefore more optimistic about investment costs [21,22]. If 25 to 30 per cent delignification is sufficient a less expensive hydrostatic, medium consistency, oxygen reactor may be installed. This may be interesting for pre-bleaching of straw and bagasse pulps as these contain less residual lignin and the bleaching sequence may be reduced. Such a SIMPLOX reactor is in operation in Carton de Colombia, Colombia [23]. Up to this time no straw or bagasse pulp oxygen bleaching is in operation. Another possibility to reduce polluting discharges from bleaching is adding oxygen to the first alkali extraction stage (EO stage), reducing colour to some extent AOX and saving up to 40 per cent chlorine dioxide, which may be used to substitue chlorine in the C stage. EO stages can easily be made as a retrofit installation in existing bleach plants. Installation costs are between $US 0.5 million to $US 0.8 million and pay back period is usually six to eighteen months.

2.7. MECHANICAL PULPING PROCESSES

The total world production of mechanical pulps (including TMP and CTMP) from wood in 1988 was 34,157 million tonnes. Ninety-five per cent of the mechanical wood pulp is produced in developed countries [1]. In mechanical pulping fibres are separated by mechanical action in the grinder or in a disk refiner sometimes by combined heat, mechanical and mild chemical treatment. The yield is usually higher than 95 per cent. Only a small portion of the wood is dissolved and the BOD and COD discharges are correspondingly low. For mechanical pulping without chemicals the BOD values are 15 to 25 kg/t and COD values 25 to 65 kg/t. In CTMP (chemithermomechanical pulp) sodium sulphite is used and a larger portion of wood substance is dissolved resulting in COD values 110 to 140 kg/t, including peroxide-dithionite bleaching. The BOD and COD load generated in mechanical pulping is just a fraction of the load generated in chemical pulping, but equal or higher than the total discharge from chemical pulping with recovery. Biological treatment especially for TMP and CTMP is required to reduce pollution. Resins in waste water from mechanical pulping are toxic and may disturb anaerobic biological treatment.

Mechanical pulping was increasing at a faster rate than chemical pulping production until one or two years ago due to substantially lower investment cost and wood consumption (high yield from wood). However electric energy demand is high (1.500 to 2.800 kWh/t) and this production is now growing slowly particularly in countries with low energy costs.

In countries with a shortage of wood, pulp is produced from bagasse by mechanical treatment in disc refiners. This technology is succesfuly used in India [24].

2.8. WASTE PAPER PROCESSING

Waste paper is an important raw material in paper production and especially paperboard manufacture. The world total waste paper recovery in 1989 was 80.369.000 t and consumption 79.568.000 t which means a utilization rate of 34 per cent and a recovery rate of 35 per cent [25]. According to FAO forecasts world waste paper consumption in the year 2000 will be about 110 million tonnes.

Waste paper is one of the most significant parts of communal refuse and yet less waste paper is utilized than discarded as garbage and this is partly incinerated. Less than 40 per cent of waste paper is actually collected. The highest waste paper utilization rates in fibre furnish is recorded in the Netherlands, the United Kingdom and Denmark, where it reached around 60 per cent in 1990. In Asia many countries are above 50 per cent and in the Republic of Korea about 70 per cent [25]. Utilization of waste paper for papermaking is ecologically desirable, as it lowers refuse and extends the life-cycle of carbons in waste paper fibres. In countries with shortage of other fibrous raw materials waste paper utilization is preventing over-cutting of forests. Replacement of virgin pulp by waste paper also decreases energy demand, as energy consumption in waste paper processing requires approx. 1.3 MWh/t [2]. The BOD discharge in mechanical waste paper processing is about 15 to 20 kg/t and COD about 40 kg/t of waste paper processed. In de-inking the emissions are higher (BOD 15 to 40 kg/t and COD 50 to 90 kg/t).

Losses in repulping of waste paper are about 13 to 14 per cent. However it should be remembered that these solid wastes would have been dumped in any event.

Waste paper is used mainly in paperboard packaging and tissue paper manufacture, but utilization in writing and printing papers, especially newsprint after de-inking is increasing.

Waste paper is a very important raw material in developing countries. However, to achieve a high recovery of waste paper collection has still to be improved and necessary conditions are high density population and existence of waste paper which is not too highly contaminated.

2.9. ENVIRONMENTAL IMPACT OF PAPERMAKING

In the first stage of papermaking, stock preparation, the fibres are treated mechanically by rotating bars in a beater ("beating") or in a conical or disc refiner ("refining"). This makes fibres flexible and to increase the external surface in order to improve fibre bonding. In this operation some fibre material may be dissolved, but the amount is marginal and is higher for unbleached pulps.

After refining of fibres, fillers and additives are added. Fillers, e.g. china clay, calcium carbonate improves optical and printing properties and by saving fibres reduces production costs. However, fillers are non-renewable materials.

The most common additives are sizing agents and starches. Resin size is fixed to fibres by alumen. A part of the resin remains in solution. To improve sizing effect and retention on fibres, modified and fortified sizes are used. Starch is used to improve surface strength. Native starch has a poor retention (about 15 to 20 per cent) and increases BOD demand of the effluent considerably. Cationic starches have a high (80 to nearly 100 per cent) retention and have a marginal influence on BOD. Retention aids e.g. polyacrylamid are added to increase retention of fillers.

After stock preparation the stock is diluted from 0.5 to 1 per cent consistency pumped to the headbox and distributed to the wire section. The fibre slurry carries a large volume of water (100 to 200 m^3/t) which is removed by filtration, suction boxes and foils and by pressing, increasing dry content from 35 to 40 per cent and with modern presses from 40 to 50 per cent and reducing the volume of water by 1 to 1.5 m^3/t. This is removed from the paper web by drying.

The semi-dry paper may be surface treated with starch or other chemicals in a size press. Dry paper may be further processed by coating with pigments, starch and other binders. This is also a source of water pollution as some of the paper due to breaks or imperfection has to be recycled.

The water removed in the wet part (white water) is partly recycled directly and partly processed in a fibre recovery equipment (save-all) to clean water for re-use and to remove fibres and fillers. The volume of white water is increased by fresh water for sprays to clean wire and felts.

The overflow from the save-all carries mainly suspended solids as not all fillers and fibres are retained in the paper mat. If short fibres e.g. straw pulp is used more fibres are passed to the white water. Suspended solid loss is the main polluting factor in papermaking.

In Czechoslovakia a paper mill integrated with a modern sulphate pulp mill is producing writing and printing paper and foodboard, total 76.357 t/a on 2 older paper machines. The water consumption on the writing-printing paper machine is 50 to 55 m^3/t. The BOD discharge is 2.45 kg/t and suspended solid discharge 6.2 kg/t.

In India, there is a great difference between medium sized mills (150 - 200 t/d) integrated with pulp mill including recovery and small pulp mills (2 - 25 t/d) as seen from the following table 7:

TABLE 7. DISCHARGES FROM INDIAN PAPER MILLS

	Old type medium mill integrated	Small mill waste paper and purchased pulp
Waste water m^3/t	60 - 80	72 - 159
Suspended solids kg/t	35 - 70	47 - 78
BOD kg/t	7 - 14	9 - 38
COD kg/t	56 - 84	49 - 91

Source: S. G. Rangan, Conventional Issue, IPPITA, New Delhi, 1987, Vol I p.141 [26].

Small paper mills have higher discharges. This is evidently the result of high water consumption and also outdated and less sophisticated machinery. These paper machines are frequently old second-hand machines from Europe and usually not upgraded.

Discharge of suspended solids are related to water consumption and to the performance of fibre recovery equipment. Closing of the mill system does not solve the problem of soluble substances causing BOD load, but reduced water consumption reduces suspended solids discharge. To implement a closed mill system with reduced water consumption requires good purification of white water and sufficiently large storage tanks are required.

Savings owing to reduced water consumption are the result of lower expenditure for fresh water collection and reduced costs for secondary effluent treatment. However extremely low water consumption causes corrosion and disturbances in the paper chemistry system due to increased content of ions and other undesirable substances. For some low quality paper grades from waste paper a nearly total closure is possible. Two such mills are in the Netherlands and Denmark.

Another requirement is a low carry-over of pollutants from the pulp mill i.e. a well washed pulp. Further chemical additives with good retention on fibres should be used e.g. cationic and not native starch.

3. ENERGY CONSERVATION IN PULP AND PAPER MANUFACTURE

Energy consumption is a complex process involving many aspects such as:
- selection of suitable equipment
- proper design of production line e.g. avoiding over-sizing of pumps, electric motors, drives, etc.
- optimization of energy distribution
- avoiding losses by steam leakage and no-load running of motors, etc.

Energy consumption is also a result of development of new processes and techniques with considerably lower energy demand. Only this aspect can be discussed as other aspects are beyond the scope of this study.

3.1. PULPING

Digestion (cooking) of lignocellulosic fibrous raw material (wood, straw) is a thermal process requiring to heat up fibrous raw material and the cooking liquor in a pressure vessel (digestor) is around 160 to 170°C either by direct steam or indirectly heating up the liquor in heat exchangers. Steam demand will depend on the material to liquor ratio and packing density of fibrous material in the digester. With straw the packing density is lower and liquor ratio usually higher resulting in a higher steam consumption. At the end of the digestion the pressure is relieved and temperature lowered to 130 to 140°C and the content is blown to a tank relieving pressure to the atmosphere. The heat content of the liquor is degraded to low pressure flash steam. In a modern continuous digester the high temperature liquor is displaced by washing water and the hot liquor is cooled down in a heat exchanger heating up the fresh cooking liquor and thus conserving high potential energy and reducing heat demand from 4 GJ/t to about 2 GJ/t of pulp and in a new type of digester even to a lower level. Such a system of energy conservation can be applied for batch cooking as well as by installing additional pressure vessels for displaced high temperature liquor, heat exchange etc.

The investment cost will depend on the available equipment in a mill and may be for a 200,000 ADT/a pulp mill in the range of $US 10 million to $US 20 million USD. Heat demand reduction is substantial and operation cost saving high resulting in a ROI of about 60 per cent and pay-back period of from 1.5 to 2 years depending on fuel prices [27]. It should be mentioned that old type simple horizontal tube continuous digesters used for straw and bagasse pulping do not have liquor displacement arrangements.

In a pulp mill without recovery in old type digesters the heat demand for cooking of wood is about 4.0 GJ/t of pulp and for straw about 5.0 GJ/t of pulp. In an old type mill recovery steam is produced by burning of black liquor reducing heat demand for cooking from 2 to 2.5 GJ/t of pulp.

The heat demand in bleaching can be lowered by reducing water demand as mentioned in a previous section. Electric energy demand can be lowered by shortening the bleaching sequence after oxygen pre-bleaching [21]. However, straw and bagasse bleach plants have always a short sequence (3 or 4 stages).

The overall energy balance for new and old wood pulp mills is presented in table 8.

TABLE 8. ENERGY BALANCE FOR NEW AND OLD PULP MILLS* USING WOOD

	New mill (GJ/t)	Old mill (GJ/t)
HEAT DEMAND		
Cooking and washing	1.0	4.0
Bleaching	0.8	1.5
Drying	3.0	3.5
Evaporation	2.8	4.0
Recovery boiler	0.9	1.0
Miscellaneous	0.2	0.5
TOTAL PROCESS	8.7	14.5
STEAM FROM IN-HOUSE FUELS		
Recovery boiler	15.0	14.0
Wood waste	3.0	2.0
TOTAL	18.0	16.0
These figures can be applied to a steam turbine CHP plant as follows:		
Back pressure turbine (kWh/t)	600	950
Heat for turbine	2.4	3.8
OVERALL STEAM BALANCE		
Process demand (GJ/t)	8.7	14.5
Turbine (GJ/t)	2.4	3.8
Total demand (GJ/t)	11.1	18.3
Own fuels (GJ/t)	18.0	16.0
Surplus/deficit	+6.9	-2.3

* Excluding the lime kiln.
Source: E. Jeffs, Pulp and Paper Int., 31 (6):85 (1989) [14].

This is a simplified view and actual possibilities in a specific mill will depend on fibrous raw material.

In outdated pulp mills the consumption is much higher. In two Indian mills using bamboo and hardwoods the heat demand for pulping is 7.4 and 10.7 GJ/t and for evaporation 6.8 GJ/t and 10.8 GJ/t respectively. This is due to low black liquor concentration and low number of evaporator effects. The total heat demand including bleaching and recovery is 18.3 GJ/t and 24 GJ/t respectively (IPPTA, March 1985).

3.2. PAPERMAKING

Papermaking from the energy consumption point of view is a process of removing water from the fibre slurry and fibre mat by filtration, suction by vacuum pressing and ultimately by drying. The bulk of the energy is consumed in drying (70 to 80 per cent). The more water that is removed by hydromechanic processes (filtration, suction, pressing) the lower the heat demand is for drying and the total energy demand, even if energy consumption in the wet part of the paper machine slightly increases. A good press section is a very important factor in energy conservation. Energy conservation in the drying section is also important. An open paper machine without a hood, or only partially enclosed and without heat recovery, has a substantially higher energy consumption. Different paper grades have also different energy consumption as seen from table 9.

TABLE 9. ENERGY CONSUMPTION BY PAPER GRADES

PAPER GRADE	1984 GJ/t	1973 GJ/t
Newsprint	5.9	7.8
Magazine	8.4	10.3
Liner	5.1	7.2
Sack paper	8.6	10.2
Fine paper	8.4	11.0

Source: 1987 EUCEPA Symposium Proceedings, EUCEPA, Paris, 1987 [28].

This table also shows the decrease in energy consumption in manufacturing various paper grades in developed countries. Energy consumption decreased from 1973 to 1984 by about 20 per cent.

Old paper mills have a much higher consumption, both electrical and heat energy. Such mills are usually in developing countries especially in the small paper mill sector. Table 10 shows the energy consumption in Indian mills (1984) as compared with German mills in 1973.

TABLE 10. COMPARATIVE ENERGY CONSUMPTION FOR PAPERMAKING IN INDIA (1984) AND GERMANY (1973) PER TONNE OF PAPER

Country Type of mill	Paper grade	Power kWh/t Stock preparation	Power kWh/t Paper machine	Total	Steam GJ/t
INDIA					
Medium mill 1	Kraft bleached	280	470	750	10.9
Medium mill 2	Kraft bleached	130	550	680	8.2
INDIA					
Small mill	Wrapping			816	9.0
Small mill	White offset			889	9.8
GERMANY					
Woodfree		250	450	700	6.6
Packaging		225	406	631	6.0

Source: IPPTA, New Delhi, 22(1): (1985) [29].

An example of an important development is improvement of paper web presses. Modern presses increase the dry content of wet paper by 5 to 10 per cent as compared with conventional presses. This makes it possible to reduce steam consumption by 15 to 25 per cent, such presses are especially efficient in liner or corrugating medium manufacture and are useful also for light paper grades.

4. EMERGING TRENDS IN TECHNOLOGY DEVELOPMENT

New pulping (cooking) methods

The trend is to reduce residual lignin in pulps by extended delignification (modified cooking). In this way active chlorine demand and the formation of organic chloride compounds during bleaching stages are reduced.

Another trend is to minimize sulphur in alkaline pulping of wood to reduce malodorous sulphur emissions. A development is expected in the improvement of catalysed delignification with a more efficient catalyser as antraquinone.

An alkali-oxygen process for pulping of straw is emerging. This uses sodium carbonate and caustic soda as cooking agent together with oxygen. Caustic soda should be used as a make-up chemical only, resulting in a recovery without causticizing [30]. A similar process is being developed for other non-wood fibrous raw materials [31].

Organosolv pulping may be also developed on a commercial scale. Lignin dissolved in organic solvents may be used as by-product.

Pulp washers

It is anticipated that belt washers will be further improved to suit straw pulp washing which has poor drainage properties. Thus a higher concentration of black liquor and less fibre losses may be achieved.

Simplified small scale chemical recovery unit

Two trends are emerging:

- simplified recovery furnace for small capacities
- recovery using amphoteric oxides, mainly ferric oxide binding alkali during burning of black liquor. The sodium ferrite is hydrolyzed to NaOH and ferric hydroxide. Burning of black liquor mixed with ferric oxide in a fluidized bed has not been successful on an industrial scale. Development is continuing i.a. in a pilot plant in India under a UNIDO/UNDP-Goverment of India project. A furnace or rotary smelter may be a solution.

Simplified oxygen bleaching for agricultural residues bleaching

At the present time possibilities are being explored to use simple hydrostatic pressure oxygen reactors for bleaching of straw pulp. This may partly exclude chlorine from bleaching.

Bio-bleaching

Xylanase is active in cleavage of lignin - cellulose bonds making lignin more accessible in bleaching. This process is being studied in order to reduce chlorine in bleaching. High temperature in tropical countries may be beneficial for the process.

Chlorine-free or chlorine reduced bleaching

New sequences applying oxygen pre-bleaching. peroxide and ozone. will reduce or exclude chlorine.

Improving drainability of straw pulp on the paper machine

New retention and drainage aids may increase capacity of paper machines which is at present low when especially using rice straw.

SECTION II

1. ENVIRONMENTAL REQUIREMENTS FOR ACHIEVING ECOLOGICALLY SOUND INDUSTRIAL DEVELOPMENT(ESID)

In the previous section an array of technologies and processes has been presented which make possible the harmony of pulp and paper manufacture with the environment. Most of the options presented are already established technologies. Some are emerging alternatives which may be implemented gradually.

1.1. WATER POLLUTION LIMITS

Water pollution is of primary interest in most countries. In the USA the Environmental Protection Agency (EPA) has established technology-based regulations on various levels without any consideration to the absorbing capacity of receiving waters on grounds that most advanced regulations can be introduced only gradually. The main levels are as follows [32].

Best practicable control technology currently available (BPT):
Based on the average of the best existing performance of direct discharges in the industry. BPT is generally the first stage or baseline regulation for an industry.

Best available technology economically achievable (BAT):
Represents the best existing performance in the industry controlling the direct discharge of toxic and non-conventional pollutants. BAT is the second stage of regulation for these pollutants.

Best conventional control technology (BCT):
Control of the direct discharge of conventional pollutants in the second stage of regulation.

New source performance standards (NSPS):
Based on best available demonstrated technology and apply for new direct discharging facilities. All pollutants are controlled.

Pulping produces a large amount of oxygen consuming substances resulting in high BOD and COD. By applying modern technology BOD and COD can be reduced to a minimum. Fibre loss expressed as total suspended solids is also important. The current EPA (1988). BPT and NSPS standards for BOD and total suspended solids (TSS) for bleached kraft (sulphate) wood pulp are given in the tables 11 and 12.

TABLE 11. CURRENT BPT AND NSPS STANDARDS FOR BOD AND TSS IN USA (1988)

	Max 30 day average				Max per day			
	BOD		TSS		BOD		TSS	
	BPT	NSPS	BPT	NSPS	BPT	NSPS	BPT	NSPS
Bleached kraft market pulp	8.05	5.5	16.4	9.5	15.45	10.3	30.4	18.2
Bleached kraft fine papers	5.5	3.1	11.9	4.8	10.6	5.7	22.15	9.1
in kg/t/90 wood pulp (air-dry pulp)								

Source: J. Folke, Regulatory Requirements for Pulp and Paper Mill Effluent Limitations, COWI Consult, Denmark, 1989 [33].

Practically achievable levels are dependent on raw material used and technology applied. The Spanish BCT and BAT Standards specify besides wood pulp also straw pulp effluents for various technologies as presented in table 12.

TABLE 12. RECOMMENDED SPANISH STANDARDS
kg/t/90

	BCT				BAT			
	Max 30 day		Max per day		Max 30 day		Max per day	
	BOD	TSS	BOD	TSS	BOD	TSS	BOD	TSS
Wheat straw corrugated paper	70.0	5.5	140.0	11.0				
Wheat straw pulp integrated production					5.0	3.5	10.0	7.0

Source: J. Folke: Regulatory Requirements for Pulp and Paper Mill Effluent Limitations, COWI Consult, Denmark, 1989 [33].

In India, the Central Board for the Prevention and Control of Water Pollution issued Minimum National Standards in 1985 presuming biological waste water treatment (see annex I). A review of standards up to 1980 is shown in UNEP publication [13].

In France, pollution standards for pulp mills date back to 1972, but actual waste water discharge permits are generally more strict.

Besides BOD, COD and TSS limits for organically bound chlorine are also considered. There have been contradictory results and views regarding toxicity of bleach waste water containing organically bound chlorine. A recent comprehensive work in Sweden confirmed toxicity of these effluents [19].

The effluent from a conventional C(95+D05)EDED bleach plant showed strong biological effects after 166 times dilution with low survival of fish fry, decreased invertebrate density, and parasitic infestation of stationary fish species. Even with dilution of over 5.000 times it was determined that all these effects could be found, although to a substantially decreased degree.

The addition of an oxygen stage or an aerated lagoon significantly decreased the intensity and extent of these effects. However, some mild effects could still be detected after 2,000 times dilution. The combination of oxygen delignification with either high chlorine dioxide substitution or with an aerated lagoon substantially decreased the effluent effects, but mild effects could still be observed after 500 to 1,000 times dilution.

Based on these results 4 levels of AOX kg/t/90 of sulphate pulp have been laid down in a tentative action plan in Sweden [34] as indicated in table 13.

TABLE 13. TENTATIVE ACTION PLAN IN SWEDEN FOR AOX (kg/t/90) DISCHARGE IN SULPHATE PULP MANUFACTURING

		kg AOX/t/90	Expected implementation
			year
Basic level	softwood	2	1992
	hardwood	1	
Level I	softwood	1	1995-1998
	hardwood	0.5	
Level II	softwood	0.5	2000-2005
	hardwood	0.3	
Level III	softwood	0.1	2010
	hardwood		

Source: N. Jirvall, Environmental Conference 'The sustainability of the Australian pulp and paper industry', APPITA, 1990 [34].

The basic level has to be reached by 1992. The basic level can be achieved by introduction of oxygen pre-bleaching, chlorine substitution by chlorine dioxide and biological treatment. Higher levels will require introduction of new technologies such as ozone bleaching, i.e. bleaching without elementary chlorine. However some authors consider the value AOX 1 kg/t as already sustainable [34].

Dioxins (TCDD and TCDF) are in very low quantities in bleach effluent, and the amount is only a small fraction compared to other industries. Dioxins can be actually eliminated by oxygen bleaching and good washing of pulp. In Australia, the limit for new eucalyptus mills is 5 ppt of Dioxin 2,3,7,8, TCDD per tonne of pulp (see annex II).

The proposed standards for non-integrated paper mills in Germany and France are very strict and detailed [33].

TABLE 14. PROPOSAL FOR NEW EMISSION STANDARDS FOR GERMAN PAPER MILLS

	TSS	COD	BOD/$_5$		NH3-N^a	Tot-p^b	AOX^c
	mg/l	kg/t	kg/t	mg/l	mg/l	mg/l	kg/t
Uncoated fine paper	50	3	1	-	10	3	0.04
Coated fine paper	50	6	2	-	10	3	0.04
Tissue	50	9	3	-	10	3	0.04
True pergament	50	12	6	-	-	3	0.025
White board	-	2	-	25	10	3	0.02
Integrated groundwood	-	3	-	25	10	3	0.01
if >50% TMP is used	-	5	-	25	10	3	0.01
Wastepaper	-	5	-	25d	10	3	0.012

Source: J. Folke, Regulatory Requirements for Pulp and Paper Mill Effluent Limitations, COWI Consult, Denmark, 1989 [33].

a For effluents exceeding 500m^3/d
b For effluents exceeding 1000 m3/d
c In special cases this value enlarges to 0.12 and 0.2 kg/t90
d if water used is lower than 103m^3/t the limit is 0.25 kg/t up to a maximum of 50 mg/l.

French emission standards for the larger paper mills (>60 t/d) are from 1989 and operate on six different classes depending on the relative amounts of virgin/secondary fibres used and the quality of products (coating and additives used). Furthermore, the standards are different for new mills and existing mills, i.e. existing mills have a five year period to adapt to new standards. table 15 [33].

TABLE 15. EMISSION STANDARDS FOR PAPER MILLS IN FRANCE (kg/t/90)

	New installations	Old installations
TSS	0.7	1.5 - 1.9
BOD$_5$	0.7 - 1.4	1.0 - 2.0
COD	2.5 - 4.0	4.0 - 8.0

Source: J. Folke, Regulatory Requirements for Pulp and Paper Mill Effluent Limitations, COWI Consult, Denmark, 1989 [33].

1.2. ACTUAL WATER POLLUTION SITUATION

The effluent limitations are rather stringent but a mill with a medium level technology and good management can meet these requirements. A short description of a mill in Czechoslovakia (North Slovakian Pulp and Paper Mills, Ruzomberok) is presented in the following paragraphs. The pulp mill was erected in 1979-1980 by Canadian suppliers. The mill is currently producing 222,000 ADT/a of kraft unbleached pulp from softwoods and mixed hardwoods alternatively on the same production line. The wood is unbarked in dry drums. The mill has conventional batch digestors with computer control. The pulp is washed in 3-stage drum filters (Na_2SO_4 losses of 6.0 to 7.0 kg/ADT). The recovery boiler has a capacity of 47.2 t of dry solids.

The major part of the pulp is bleached by a C/D-E-D-E-D sequence producing 170.000 ADT/a softwood and hardwood bleached pulp. 22.500 ADT/a of softwood pulp is used as unbleached. The water consumption in bleaching is about 40 to 50 m^3/t. The effluent from the pulp mill is treated in an activated sludge treatment plant together with municipal effluent. The efficiency on BOD is about 80 to 90 per cent for the mixed effluent. The heat consumption in the pulp mill is 19.5 GJ/ADT. The bark is burned in a boiler together with heavy fuel oil and natural gas. Evidently it is a medium level mill with a comparatively high heat demand.

The effluent discharges are as follows:

		Before biological treatment		After treatment (estimate)
BOD_5	kg/t air dry pulp	26.2	5.24	(80% efficiency)
COD	kg/t air dry pulp	145	72	(50% ")
TSS	kg/t air dry pulp	35.0	10.5	(70% ")

Taking into consideration the minimum efficiency of the activated sludge treatment the mill is within the limits of US-EPA BPT standards. Fibre losses are high most probably due to hardwood pulp. The pulp mill is partly integrated with a paper mill producing 76,500 t fine paper and foodboard. The BOD discharges are about 2 to 2.4 kg/t and TSS about 6 kg/t. BOD discharges are high, as undried pulp is used from the pulp mill. The effluent is discharged directly to the river increasing total BOD discharges (together with pulp effluent) from 7.2 to 7.6 kg/t which is slightly over the BPT limit.

Most advanced mills can achieve the NSP limits as BOD is decreased when using oxygen-bleaching. The situation is more difficult in developing countries. A new, modern, high capacity mill recently rebuilt in Brazil (e.g. Suzano mill) or in Indonesia (Indah Kiat mill) using very modern equipment and technology can fulfil BPT and even NSPS standards. However old type mills with poor efficiency of chemical recovery and small mills without recovery capacity are discharging large quantities of polluting substances (see annex III). Certain old mills with chemical recovery are discharging 60 to 90 kg BOD/t of pulp. Even with activated sludge treatment it is unlikely that these mills can meet stringent standards. Small mills are even in a more difficult situation as they discharge a total volume of black liquor with a BOD load of 220 to 280 kg/t of paper. However, in a given locality the impact of an old type 100 to 150 t/d mill with recovery or a small mill of 10 to 20 t/d is not necessarily higher than that of a very large modern mill with 1,000 to 1,500 t/d. It depends on the absorbing capacity of the receiving waters whether such a load is acceptable. Nevertherless, the ultimate goal is to improve recovery efficiency in medium size mills and to develop a suitable recovery as well as implement biological treatment to prevent oxygen-deficiency in receiving waters.

1.3. MEASURES TO REDUCE WATER POLLUTION

The largest source of polluting substances is the cooking operation. Evidently the most important measure to reduce water pollution is a proper extraction, collection, evaporation and burning of cooking waste black liquor including recovery of chemicals. The most expensive part of the recovery system is the recovery furnace.

A furnace with a capacity of 200.000 to 300.000 ADT/a of pulp is about $US 60 million to $US 90 million. This represents about 10 to 14 per cent of the total investment costs for a big new 'greenfield mill'. The costs are even higher for a small pulp mill. In China, the costs of a recovery system for a 10.000 t/a pulp mill are estimated to be $US 4.5 million (in 1989) [4]. In India, the fixed cost estimates of a recovery system for a 50t/d (about 15.000 t/a) pulp mill including desilication are estimated to be $US 6.6 million to $US 7.2 million [35,36]. The economy of such an investment depends mainly on caustic soda prices. In Europe, in 1988 the NaOH price was about $US 210 per tonne, in the USA in 1989 it was $US 330 to $US 360 per tonne. The caustic soda prices in India are extremely high (nearly Rs 10,500 per tonne i.e. $US 560 per tonne). Annual costs of caustic soda for a 50 t/d pulp mill are about 50 million Rs ($US 2.75 million to $US 2.80 million per year). At a recovery efficiency of 75 per cent, savings in purchased caustic soda will be about $US 2.0 million per year. Actual savings will be less owing to cost of lime for causticizing, operation costs of desilication and recovery plant. Nevertheless an acceptable pay-back period is anticipated.

Black liquor incineration and chemical recovery substantially reduces the amount of polluting substance, but cannot ensure limits of BOD discharge. A biological treatment is required. Aerated lagoons and activated sludge treatment are frequently used in advanced pulp mills. The retention time in aerated lagoons is usually 3 to 10 days but in extreme cases up to 30 days [37]. The BOD reduction rate is 50 to 75 per cent and in some Finnish plants during summer it is from 85 to 90 per cent. The retention time in activated sludge treatment is 2 to 18 hours. Average BOD reduction rates are 85 to 95 per cent, COD reduction is about 50 per cent. AOX values are reduced at a rate of 40 to 60 per cent and chlorinated phenolics from 60 to 95 per cent. Aerobic biological treatment produces a large amount of sludge which is dewatered on filter or screen presses from 25 to 37 per cent and at least partly burned in a bark-fired boiler disposed of in land filling. The weight of sludge is about 0.09 kg solids per kg of BOD removed. The activated sludge process is successfully used e.g. in an Indian rayon pulp mill [38] with a BOD reduction rate of over 90 per cent, a COD rate of over 50 per cent and TSS reduction rate of about 70 per cent.

Cost comparison between activated sludge and aerated stabilization basin for a 270,000 ADT/a greenfield mill shows the following data (prices USA, I-Quarter 1988):

		Activated sludge	Aerated stabilization basin
Capital costs	$US/	39,770,000	27,159,000
- per t of pulp	$US/adt	147	100
Operating cost assuming 10 % interest and 20 years of pay-back	$US/adt	17	12
Operating cost per t of pulp	$US/adt	11	6
Total	$US/adt	28	18

The increase in the pulp operation cost is expected to be in the range of 7 to 9 per cent and 4 to 6 per cent for activated sludge treatment and aerated stabilization basin, respectively. This percentage however will depend very much on the mill characteristics.

The operating costs are in accordance with estimates in India [38]. Investment costs for a 50 ADT/d pulp mill are estimated to be Rs 12 million (about $US 660,000) i.e. about $US 47 per tonne of pulp [35, 36]. This is in accordance with an installation mentioned earlier [38]. The investment and operation costs are considered as too heavy a burden and the use of waste liquor for irrigation in agriculture is recommended [26]. In India, the tolerance limits for effluent for irrigation are specified in Indian Standard ISI No 3307/1977. A similar good experience with irrigation using pulp mill waste water is found in Indonesia.

In some cases anaerobic treatment can be used. Under anaerobic conditions carbohydrates are converted to methane, but lignin is not affected. This method is used in a Spanish mill producing high yield pulp by the soda process from wheat straw and together with waste paper corrugating medium. The black liquor and paper mill waste water are treated in 2 simple void reactors. The retention time is seven days. The BOD reduction rate is about 95 per cent, COD rate is 60 to 65 per cent. About 0.142 m^3 methane per 1 kg COD reduction is produced. Such an investment is profitable as with an investment of about $US 4 million, the profit from methane production is about $US 1 million per year in 1983 prices [39]. The advantage of anaerobic treatment is the low amount of sludge but the process is more sensitive.

Neither aerobic nor anaerobic treatment affects lignin and colour. This can be reduced by oxygen bleaching or by precipitation into effluents. This alternative is expensive.

A lower brightness paper is the cheaper way to reduce the discharge from bleaching plants, it will not eliminate the problem but may be a step in the right direction.

1.4. MEASURES TO REDUCE AIR POLLUTION

Particulate emission from recovery boiler (mainly Na_2SO_4), sulphur dioxide and total reduced sulphur compounds (hydrogensulphide, mercaptan, methyl- dimethylsulphide) are problems in sulphate pulping. Finnish limits are some of the problems given in annex IV. The SO_2 in Finland is limited to 4 kg/t of pulp in new installations since 1.7.1987 and to 6.0 kg/t in old installations (up to 31.12.1987). Swedish new guidelines limit total sulphur emissions to 1.5 kg/t of pulp. In Czechoslovakia individual TRS compounds are limited as follows:

	Conc. outside atmosphere	
	kg/m^3 daily	kg/m^3 max.
Hydrogen sulphide	8.0	8.0
Methylmercaptane	0.2	0.4
Dimethylsulphide	1.0	2.0
Dimethyldisulphide	0.1	0.2

As mentioned earlier regarding the pulp mill in Czechoslovakia condensates from digestor and evaporation plants are stripped in a column and burned with all concentrated TRS compounds in the bark boiler. To avoid escape of malodorous compounds during shutdown of the boiler a MODO emergency incinerator was installed (about $US 1 million). Diluted gases are at the present time vented into the atmosphere, but a collection system is being installed. The total SO_2 emissions including bark boiler are 13.19 kg/t of pulp. However, the main part (80 per cent) is from the bark boiler. Without this the SO_2 emissions are 2.38 kg/t. TRS emissions as sulphur are 0.27 kg/t of pulp.

SECTION III

BARRIERS

An array of technologies is available to meet environmental requirements but there are still some technical and economical barriers:

In wood pulping almost all stringent limits can be met by implementing modern technology. However discharges of chlorinated organic compounds from bleaching and malodorous sulphur compound emissions from kraft pulping cannot be reduced by available technology to meet stringent ESID norms. It is expected that by the year 2000, bleaching discharges will be at a sustainable level.

In agricultural residues pulping (straw, bagasse) clean production options are more limited due to specific properties of these raw materials e.g. high silica content and not all clean production options developed for wood pulping are applicable to agricultural residues pulping. Consequently in the next decade it will not be possible to reduce e.g. BOD and suspended solids discharges as drastically as with wood pulping.

Most important are the economic barriers. In a modern, large scale pulp mill combustion of pulping waste black liquor and recovery of chemicals requires about 30 per cent of total investment cost. Modern 'greenfield' mills spend about 20 per cent of total investment costs for environmental protection. These investments are absent in small pulp mills. To implement these clean production options would double investment costs as compared with a mill without recovery, biological treatment of effluents, etc.

These clean production options have been developed mainly for large mills and scaling down would result in lower efficiency such as heat consumption and chemical recovery efficiency. It would also increase relative investment cost per tonne of pulp. In China, the budget for a recovery system in a 10,000 t/a mill is estimated to be $US 4.5 million. In many cases, small mills cannot afford such an investment [4].

Serious economic barriers are the regulations pertaining to import duty on imported equipment in some developing countries. In India, import duty for paper machinery is 40 per cent. There are similar restrictions in Brazil. Shortage of convertible currency is also a limitation as most modern clean production technologies and equipment have to be imported from Europe, North America or Japan.

The pulp and paper industry is a capital intensive industry. A large pulp mill of 200,000 to 300,000 t/a pulp will cost about $US 340 million to $US 450 million. Such a mill will meet present environmental norms and will be in a position to adjust to even more stringent ESID norms at the expected level by the year 2000. To finance such a greenfield mill in developing countries requires international financing. Such a mill gives less employment opportunities than small mills. These two barriers will prevent implementation of clean production options available in large mills for the next 10 to 20 years.

Some countries e.g. India. give tax incentives to small mills to promote employment.

International lending institutions, such as the International Finance Corporation (IFC), the World Bank, would only finance projects which meet environmental guidelines. This also could be a barrier mainly for small mills until new economically sound technologies for such mills can be developed. To close down a mill because of poor environmental performance could be a social problem for developing countries. Maybe a partial solution could be to transfer pulping capacity from the small pulp mills to large units with recovery systems, and use the small ex-pulp mills for conversion to paper.

Price fluctuations of chemicals such as caustic soda and chlorine may act against implementation of clean production options. As caustic soda prices increase more rapidly than chlorine some mills have the tendency to reduce caustic soda charges thus increasing residual lignin content and using more chlorine in bleaching.

It can be concluded that varying raw material properties in developing countries and high investment costs are the main barriers to implementation of clean production options.

SECTION IV

INDUSTRY

Despite financial and technical difficulties in implementing clean production options the industry in many developing countries has improved the environmental situation. In India, evaporation and combustion of black liquor and recovery of chemicals from bamboo pulping has been solved even if the bamboo contains a high amount of silica. In fact in India most of the pulp production is manufactured in mills with recovery. In China, recovery furnaces have been developed for medium pulp mills and the number and production of mills using recovery is increasing. The annually recovered caustic soda increased by 30 per cent between 1982 and 1987. In South America bagasse mills have alkali recovery. In North Brazil a Broby-type smelter was introduced in a mill using bagasse.

Large new mills e.g. the Indah Kiat mill in Indonesia and the Suzano mill in Brazil have applied new technologies such as displacement cooking thereby saving energy and oxygen bleaching. The Carton Colombia mill implemented a non-pressurized SIMPLOX oxygen pre-bleaching stage. Hindustan Newsprint in Kerala (India) is testing, on a commercial scale, desilication developed by UNIDO/SIDA together with the Central Pulp and Paper Research Institute, India.

Apparently valuable experience has been gained in industry in developing countries and this information should be disseminated. Industry should be encouraged to implement better pulp washing equipment and oxygen bleaching in straw and bagasse pulping.

SECTION V

GOVERNMENT

Government has an important role to play in environmental protection and can bring about changes by issuing environmental standards, supporting environmental measures and by tax incentives or direct subsidies. Most countries have issued such standards. In India there are three specific terms of legislation:

The Water Prevention and Control of Pollution Act of 1974 and The Air Prevention and Control of Pollution Act of 1981 and a comprehensive legislation of the Environmental Protection Act, 1986. The Indian Central Board for Prevention and Control of Water Pollution issues standards. The Government Institutes, NEERI (National Environmental Engineering Institute), and the Central Pulp and Paper Research Institute, are conducting research in environmental protection. Similar government supported institutes are found in China, Myanmar, Indonesia, and other countries.

Government tax incentives or subsidies support environmental projects in India and other countries.

It is suggested, that governments co-ordinate environmental protection guidelines and limits and concentrate on all aspects, such as

- limiting discharge of BOD and TSS
- setting acceptable levels for organic chlorinated compounds
- setting limits for air pollution.

The environmental guidelines should be realistically attainable to avoid closing down mills and generating social problems.

Tax incentives and direct subsidies should preferably support projects with the maximum positive environmental impact.

The Government programme should provide a progressive approach for existing mills giving them time to attain the limits. Furthermore assistance and support to research institutions in their search for appropriate effluent disposal technologies should be an integral part of the Government programme.

SECTION VI

INTERNATIONAL CO-OPERATION

UNIDO and FAO have supported and upgraded research centres and institutes in India, Indonesia, Myanmar, Thailand, the Philippines and other countries. These institutes are conducting research in environmental protection. Some specific projects supported by UN Agencies and national assistance agencies are:

- Desilication project executed jointly by UNIDO, SIDA and the Central Pulp and Paper Research Institute, India;

- A UNIDO and Government of India project chemical recovery (pilot) plant for small pulp mills using non-wood raw materials

- A UNIDO supported project in India focused on energy saving etc.

- Seminars have been organized by UNIDO and UNEP in Bangkok (1985) and Beijing (1988. 1989) focusing on new technologies and environmental protection when using non-wood materials;

Assistance of UNIDO in the following areas is suggested:

- Continuation of testing and development of a recovery system for small pulp mills;
- Adaptation of oxygen bleaching to non-woody materials in small pulp mills;
- Improvement of washing of non-wood pulp;
- Fibre recovery in processing non-wood pulp to reduce TSS losses;
- Improvement of fibre retention in non-wood pulp papermaking;
- Intensification of biological waste water treatment in tropical conditions;
- Extended delignification of non-wood raw materials;
- Non-sulphur carbonate-caustic soda pulping of straw with simple recovery;
- Transference of technology between countries through TCDC, co-operation North-South;
- Dissemination of information between developed and developing countries;
- Energy and water savings in existing mills;
- Establishment and strengthening of research centres for the develoment of appropriate effluent disposal technologies;
- Human resources development.

SECTION VII

CONCLUSIONS

At present clean production options are available for wood pulp manufacture especially for BOD and COD and TSS discharges. The situation is still not satisfactory regarding reduced discharges of chlorinated organic compounds. A suitable technology will be developed probably by the year 2000. However this will increase production costs. Less optimistic is the outlook regarding malodorous sulphur compounds in kraft pulping.

The main barriers in implementation of clean production technology in developing countries in order of importance are:

- different properties of non-wood fibrous raw materials used in developing countries making environmental measures less effective when compared with wood pulping;
- high investment costs of clean production technologies;
- difficulties in scaling down clean production technologies to small pulp and paper mill level;
- high import duty in some countries for equipment.

To overcome these technical barriers further UNIDO assisted research is required. To overcome financial problems Government support in the form of tax incentives or direct subsidies and import duty exemptions is desirable.

ANNEX I - EFFLUENT STANDARDS FOR PULP AND PAPER INDUSTRIES IN INDIA

(Ref.: Minimal national standards small pulp and paper mills. Comprehensive Industry Document Series: COINDS/23/85, Central Board for the Prevention and Control of Water Pollution, 1985)

Parameter	Permissible Limit Without Recovery	 With Recovery
Wastewater discharges (m^3/t)	200 (pulp and paper)	50 (Waste paper)
pH	6.5. - 8.5.	6 - 9
Suspended Solids (mg/l)	100	100
BOD_5 (mg/l)	30	50
COD (mg/l)	350	--
Implementation date for water quantity	Dec.1990	Dec,1993 (10 % reduction each year)

In the future a limit will also be put on the discharge of:
- TOCl (Total Organic Chlorine Compounds)
- AOX (Absorbable Organic Halides)
- colour.

ANNEX II

AUSTRALIA: EMISSION STANDARDS FOR NEW BLEACHED EUCALYPTUS KRAFT PULP MILLS

Discharge opacity (% obscuration)	
Recovery boiler	35
Other boilers	20
Lime kiln, rotary	10
Lime kiln, other	20
Final discharge particulates (mg Nm^3)	
Recovery boiler at 12 % CO_2	150
Lime kiln at 10 % CO_2	150
Power boiler at 12 % CO_2	225
Sulphuric acid mist and sulphur trioxide measured as SO_3	200
Total reduced sulphur measured as H_2S (mg/Nm^3, continuous 12-h moving average)	
Recovery boiler at 8 % O_2	5
Lime kiln at 10 % O_2	10
Hydrogen chloride (mg/Nm^3)	400
Chlorine and chlorine compounds other than hydrochloric acid (mg/Nm^3)	200
Total suspended solids (kg/adt of pulp)	8
BOD_5, one day maximum (kg/adt)	7
Organochlorines measured as absorbable organic 5halide (AOX) (kg/adt)	
Yearly moving average	1
Based on any one test	2.5
Dioxin 2,3,7,8 TCDD (parts per trillion)	5
Oil and grease	no visible contamination

Source: Pulp and Paper Int., 32 (3):45 (1990).

ANNEX III EFFLUENT FROM LARGE MILLS IN INDIA

Large mills (wood based) Kraft	Capacity (TPD)	Effluent (m^3/t paper)	Suspended solids (ppm)	BOD (ppm)	BOD/Load (kg/t)
Mill 1	200	315	200-500	80-350	99
Mill 2	150	450	400-700	200-250	91
Mill 3	120	270	400-600	200-300	60

EFFLUENT FROM SMALL MILLS IN INDIA

Small mills (Straw based)	Capacity (TPD)	Effluent (m^3/t paper)	Suspended solids (ppm)	BOD (ppm)	BOD/Load (kg/t paper)
Mill 1 (Bleached)	30	320	800-1000	600-800	224
Mill 2 (Bleached)	40	400	600-800	800-1000	280

Source: IPPTA, 21(2), (1984), p. 26.

ANNEX IV AIR QUALITY GUIDELINES - FINLAND

Substance		Max. concentration
Sulphur dioxide	year	40 ug/m^3
	day	200 ug/m^3
	hour	500 ug/m^3
Particulates	year	60 ug/m^3
	day	150 ug/m^3
Nitrogen dioxide	day	150 ug/m^3
	hour	300 ug/m^3
Carbon monoxide	8 hours	10 ug/m^3
	hour	30 ug/m^3

Source: Ministry of the Environment, Finland, 1986.

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