

Environmental, Health, and Safety Guidelines

Pulp and Paper Mills

Introduction

The Environmental, Health, and Safety (EHS) Guidelines are technical reference documents with general and industry-specific examples of Good International Industry Practice (GIIP)¹. When one or more members of the World Bank Group are involved in a project, these EHS Guidelines are applied as required by their respective policies and standards. These industry sector EHS guidelines are designed to be used together with the **General EHS Guidelines** document, which provides guidance to users on common EHS issues potentially applicable to all industry sectors. For complex projects, use of multiple industry-sector guidelines may be necessary. A complete list of industry-sector guidelines can be found at: www.ifc.org/ifcext/enviro.nsf/Content/EnvironmentalGuidelines

The EHS Guidelines contain the performance levels and measures that are generally considered to be achievable in new facilities by existing technology at reasonable costs. Application of the EHS Guidelines to existing facilities may involve the establishment of site-specific targets, with an appropriate timetable for achieving them.

The applicability of the EHS Guidelines should be tailored to the hazards and risks established for each project on the basis of the results of an environmental assessment in which site-

specific variables, such as host country context, assimilative capacity of the environment, and other project factors, are taken into account. The applicability of specific technical recommendations should be based on the professional opinion of qualified and experienced persons. When host country regulations differ from the levels and measures presented in the EHS Guidelines, projects are expected to achieve whichever is more stringent. If less stringent levels or measures than those provided in these EHS Guidelines are appropriate, in view of specific project circumstances, a full and detailed justification for any proposed alternatives is needed as part of the site-specific environmental assessment. This justification should demonstrate that the choice for any alternate performance levels is protective of human health and the environment.

Applicability

The EHS Guideline for Pulp and Paper Mills includes information relevant to pulp and paper manufacturing facilities including wood-based chemical and mechanical pulping, recycled fiber pulping, and pulping based on non-wood raw materials such as bagasse, straw, and reed. It does not include production or collection of raw materials which are addressed in other relevant EHS Guidelines. Annex A contains a description of industry sector activities.

This document is organized according to the following sections:

Section 1.0 — Industry-Specific Impacts and Management
Section 2.0 — Performance Indicators and Monitoring
Section 3.0 — References and Additional Sources
Annex A — General Description of Industry Activities
Annex B — Effluents and Emissions Guidelines / Resource Use Benchmarks

¹ Defined as the exercise of professional skill, diligence, prudence and foresight that would be reasonably expected from skilled and experienced professionals engaged in the same type of undertaking under the same or similar circumstances globally. The circumstances that skilled and experienced professionals may find when evaluating the range of pollution prevention and control techniques available to a project may include, but are not limited to, varying levels of environmental degradation and environmental assimilative capacity as well as varying levels of financial and technical feasibility.

1.0 Industry-Specific Impacts and Management

The following section provides a summary of EHS issues associated with pulp and paper mills, which generally occur during the operational phase, along with recommendations for their management. Recommendations for the management of EHS issues common to most large industrial facilities during the construction, operation and decommissioning phases are provided in the **General EHS Guidelines**.

1.1 Environment

The more significant environmental aspects of pulp and paper mills during the operational phase relate to:

- Wastewater
- Air emissions
- Waste
- Noise

Wastewater

Pulp and paper manufacturing activities may generate wastewater discharges at a rate of 10-250 cubic meters per metric ton (m³/t) of product. Product is measured as air dry pulp (ADP²) in pulp mills, and as weight of paper sold in paper and board mills. Prior to treatment pulp mill effluents are high in total suspended solids (TSS; mainly from cooking and pulping process screening, washing, and bleaching stages as well as from debarking residue, chemical recovery inorganics and fillers); biochemical oxygen demand (BOD) chemical oxygen demand (COD) and dissolved organic compounds mainly arising from wet debarking cooking/pulping, screening, washing, bleaching, and chemical recovery plant liquor spills). Bleach plant effluents may include PCDD (poly chlorinated

² Air dry pulp refers to pulp that is 90% dry.

dibenzodioxins) and PCDF (poly chlorinated dibenzofurans), commonly referred to as chlorinated dioxins and furans. When Elemental Chlorine Free (ECF) or Total Chlorine Free (TCF) bleaching technologies are used, the concentrations of dioxins and furans in the effluents are below the detection limits.³

Among the sources of nitrogen and phosphorus compounds released into wastewaters, and potentially contributing to eutrophication of receiving waters, is the wood raw material which is also a source of resin acids. Resin acids, especially those based on coniferous wood pulp, can be toxic to fish and benthic invertebrates. Chlorinated phenols can be produced by elemental chlorine based bleaching of pulp.

Other issues related to wastewater discharges may include fish tainting, color related to COD content and discharges of black liquor, pulp spills from overflowing tanks, and runoff from log yards. This last source may contain toxic chemicals (such as tannins, phenols, resins, and fatty acids) leached from the timber, and soil and other materials washed out of the bark

Wastewater Management – General

Information about water conservation strategies applicable to most industrial facilities, which may contribute to the reduction of wastewater streams, is provided in the **General EHS Guidelines**. Industry-specific wastewater prevention strategies potentially applicable to most pulp and paper manufacturing processes are presented below. Recommended wastewater prevention and control methods include the following:

³ Of the chemicals listed in Annex C of the Stockholm Convention, only PCDD and PCDF have been identified as being produced during the production of pulp using elemental chlorine. Of the 17 PCDD/PCDF congeners with chlorine in the 2,3,7 and 8 positions, only two congeners – namely 2,3,7,8-TCDD and 2,3,7,8-TCDF – have been identified as potentially being produced during chemical pulp bleaching using chlorine. Most of the formation of the 2,3,7,8-TCDD and 2,3,7,8-TCDF is generated in the C-stage of bleaching via the reaction of chlorine with precursors of TCDD and TCDF (UNEP, 2006).

- Dry debarking of wood;
 - Systems for collection and recycling of temporary and accidental discharges from process water spills;
 - Sufficient and balanced volumes of pulp storage, broke storage and white water storage tanks to avoid or reduce process water discharges;
 - Recycling of wastewater, with or without simultaneous recovery of fibers (using filters or flotation plants);
 - Separation of contaminated and non-contaminated (clean) wastewaters with collection and reuse of clean non-contact cooling waters and sealing waters;
 - Potentially contaminated stormwater includes runoff from log and wood handling areas, process equipment, building roofs and areas immediately around the mill process areas. This should be combined with process effluent for treatment.
- Reducing application of elemental chlorine by decreasing chlorine multiple or increasing the substitution of chlorine dioxide for molecular chlorine
 - Minimizing precursors such as dibenzo-p-dioxin and dibenzofuran entering the bleach plant by using precursor-free additives and thorough washing;
 - Maximize knot removal
 - Eliminating pulping of furnish contaminated with polychlorinated phenols
- Removal of hexenuronic acids by mild hydrolysis for hardwood pulp, especially eucalyptus;
 - Collection and recycling of spent cooking liquor spills;
 - Stripping and reuse of evaporation and digester condensates in order to reduce odor producing total reduced sulfur (TRS) compounds (Kraft and sulfite mills).
 - Neutralization of spent cooking liquor before evaporation and reuse of condensate in order to reduce dissolved organics (Sulfite mills);
 - Including chemical recovery in sulfite as well as Kraft mills.

Guidance applicable to the management of cooling water, and additional guidance applicable to stormwater, is presented in the **General EHS Guidelines**.

Wastewater Management – Kraft and Sulfite Pulp Mills

Additional recommended wastewater prevention and control methods for Kraft and sulfite mills include the following:

- Oxygen delignification ahead of the bleach plant;
- Efficient washing of the pulp ahead of the bleaching (Kraft and sulfite mills);
- Decreasing or eliminating the formation of 2,3,7,8-TCDD and 2,3,7,8-TCDF in wood and non-wood bleaching processes by⁴:
 - Replacement of elemental chlorine bleaching with elemental chlorine free (ECF) bleaching⁵ or total chlorine free (TCF) bleaching

⁴ UNEP, 2006.

Wastewater Management – Mechanical and Chemi-mechanical Mills

Additional recommended wastewater prevention and control methods for mechanical and chemi-mechanical mills include the following:

- Minimizing reject losses;
- Maximizing water recirculation in mechanical pulping process;
- Application of thickeners to effectively separate water systems from the pulp and paper mills;

⁵ ECF bleaching requires on-site manufacture of chlorine dioxide (ClO₂). The ClO₂ process chosen should have low production of chlorine as a by-product of ClO₂ production.

- Separation of pulp mill and paper mill water systems as well as use of counter-current water system from paper to pulp mill to reduce overall water consumption, TSS and dissolved organics.

Wastewater Management – Paper and Integrated Mills

Additional recommended wastewater prevention and control methods for paper and integrated mills include the following:

- Recycling of white water, with fiber recovery by means of disc filters, drum filters or micro flotation units and minimization of the number of fresh water intake points to the white water system
- Separate treatment of coating wastewaters, e.g. by ultra filtration – recycling of coating chemicals;
- Substituting potentially harmful process chemicals with less harmful alternatives.

Wastewater Treatment

End of pipe wastewater treatment technologies will depend on several factors including effluent composition, measurable effluent quality requirements, and discharge location (e.g. direct to water course or pre-treatment before discharge to municipal or other WWTP). Pulp mill wastewater treatment should typically include primary treatment consisting of neutralization, screening, sedimentation (or occasionally flotation/ hydrocycloning) to remove suspended solids, biological/secondary treatment to reduce the organic content in wastewater and destroy toxic organics, and, less frequently, tertiary treatment to further reduce toxicity, suspended solids, organics, and color. Wastewater treatment processes generate sludge which requires management as a waste material or as by-products.

Generic wastewater treatment technologies are discussed in the **General EHS Guideline**. Specific recommended applications common in the paper and pulp industry are as follows:

- **Primary mechanical treatment:** A mechanical clarification basin or settling pond is commonly used to remove suspended solids from wastewater. Chemical flocculation to assist in the removal of suspended solids is sometimes applied;
- **Secondary treatment:** Biological treatment is applied in most types of pulp and paper operations with relatively high discharges of organic pollutants, including toxic compounds such as resin acids and chlorinated organics. Specific applications include a number of different types and configurations of biological treatment. The most commonly used systems include a combination of i) activated sludge; ii) aerated lagoons; iii) biological filters of various types, often used in combination with other methods; iv) anaerobic treatment used as a pre-treatment stage, followed by an aerobic biological stage; and v) combinations of different methods, when very high efficiencies are necessary;
- Additionally, extended aeration time is sometimes required to oxidize toxic compounds such as resin and fatty acids, reduce biological sludge formation and to help ensure consistently high levels of treatment
- Anaerobic biological pretreatment is favored for certain types of effluents that are high in BOD/COD and low in toxic substances, such as sulfite pulping condensates and mechanical pulping and RCF effluents, with reuse of the remaining purified condensates to reduce overall water consumption and effluent volumes.

Air Emissions

The principal air emissions in pulp and paper production consist of process gases which vary by type of pulping process and which may include sulfur compounds (with associated odor issues), particulate matter, nitrogen oxides, volatile organic compounds, chlorine, carbon dioxide, and methane. Other common sources of emissions include flue gases from incineration plants and from auxiliary steam and power generating units emitting particulate matter, sulfur compounds and nitrogen oxides.

Process Gases – Kraft and Sulfite Mills

Malodorous Gases (Kraft mills) - Kraft pulping processes typically emit highly malodorous reduced sulfur compounds denoted as total reduced sulfur (TRS), which include hydrogen sulfide, methyl mercaptan, dimethyl sulfide, and dimethyl disulfide. Wastewater treatment plants can sometimes be a more significant source of malodorous gases than the process itself. Recommended emissions management strategies include the following:

- For bleached and unbleached Kraft mills, malodorous gases from vents at all points in the process handling black liquor, unwashed brown pulp, partially washed brown pulp, unbleached pulp, and condensates should be collected and incinerated to completely oxidize all reduced sulfur compounds;
- In the case of high concentration gases (generally from condensates and digester vents), a stand-by system for incineration should be provided, designed to take over from the main system, as required, thus minimizing venting of TRS gases to the atmosphere;
- In sensitive situations (i.e. proximity to residential areas), consideration should be given to a standby incinerator or other alternative incineration point for the low-concentration

TRS gases. The recovery boiler is the preferred point of incineration;

- As far as possible, the point of discharge of the necessary emergency vents to atmosphere should be a high, hot stack, such as the recovery or power boiler.
- When waste water treatment plant odors are problematic, considering use of oxygen activated sludge with capture and subsequent incineration of gaseous emissions.

Incineration of the TRS gases can be accomplished within the process equipment, preferably in the recovery boiler where sulfur can be recovered, but also in the power boiler. For concentrated gases, other options include the lime kiln (although the resulting generation of calcium sulfate needs to be considered), or in a separate external incinerator.

Recovery Boilers (Kraft and sulfite mills) – Emissions from recovery boilers are typically characterized by the presence of particulate matter and sulfur dioxide. Other key constituents include nitrogen oxides and sometimes hydrogen sulfide in kraft mills. Sulfur dioxide recovery is considered fundamental in sulfite mills. Primary emissions management strategies include the following:

- Oxidation of black liquor prior to direct contact evaporation⁶;
- Reducing sulfur emissions by concentrating black liquor in the evaporator (Kraft mills) above 75% dry solids before incineration in the recovery boiler;
- Reducing sulfur emissions by controlling combustion process parameters in the recovery boiler including temperature, air supply, distribution of black liquor in the furnace, and furnace load (Kraft mills);

⁶ Applicable to existing facilities, as direct contact evaporators should not be used in new facilities.

- Reduced emissions of nitrogen oxides (NO_x) by control of firing conditions, such as excess air;
- Collecting SO₂ emissions by absorption in alkaline solution to generate new cooking liquor (sulfite pulp mills)

Stacks should be designed according to the Good International Industry Practice (GIIP) approach provided in the **General EHS Guidelines**.⁷

Lime Kilns (Kraft mills) – The calcination reaction process results in emissions of NO_x, SO₂, and particulate matter. TRS gases may also be released due to poor removal of sodium sulfide (Na₂S) from the lime mud. Recommended primary emissions management strategies include the following:

- SO₂ emissions should be reduced through use of low sulfur content fuel and control of excess oxygen;
- NO_x emissions should be reduced through control of firing conditions;
- Hydrogen sulfide emissions should be reduced by proper kiln operation and control of residual sodium sulfide in the lime mud. This can be achieved by proper lime mud washing and filtering to remove sodium sulfide and decrease water content (to about 20 to 30 percent) which permits on-filter air oxidation of residual sulfide prior to the dried mud entering the kiln.

Recommended secondary emissions control measures applicable to the above sources of emissions include the following:

- Use of secondary particulate emissions controls such as electrostatic precipitators in recovery boilers, auxiliary boilers, and lime kilns;
- Use of secondary SO₂ emissions controls such as alkaline wet scrubbers for removal of acid gases and by-products of the incineration of TRS gases.

Volatile Organic Compounds (All mills)⁸ - Volatile organic compounds (VOCs) are emitted to the atmosphere from poorly designed utility boilers burning bark and other wood-based fuel.

At mechanical pulping mills, principal sources of VOC emissions include evacuation of air from wood-chip washing and from the condensing shower, where steam released in mechanical pulping processes, contaminated with volatile wood components, is condensed. The concentrations of VOCs depend on the resin content of the wood and the specific defiberizing techniques applied. The emitted substances include acetic acids, formic acids, ethanol, pinenes, and terpenes.

Recommended measures to minimize VOC emissions include:

- Ensure that VOC emissions from mechanical pulping of wood with high extractive (resin) content are recovered in the heat recovery units and the start-up scrubber (for TMP steam), and collect and further treat volatile compounds. VOC-containing exhaust air can be incinerated in existing boilers or a separate furnace. Terpenes can be recovered from those contaminated condensates that contain mainly terpenes;
- Operating bark boilers with excess oxygen sufficient to prevent VOC (and CO) emissions while minimizing formation of NO_x. Fluidized bed technology is preferred for solid waste boilers.

⁷ For pulp mills, this may consist of a high single stack typically over 100 meters in height above immediately surrounding land or as defined by atmospheric emissions dispersion modeling.

⁸ This section addresses VOCs other than the malodorous compounds discussed above.

Combustion Sources

Pulp and paper mills are large energy and steam consumers sometimes making use of auxiliary boilers (bark boilers and additional steam boilers) for the generation of steam energy. Emissions related to the operation of these steam energy sources typically consists of combustion by-products such as NO_x, SO_x, PM, and volatile organic compounds (VOCs), and greenhouse gases. Recommended management strategies include adoption of a combined strategy which includes a reduction in energy demand, use of cleaner fuels, and application of emissions controls where required. In energy efficient non-integrated pulp mills, the heat generated from black liquor and bark combustion should exceed the energy requirement for the entire production process.

Recommendations on energy efficiency are addressed in the **General EHS Guidelines**. Additional recommendations specific to pulp and paper operations include:^{9, 10}

- Reducing heat losses and heat consumption by increasing dry solids content of bark which is burnt increasing efficiency of steam boilers (e.g. use of economizers); increasing effectiveness of the secondary heating system (e.g. hot water about 85 °C); increasing use of secondary heat to heat buildings; and increasing high pulp concentration, as well as maintaining a tightly closed water system and a partially closed bleaching plant
- Reducing electric power consumption by maintaining as high a pulp consistency as possible in screening and cleaning; controlling the speed of large motors rather than using throttling valves or dampers for flow control; using

efficient vacuum pumps; and proper sizing of pipes, pumps and fans;

- Maximizing the generation of electric power by maintaining high boiler pressure; keeping outlet steam pressure in the back-pressure turbine as low as technically feasible; using a condensing turbine for power production from excess steam and maintaining high turbine efficiency; and preheating of air and fuel charged to boilers.

Guidance for the management of small combustion source emissions with a heat input capacity of up to 50 MW_{th}, including exhaust emission guidelines, is provided in the **General EHS Guidelines**. Guidance applicable to combustion sources greater than 50 MW_{th} is presented in the **Thermal Power Guidelines**.

Residues and Waste

Pulp and paper mills typically generate significant quantities of non-hazardous solid wastes but very little hazardous wastes. Industry specific wastes include bark from debarking of wood, residual pith from bagasse pulping, inorganic sludge (e.g. green liquor sludge, lime sludge) from chemical recovery, trash (e.g. plastics) separated from paper/card in RCF plants, and fiber (i.e., primary clarifier) sludge and biological sludge from wastewater treatment. A small amount of hazardous waste is generated in all mills, and includes oil and grease residues, scrap electrical equipment, and chemical residues which normally amount to about 0.5-1kg/ton of product.

The classification of solid wastes as hazardous or non-hazardous should be established based on local regulatory criteria. Hazardous and non-hazardous wastes should be carefully segregated to reduce the volume of wastes that could be contaminated with hazardous material and hence classified as hazardous. Guidance for management and safe disposal of hazardous and non-hazardous industrial waste is addressed in

⁹ EU BREF (2001).

¹⁰ See also Williamson (1994) for additional guidance on energy efficiency improvements.

the **General EHS Guidelines**. Additional guidance specifically applicable to pulp and paper mills includes the following:

- Solid waste volumes should be reduced to the extent feasible through in-situ reuse and recycling of materials, example of which include:
 - Recycling of fiber sludge;
 - Reintroducing knots and screenings into the digestion process;
 - Improving sludge dewatering to facilitate burning of sludge (often in auxiliary boilers, using a support fuel);
 - Reducing the generation of organic wastes such as bark by debarking in the forest (leaving the bark behind as soil conditioner);
 - Incinerating organic wastes, such as bark¹¹, in steam generating boilers to reduce overall fuel consumption.
- Additional waste management recommendations include:
 - Debarking waste¹² should be minimized through clean wood handling followed by segregation of clean organic fractions that can be used as a fuel in steam generation while the remaining fraction should be landfilled;
 - Bark ash, wood ash and other ashes may be recycled as fill material in construction work, road construction, as a soil conditioning agent, or otherwise landfilled;
 - Lime mud (Kraft mills) is normally recycled in the mill recovery system but excess material can be commercially used for liming of acid soils or otherwise landfilled;
 - Green liquor sludge (Kraft mills) can be used as a daily cover in solid waste landfills after improved

¹¹ "Bark" is the main part of the bark removed from the logs which is relatively clean and suitable as fuel for a solid fuel boiler.

¹² "Debarking waste" is a smaller fraction of the bark, contaminated with soil and gravel, which may not be suitable as fuel.

- dewatering or, less frequently, as forest fertilizer (based on an analysis of nutrient contents and potential impacts from land application). It can also be used as a neutralization agent for acidic wastewater;
- Deinking sludge (RCF mills) can be used as a filler in other paper grades, composted with other organic materials for preparation of soil products, or else incinerated;
 - Pith (bagasse mills) can be composted with other organic materials for preparation of soil products or else incinerated;
 - Fiber sludge can be recycled into production on site, sold to other mills, or sent off-site for use in other products. It can also be incinerated or used as landfill daily cover material;
 - Biological sludge can be incinerated in the bark boiler together with fiber sludge, or evaporated and incinerated in the kraft mill recovery system. It can also be composted with other organic materials for the preparation of soil products;
 - Tertiary treatment sludge can be blended with other sludge for incineration in the bark boiler as well as composted with other organic materials for preparation of soil products.¹³

Noise

Pulp and paper mills are inherently noisy due to the large amount of mechanical equipment, transport vehicles, physical

¹³ The applicability of sludge management methods depends on the actual quality and type of sludge. For example, incineration in the recovery boiler is typically only applicable for biological sludge in Kraft mills. Incineration in a bark boiler or separate incinerator is feasible only for sludge with relatively high contents of organics and high contents of dry solids. Composting is feasible only for sludge with high contents of organics. Sludge from a waste treatment plant needs to be evaluated on a case-by-case basis to establish whether it constitutes a hazardous or a non-hazardous waste and its potential impacts from land application.

activities, and energy usage, notably vacuum pumps, liquid pumps and steamgeneration systems. Guidance for noise management is provided in the **General EHS Guidelines**.

1.2 Occupational Health and Safety

Occupational health and safety issues should be considered as part of a comprehensive hazard or risk assessment, including, for example, a hazard identification study [HAZID], hazard and operability study [HAZOP], or other risk assessment studies.

The results should be used for health and safety management planning, in the design of the facility and safe working systems, and in the preparation and communication of safe working procedures.

General facility design, operation, and monitoring measures to manage principal risks to occupational health and safety are provided in the **General EHS Guidelines**. General guidance specific to construction and decommissioning activities is also provided along with guidance on health and safety training, personal protective equipment and the management of physical, chemical, biological and radiological hazards common to all industries.

Occupational health and safety issues for further consideration in pulp and paper mills include:

- Chemical hazards
- Physical hazards
- Wood dust
- Biological agents
- Heat
- Confined spaces
- Noise
- Radiation

Chemical hazards

Numerous chemicals are used and manufactured in the pulp and paper industry that can have adverse impacts on worker health and safety. These include:

Gases—such as reduced sulfur compounds (kraft pulping), oxidized sulfur compounds, mainly sulfur dioxide (kraft and sulfite pulping), chlorine, chlorine dioxide, terpenes and other volatile organic compounds, and oxygen;

Liquids—including sodium hydroxide and other caustics, acids such as sulfuric acid, cooking byproducts such as turpentine, sodium hypochlorite, aqueous solution of chlorine dioxide, hydrogen peroxide, biocides, papermaking additives, solvents, and dyes and inks; and

Solids—including sodium chlorate, sodium sulfate, lime, calcium carbonate, ash, and asbestos (used for insulation).

Recommended measures to prevent, minimize, and control potential worker health and safety impacts from chemicals include:

- Automate pulping and bleaching operations to the extent possible, such that operators can monitor and operate the processes from control rooms isolated from potential chemical exposures and other health and safety hazards. Effective process control also minimizes the use of bleaching and other chemicals;
- Provide engineering controls, such as automatic digester capping valves; local exhaust at batch digesters and blow tanks capable of venting at the rate that the vessels' gases are released; negative pressure in recovery boilers and sulfite-sulfur dioxide acid towers to prevent gas leaks; ventilated full or partial enclosures over post-digestion vessels; enclosed or ventilated lime conveyors, elevators,

and storage bins; canopy enclosures with dedicated exhaust ventilation for each bleaching tower and washer; and enclosures over sheet dryers;¹⁴

- Install continuous gas monitors with alarms where leaks or generation of hazardous gases may occur, such as chemical recovery, chlorine storage area, chlorine dioxide generator, and bleaching areas, and provide all employees, contractors, and visitors in these areas with emergency escape respirators;
- Maintain a current database of all chemicals used and manufactured in the mill, including data on hazards, toxicology, biological properties, etc.;
- Identify and prevent possible chemical reactions that can result in formation of hazardous gases and other substances (e.g., combination of spent sulfate pulping liquor and acids in the wastewater system can generate hydrogen sulfide). All chemicals used or manufactured at the site should be reviewed for reactivity with other classes of chemicals used at the facility;
- Label, mark, package and store all chemicals and hazardous materials according to national and internationally recognized requirements and standards;
- Ensure contractor personnel, including maintenance contractors retained during shutdowns, are trained in and follow site safety procedures, including use of personal protective equipment and handling of chemicals;
- Train workers in handling of chlorine dioxide and sodium chlorate. Wet sodium chlorate spills with water and keep any contaminated clothing wet until laundered;
- Avoid the use of elemental chlorine for bleaching;
- Use water-based (rather than solvent-based) inks and dyes;

- Keep sulfur storage bins free of sulfur dust accumulation;
- Implement an inspection and maintenance program to prevent and identify leaks, equipment failure, etc.

Physical hazards

The most severe injuries in this sector are often attributable to the failure of lockout - tagout systems. Robust lockout - tagout procedures as described in the **General EHS Guidelines** should be implemented.

General Physical Hazards

Recommended measures to prevent, minimize, and control general physical hazards (e.g. trips, falls, and materials handling hazards) include:

- Install catch platforms under conveyors that cross passageways or roadways;
- Quickly clean up spills;
- Use non-skid walking surfaces that allow drainage;
- Install guard rails on walkways adjacent to production lines or at height, and clearly mark traffic lanes for vehicles and pedestrians;
- Equip mobile equipment with roll-over protection.
- Establish routines to ensure that heavy loads are not moved by crane over personnel;

Machine Safety

Pulp mills employ wood processing and other equipment such as debarkers and chippers with the potential to expose workers to severe injury.

¹⁴ International Labour Organization, Encyclopaedia of Occupational Health and Safety, 4th Edition, Chapter 72, Pulp and Paper Industry, Occupational Hazards and Controls.

Recommendations to prevent, minimize, and control injuries from chipping and debarking¹⁵ equipment include:

- Equipment with moving parts (e.g., the in-running nips between the chain and sprocket of conveyors; conveyor drums, drive belts, pulleys, and shafts; rollers on paper machines; shredder feed rolls; etc.) should be fitted with safety guards or interlocks capable of preventing access to moving parts;
- Equipment must be shut off and locked out before maintenance, cleaning, or repairs are undertaken;¹⁶
- Workers should be trained specifically in the safe use of debarking, chipping, and other equipment
- Work stations should be aligned to minimize human danger from fragments which could arise from breakage;
- Equipment should be regularly inspected and maintained to prevent equipment failure;
- All personnel operating cutting equipment should use protective eyewear, and other PPE as necessary.

Log Handling Activities

Logs are generally unloaded from railroad cars or heavy trucks and stacked by machines before being moved to log conveyors and log decks for processing in the pulp mill. Injuries due to vehicle movement in log yards can be severe, in addition to injuries from logs that roll off or are dropped by handling equipment or are dislodged from log stacks.

Recommendations to prevent, minimize, and control injury in log yards include¹⁷:

¹⁵ Specific techniques for minimizing injuries associated with cutting and debarking equipment can be found at US OSHA (2003), available at: http://www.osha-slc.gov/SLTC/etools/sawmills/log_breakdown.html

¹⁶ See, for example, U.S. Occupational Health Administration regulations for Pulp, Paper, and Paperboard Mills, 29 Code of Federal Regulations (CFR) 1910.261(a), and relevant American National Standards Institute codes, such as O1.1-2004: Woodworking Machinery Safety Requirements.

- Establish and follow safety practices for unloading logs, lumber and chips;¹⁸
- Complete mechanization of log yard activities should be considered to reduce human contact with logs during handling and stacking activities;
- Transport routes within log yards should be clearly demarcated and vehicle movement should be closely controlled;
- Log stacks should not be higher than a safe height defined by risk assessment which should take account of site-specific circumstances including stacking methodology;¹⁹
- Access to log yards should be restricted to authorized personnel;
- Log decks should have stops, chains, or other guards to prevent logs from rolling down and off the deck;
- Workers should be trained in safe working procedures in log stack and deck areas, including avoidance of falling logs and planning of escape routes;
- Workers should be provided with protective steel capped boots, hardhats, and high visibility jackets;
- All mobile equipment should have audible reversing alarms.

Wood dust

Exposure to wood dust is a potential concern in the wood handling area of pulp mills (e.g. in semi-mechanized chippers), as well as in the initial stages of pulping. Exposure to fiber dust can occur in paper mills. Paper fiber dust is also a fire hazard.

¹⁷ Specific techniques for log receiving and handling can be found at US OSHA (2003), available at: <http://www.osha-slc.gov/SLTC/etools/sawmills/receive.html> and <http://www.osha-slc.gov/SLTC/etools/sawmills/convey.html>

¹⁸ See, for example, U.S. Occupational Health Administration regulations for loading and unloading logs, 29 Code of Federal Regulations (CFR) 1910.266(h)(6), and Oregon Administrative Rule (OAR) 437-02-312.

¹⁹ Manual stacking operations may typically limit stacking height to 2 meters while mechanical stacking operations may safely work with greater stacking heights.

Recommended measures to prevent, minimize, and control dust include:

- Enclose and ventilate saws, shredders, dusters, and wood chip conveyors;
- Consider enclosed chip storage;
- Avoid use of compressed air to clear wood dust and waste paper;
- Enclose and ventilate areas where dry, dusty additives are unloaded, weighed, and mixed, or use additives in liquid form;
- Regularly inspect and clean dusty areas to minimize dust explosion risk.

Biological agents

Biological agents include microorganisms such as bacteria, fungi and viruses, some of which may be pathogenic.

Microorganisms develop particularly in paper machines' closed-loop systems, biological treatment plants for mill wastewaters, and water cooling towers.

Recommended measures to prevent, minimize, and control exposure to biological agents include:

- Design biological treatment plants to minimize the potential for growth of pathogenic organisms;
- Use biocides in cooling water and in pulping and papermaking processes to minimize growth of microorganisms.

Heat

Many pulping operations, including pulp cooking, pulping chemical recovery, lime production, and paper drying involve high temperatures and, in some cases, high pressures. Heat protection measures common to most large industrial operations are discussed in the General EHS Guideline. In addition,

measures to prevent, minimize, and control heat exposure in the pulp and paper sector include:

- Provide air-conditioned control rooms, including in wood preparation, pulping, bleaching, and paper-making areas;
- Schedule work in hot areas to allow acclimatization and rest periods;
- Automate smelt removal from the chemical recovery boiler. Provide heavy-duty protective clothing to workers potentially exposed to molten smelt or other high-temperature materials;
- Implement safety procedures to minimize the potential for smelt/water explosions. Smelt should be transferred at a controlled rate, and recovery boilers maintained to prevent water leaks from the tube walls of the boiler. Chemical recovery boiler operations should be shut down at the first indication of a leak;
- Consider use of mobile equipment with air-conditioned enclosed cabs.

Confined Spaces

Operation and especially maintenance work may include confined space entry. Examples include: boilers, dryers, degreasers, digesters, blow pits, pipeline pits, process and reaction vessels, tanks, and vats. Impacts and mitigation measures for confined space entry are addressed in the **General EHS Guideline**.

Noise

Two major sources of noise are wood debarking in pulp mills and the paper machine in paper mills, but other processes can also be noise generators. Use of control rooms, as discussed above, is an effective engineering control. Additional recommendations on the management of occupational noise are provided in the **General EHS Guidelines**.

Radiation

Certain measurement equipment, particularly in paper mills, contains radioactive material. These units are typically sealed, but damage to or maintenance of devices containing radioactive material may result in exposure. These devices should be designed and operated according to applicable national requirements and internationally accepted standards for occupational²⁰ and/or natural²¹ exposure to ionizing radiation, such as “International Basic Safety Standard for protection against Ionizing Radiation and for the Safety of Radiation Sources”²² and its three interrelated Safety Guides. Additional recommendations on the management of radiation exposure are provided in the **General EHS Guidelines**.

1.3 Community Health

Community health and safety issues during the construction and decommissioning of pulp and paper mills are common to those of most large industrial facilities and their prevention and control is discussed in the **General EHS Guidelines**.

Community health and safety impacts primarily occur during the operation phase of pulp and paper facilities and include:

- Chemical storage, use, and transport
- Odors
- Traffic

Chemical Storage Use and Transport

Major accidents can result in releases, fires, and explosions in pulping or bleaching operations or during product handling and transport outside the processing facility. Guidance for the

management of these issues is presented below and in relevant sections of the **General EHS Guidelines** including: Traffic Safety; Transport of Hazardous Materials; and Emergency Preparedness and Response.

Odors

Chemical pulping, and Kraft pulping in particular, generates malodorous reduced sulfur compounds that can create a nuisance for nearby residents. Modern air pollution controls, as discussed in Section 1.1, prevent the odors formerly associated with pulp mills although emissions can still occur during upset conditions. Therefore, greenfield projects should consider the location and distance of a proposed facility with regards to residential or other community areas.

Traffic

Pulp and paper mills require a large volume of wood, either as logs or as chips, and export a large volume product, and these materials are often transported by truck. This can result in a significant increase in truck traffic in the community. Traffic safety measures are addressed in the **General EHS Guideline**.

²⁰ Organizations processing, or applying radioactive substances for purposes such as medical or industrial processes, education, training, research, etc.

²¹ Underground mines (other than those for radioactive ore), spas, radon prone areas, etc.

²² IAEA Safety Series No. 115.

2.0 Performance Indicators and Monitoring

2.1 Environment

Emissions and Effluent Guidelines

Tables 1(a) through 1(l) provide the effluent guidelines and Table 2 the emissions guidelines for pulp and paper mills. These guidelines are assumed to be achievable under normal operating conditions in appropriately designed and operated facilities through the application of pollution prevention and control techniques discussed in the preceding sections of this document.

Effluent guidelines represent annual average values²³ and are applicable for direct discharges of treated effluents to surface waters for general use. Site-specific discharge levels may be established based on the availability and conditions in the use of publicly operated sewage collection and treatment systems or, if discharged directly to surface waters, on the receiving water use classification as described in the General EHS Guideline. These levels should be achieved, without dilution, at least 95 percent of the time that the plant or unit is operating, to be calculated as a proportion of annual operating hours. Deviation from these levels in consideration of specific, local project conditions should be justified in the environmental assessment.²⁴

Emissions guidelines are applicable to process emissions.

Combustion source emissions guidelines associated with

²³ Daily averages should not be greater than 2.5 times the annual average values.

²⁴ The effluent guidelines are based on production load (e.g. emissions as kg per ton of produced pulp or paper). In separate (non-integrated) pulp mills and paper mills, the specific data (e.g. "kg/ton air dry pulp" or "kg/ton paper") is unambiguous. In an integrated mill, the emission indicator is usually given as "kg per ton of paper", which should include the emissions of both the pulp mill and the paper mill. If an integrated mill sells both paper and pulp, the most relevant indicator would be "kg/ton pulp total", where "pulp total" is approximately the sum of produced paper and marketed pulp.

steam- and power-generation activities from sources with a capacity equal to or lower than 50 MW_{th} are addressed in the **General EHS Guidelines** with larger power source emissions addressed in the **Thermal Power EHS Guidelines**. Guidance on ambient considerations based on the total load of emissions is provided in the **General EHS Guidelines**.

Resource Use

Table 3 provides examples of energy use and water consumption from the pulp and paper sector that can be considered as indicators of the sector's efficiency and may be used to track performance changes over time. The actual energy consumption depends on the process configuration, process equipment, and process control efficiency.

Environmental Monitoring

Environmental monitoring programs for this sector should be implemented to address all activities that have been identified to have potentially significant impacts on the environment, during normal operations and upset conditions. Environmental monitoring activities should be based on direct or indirect indicators of emissions, effluents, and resource use applicable to the particular project.

Monitoring frequency should be sufficient to provide representative data for the parameter being monitored. Monitoring should be conducted by trained individuals following monitoring and record-keeping procedures and using properly calibrated and maintained equipment. Monitoring data should be analyzed and reviewed at regular intervals and compared with the operating standards so that any necessary corrective actions can be taken. Additional guidance on applicable sampling and analytical methods for emissions and effluents is provided in the **General EHS Guidelines**.

2.2 Occupational Health and Safety

Occupational Health and Safety Guidelines

Occupational health and safety performance should be evaluated against internationally published exposure guidelines, of which examples include the Threshold Limit Value (TLV[®]) occupational exposure guidelines and Biological Exposure Indices (BEIs[®]) published by American Conference of Governmental Industrial Hygienists (ACGIH),²⁵ the United States National Institute for Occupational Health and Safety (NIOSH),²⁶ Permissible Exposure Limits (PELs) published by the Occupational Safety and Health Administration of the United States (OSHA),²⁷ Indicative Occupational Exposure Limit Values published by European Union member states,²⁸ or other similar sources.

Accident and Fatality Rates

Projects should try to reduce the number of accidents among project workers (whether directly employed or subcontracted) to a rate of zero, especially accidents that could result in lost work time, different levels of disability, or even fatalities. Facility rates may be benchmarked against the performance of facilities in this sector in developed countries through consultation with published sources (e.g. US Bureau of Labor Statistics and UK Health and Safety Executive)²⁹.

Occupational Health and Safety Monitoring

The working environment should be monitored for occupational hazards relevant to the specific project. Monitoring should be

designed and implemented by credentialed professionals³⁰ as part of an occupational health and safety monitoring program. Facilities should also maintain a record of occupational accidents and diseases and dangerous occurrences and accidents. Additional guidance on occupational health and safety monitoring programs is provided in the **General EHS Guidelines**.

²⁵ <http://www.acgih.org/TLV/>

²⁶ <http://www.cdc.gov/niosh/npg/>

²⁷

http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=9992

²⁸ http://europe.osha.eu.int/good_practice/risks/ds/oe/

²⁹ <http://www.bls.gov/iif/> and <http://www.hse.gov.uk/statistics/index.htm>

³⁰ Credential professionals may include Certified Industrial Hygienists, Registered Occupational Hygienists, or Certified Safety Professionals or their equivalent.

3.0 References and Additional Sources

Allan M. Springer, Ed.: Industrial Environmental Control – Pulp and Paper Industry, 3rd edition, Tappi Press, Atlanta, Ga., 2000

Environment Canada. 2004. Regulations Amending the Pulp and Paper Effluent Regulations [embedding the Environmental Effects Monitoring requirements under Schedule IV]. Published in Part II of the Canada Gazette on May 19, 2004.

European Commission. 2001. Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques in the Pulp and Paper Industry. December 2001.

Finnish Environment Institute, A Strategic Concept for Best Available Techniques in the Forest Industry, 2001, URL:
<http://www.ymparisto.fi/download.asp?contentid=10759&lan=en>

Finnish Environment Institute, Continuum - Rethinking BAT Emissions of the Pulp and Paper Industry in the European Union, 2007. URL:
<http://www.environment.fi/download.asp?contentid=65130&lan=en>

International Labour Organization, Encyclopaedia of Occupational Health and Safety, 4th Edition, Chapter 72, Pulp and Paper Industry, Occupational Hazards and Controls.

Oregon Administrative Rule (OAR) 437-02-312

Peter N. Williamson, Ed., Patti Turner, Techn. Ed.: Water Use and Reduction in the Pulp and Paper Industry – A Monograph, Canadian Pulp and Paper Association, 1994

Swedish Paper Industry's Council for Development of Occupational Health and Safety (2005).

United Nations Environment Programme (UNEP), 2006. Revised edited draft guidelines on best available techniques and guidance on best environmental practices relevant to Article 5 and Annex C of the Stockholm Convention on Persistent Organic Pollutants. Expert Group on Best Available Techniques and Best Environmental Practices.

US EPA: Final Pulp, Paper, and Paperboard "Cluster Rule".

U.S. Occupational Health Administration regulations for Pulp, Paper, and Paperboard Mills, 29 Code of Federal Regulations (CFR) 1910.261

U.S. EPA. 2002. Sector Notebook Project, Profile of the Pulp and Paper Industry, 2nd Edition. EPA/310-R-02-002. November 2002
<http://www.epa.gov/compliance/resources/publications/assistance/sectors/notebooks/pulp.html>

Annex A: General Description of Industry Activities

The main steps in pulp and paper manufacturing are: (a) raw material preparation (such as debarking and chipping wood), (b) pulp manufacturing, (c) pulp bleaching, and (d) paper manufacturing, which are described below. Pulp mills and paper mills may exist separately or as integrated operations.

Raw Material Preparation³¹

Wood is the predominant source of cellulose fiber for paper products, although other fiber sources, such as straw, bagasse, and bamboo, are used in areas with limited access to forest resources, especially in developing countries. Some non-wood plants, such as abaca, cotton, and hemp, are used as the source of fiber for specialty applications.

Wood used to make pulp can arrive at the mill in a variety of forms including wood logs, chips, and sawdust. In the case of roundwood (logs), the logs are cut to manageable size and then debarked. At pulp mills integrated with lumbering facilities, acceptable lumber wood is removed at this stage. At these facilities, any residual or waste wood from lumber processing is returned to the chipping process; in-house lumbering rejects can be a significant source of wood at such facilities.

The bark of those logs not fit for lumber is usually removed mechanically (in a drum debarker) in order to prevent contamination of pulping operations³². Depending on the moisture content of the bark, it may then be burned for energy production. If not burned for energy production, bark can be used for mulch, ground cover, or to make charcoal. Wet

debarking processes, which have substantially been abandoned by the industry generate wastewater that contains nutrients, fiber, and oxygen-consuming organic compounds such as resin acids, fatty acids, etc.

Certain mechanical pulping processes, such as stone groundwood pulping, use roundwood; however, the majority of pulping operations require wood chips. A uniform chip size (typically 20 mm long in the grain direction and 4 mm thick) is necessary for the efficiency of the processes and for the quality of the pulp. The chips are then put on a set of vibrating screens to remove those that are too large or small. Large chips stay on the top screens and are sent to be re-cut, while the smaller chips are usually burned with the bark or may be sold for other purposes.

Non-wood fibers are handled in ways specific to their composition in order to minimize degradation of the fibers and thus maximize pulp yield. Non-wood raw materials are usually managed in bales.

Pulping Processes

Raw plant material primarily comprises cellulose fibers, hemicelluloses, and lignin, a natural binding material that holds together cellulose fibers in wood or in the stalks of plants. In the pulping process, the raw cellulose-bearing material (raw plant material or recycled paper) is broken down into its individual fibers, known as pulp. Pulping processes are generally categorized as chemical and mechanical. Chemical pulping relies mainly on chemical reactants and heat energy to soften and dissolve lignin in wood chips, followed by mechanical refining to separate the fibers. Mechanical pulping often involves some pretreatment of wood with steam heat and/or

³¹ Information adapted from U.S. EPA, Sector Notebook Project, Profile of the Pulp and Paper Industry, 2nd Edition, EPA/310-R-02-002, November 2002.

³² Hydraulic debarking which uses high-powered water jets is considered obsolete and environmentally undesirable due to the high levels of BOD generated in the effluent.

weak chemical solution, but relies primarily on mechanical equipment to reduce wood into fibrous material by abrasive refining or grinding. Different pulping processes result in pulp with specific properties suited for different end uses.

Wood-Based Chemical Pulping

Principal chemical pulping processes include the alkaline sulfate (or Kraft) pulping process, acid sulfite, and semi-chemical pulping. Kraft pulping represents approximately 80% of current pulp production worldwide and virtually all new construction. Compared with mechanical pulping processes, Kraft and sulfite pulps usually have higher market value and have higher costs of production. Their fiber quality is better for most purposes, with generally less lignin or other wood constituents and proportionately more cellulose fiber and more intact fibers. Kraft and sulfite pulps can be more readily bleached to yield high brightness or whiteness that is desirable in many paper products, and Kraft pulp typically produces a stronger sheet of paper or paperboard than other pulping processes.

Kraft Pulping

The Kraft pulping method accounts for approximately 80 percent of world pulp production.³³ Kraft pulping has become the dominant chemical pulping method because of better fiber strength compared to sulfite pulping, its applicability to all wood species, and the ability to recover chemical feedstocks efficiently.

In the Kraft pulping process, wood chips are combined in a digester with white liquor, an aqueous solution comprising principally sodium sulfide (Na_2S) and sodium hydroxide (NaOH), which breaks down lignin and, to a lesser extent, hemicelluloses

under elevated temperature and elevated pressure, freeing the cellulose fibers (pulp). Following digestion, the resulting black liquor, which contains dissolved organic substances, is separated from the pulp, called brown stock. The brown stock is treated with oxygen in the presence of sodium hydroxide to remove some of the residual lignin in a process referred to as oxygen delignification. The brown stock is then bleached, as described below, to achieve desired brightness, strength, and purity of the final pulp product.

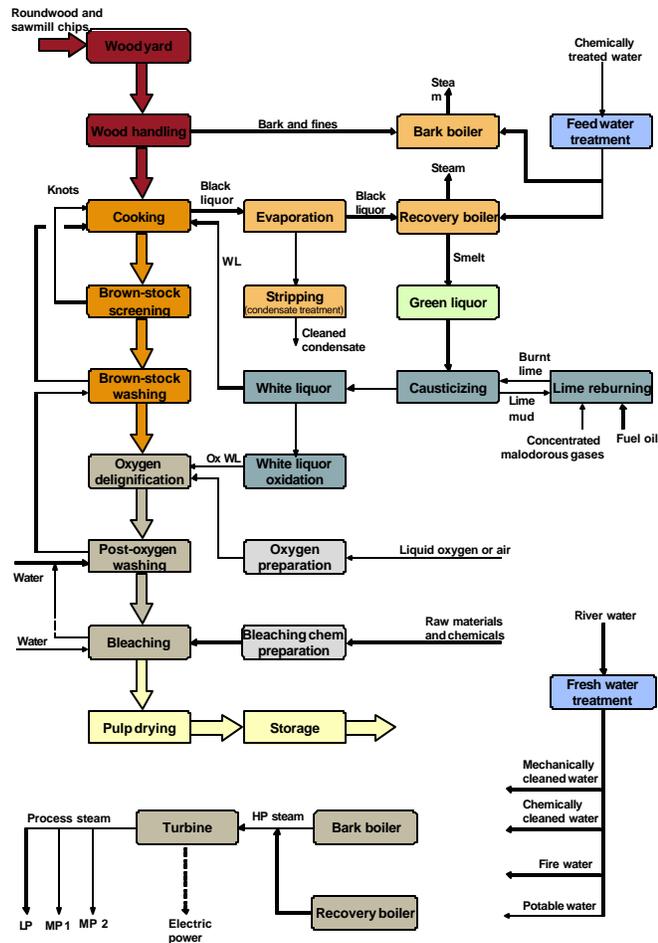
The chemical feedstocks are recovered in what is referred to as the liquor cycle. Black liquor is typically concentrated by evaporation of water and then burned in a recovery furnace, which destroys the organic constituents and generates heat used to make steam for other facility uses. Smelt, a molten salt mixture consisting principally of sodium carbonate (Na_2CO_3) and sodium sulfide, is formed at the bottom of the recovery boiler, and is dissolved in an aqueous solution, forming green liquor. In the causticizer, lime (CaO) is added to the green liquor, which converts sodium carbonate back to sodium hydroxide, forming white liquor, which is used again in the digesters. Lime mud, principally comprising calcium carbonate (CaCO_3), is also generated in the causticizer. The lime mud is converted back into lime by heating in the lime kiln.

Liquid streams from the Kraft pulping process are mostly re-used in the pulping operations or, in the case of bleached pulp, in the bleach plant. Liquid effluents from brownstock preparation should be limited to small amounts of condensates and spills. Gaseous emissions include sulfur dioxide, hydrogen sulfide and other reduced sulfur compounds, nitrogen oxides, and particulate matter.

A typical Kraft pulping process (including bleaching processes, discussed below) is shown in Figure 1.

³³ European Commission, Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques in the Pulp and Paper Industry, December 2001.

Figure 1. The Kraft pulp manufacturing process



Sulfite Pulping

The sulfite cooking process is based on the use of aqueous sulfur dioxide and a base. The base used affects the process conditions, chemical and energy recovery, water use, and properties of the pulp. Calcium, sodium, magnesium, and ammonium have been used, although the dominant sulfite pulping process is magnesium sulfite pulping and the calcium sulfite process is now considered environmentally unacceptable

for new construction. Use of sodium base and ammonium base has largely been discontinued because of higher costs. Although calcium base is relatively inexpensive, the cooking chemicals cannot be recovered and are discharged; therefore, it is generally not used in new installations.

Sulfite pulps are easier to bleach than Kraft pulps, which permits TCF bleaching (see Bleaching, below), and sulfite pulping produces fewer malodorous gases and has a higher material yield than Kraft pulping. However, because of weaker fiber and poor recovery technology (apart from magnesium base), the sulfite process has not been competitive and has often resulted in more water effluents. Other significant limitations of this process include its much higher net energy consumption than the Kraft process as well as limitations on the use of certain wood species (e.g. pine wood), which limits the raw material base. For these reasons, most major new chemical pulping investments use the Kraft process.

Semi-Chemical Pulping

In semi-chemical pulping, wood chips are partially digested to weaken the bonds between fibers, and then the chips are then mechanically treated in a refiner, which uses mechanical action to separate the fibers. Semi-mechanical pulping produces pulp with high stiffness that is commonly used in manufacture of corrugated board. The most common semi-chemical pulping process is the neutral sulfite semi-chemical (NSSC) process. Other semi-chemical pulping processes in use include alkaline cooking with sodium hydroxide liquor (soda cooking) or modified sulfate liquor.

The yield of semi-chemical pulping ranges from 55 to 90 percent, depending on the process used; however, pulp residual lignin content is also high, so bleaching is more difficult than for Kraft and sulfite chemical pulps. Because the process

conditions are less severe than for Kraft and sulfite chemical pulp and because semi-chemical pulps are generally not bleached, the processes are relatively straightforward. In addition, lesser amounts of chemicals are needed for semi-chemical pulping compared with Kraft and sulfite chemical pulping.

Because the cooking liquors from semi-chemical pulping contain lower concentrations of organic substances than those from Kraft and sulfite processes, chemical recovery is more costly, and some semi-chemical pulping mills treat and discharge the spent liquor with no recovery of the process chemicals. Since the efficiency of the recovery process is lower, untreated wastewater from semi-chemical mills tend to be more highly concentrated than those from kraft mills.

Wood-Based Mechanical Pulping

Mechanical pulping processes include thermo-mechanical pulping (TMP), chemi-thermomechanical pulping (CTMP), and groundwood pulping, as well as other variations. The TMP and CTMP processes involve reduction of wood chips into pulp in mechanical disk refiners, usually after pretreatment of chips with steam and/or weak chemical solutions. The older groundwood process involves grinding of wood bolts (small logs) into pulp against a grindstone.

Mechanical pulping gives high yields, but the mechanical disintegration requires high amounts of electric energy in the refining processes. Mechanical pulps are usually used for printing and writing papers where high opacity and good ink absorption are needed and for some paperboards where higher bulk and cheaper pulps are preferred. CTMP may be used for tissue and fluff pulps as well.

Thermo-mechanical Pulping (TMP)

Wood chips are usually washed before thermo-mechanical pulping to remove stones, sand, scrap metal or other hard debris that may cause wear or damage to the refiner plates. The washed and screened chips are preheated with steam and then refined either in a single stage at an elevated temperature and pressure or in a two-stage refining system in which the first stage is followed by a second refining stage under pressure or at atmospheric pressure. The pulping of screen rejects is often carried out in the second stage refiner. The application of more mechanical energy instead of chemical dissolution results in more pronounced fiber fragmentation and formation of fine material. TMP pulp is most often used for newsprint.

Much of the comparatively high amount of electrical energy required in refiner mechanical pulping is converted into heat as steam that is evaporated from wood moisture and dilution water in the refiners. Because of the pressurized conditions (pressure up to 5 bars above atmospheric), a significant amount of the steam generated may be recovered and used to produce clean process steam (e. g., for use in paper drying). Part of the energy may also be recovered as hot water.

Fresh wood is preferred as raw material. If the wood for thermo-mechanical pulping is stored, it is usually stored in water or sprinkled with water to prevent drying. Thus, water collection systems may be required in the wood yard to avoid discharge of water containing organic substances. Part of the organic substances of the wood is dissolved in water and discharged from the pulping process. However, because the wood loss during the TMP manufacturing is very low and most of the wood material is converted into pulp, the heat value of the wastewater in a TMP mill is too low to be recovered in the same way as in a chemical pulp mill (e.g., black liquor). Therefore, effluent treatment is necessary at a TMP mill.

Chemi-thermo-mechanical Pulping (CTMP)

The CTMP process combines the TMP process with a chemical impregnation of the wood chips. Washed and screened wood chips are immersed in an alkaline chemical solution in an impregnation tower. Sodium sulphite (Na_2SO_3) is primarily used for softwoods, and alkaline peroxide has been predominantly used for hardwoods. After chemical impregnation, the chips are pre-warmed, and their temperature increases further in the first to second stages of subsequent refining. For similar reasons as TMP, CTMP is often integrated with a paper or board mill; however, CTMP is also manufactured as market pulp.

The combination of heat and chemicals softens the lignin and facilitates the release of the cellulose fibers, making pulp with increased strength and stiffness, but also resulting in lower yields and, as a consequence, generation of more pollutants relative to TMP. As with TMP, the process waters can be recovered economically, and residuals discharged after treatment.

CTMP was originally applied mainly on spruce wood, but is now applied also on hardwoods with low density, such as aspen. CTMP is used for tissue, paperboard and fluff pulps, but the aspen grades are also used in increasing amounts for printing and writing grades with lower fiber costs than for chemical pulps.

Groundwood Pulping

In groundwood pulping, the initial defibration takes place in grinders by forcing logs against special rotating grinding stones with the wood fibers parallel to the axis of a stone. Most of the energy put into the grinding process is transformed into heat, which helps to soften the lignin bonds and release the cellulose fibers. A shower of water over the grinding stones is used to

dissipate heat, reduce friction, and transport the fibers to the next process stages.

In the Pressure Grinding Process (PGW), the grinding process takes place at overpressure (up to around 3 bar), which allows the process to be operated at higher temperatures. The higher temperatures result in more intensive softening of lignin and improved pulp qualities (e.g., higher strength), but the technical and financial requirements are considerably greater. Low-pressure steam is generated when the pulp is depressurized. The recovered low-pressure steam is usually used for the production of warm process water.

A relatively inexpensive method to improve the quality of groundwood is the thermogrinding process (TGW). In this process, the heat losses which result from evaporation in the grinding zone are reduced and the process temperature is optimized with stability controllers instead of increased pressure.

Recycled Fiber Pulping (RCF)

Recovered paper has become an increasingly important source of fiber for papermaking. Currently, nearly 50 percent of the fiber raw material for papermaking is based on recycled fiber.³⁴ In the recycling process, recycled paper or paperboard is rewetted and reduced to pulp, principally by mechanical means. Inks, adhesives, and other contaminants may be removed by chemical deinking and mechanical separation. Because the fibers in recycled paper and paperboard have been fully dried and then rewetted, they generally have different physical properties than virgin wood pulp fibers. In some cases, mills using recycled paper, without deinking, can operate without any effluent discharge due to the use of closed water cycles together with small anaerobic or aerobic biological treatment systems to

³⁴ U.S. EPA, Sector Notebook Project, Profile of the Pulp and Paper Industry, 2nd Edition, EPA/310-R-02-002, November 2002.

remove some dissolved organics from the recycled waters. The closed cycle processes are practical where the product can tolerate a certain degree of dirt and contamination, as in some packaging and construction paper grades. In some recycle plants, approximately 30 to 40% of the raw material processed results in sludge that requires management as a solid waste.

Without Deinking

Processing of recovered paper without deinking is sufficient for applications that do not require high brightness, such as corrugated board, carton board, and some tissue.

With Deinking

Deinking processes are used to remove ink to make the pulp brighter and cleaner. Sometimes bleaching is also applied after deinking. Recycled fiber with deinking is used for applications requiring higher brightness, such as newsprint, magazine paper, and tissue.

Process waters are similar to those from systems without deinking. However, deinking results in lower yields and requires additional internal treatment. The pulp yield may be as low as 60 to 70 percent of the recovered paper entering the process; therefore, as much as 30 to 40 percent of the entering material may enter the white water and need to be treated and removed before discharge of the wastewater.

Pulping Based on Non-Wood Raw Materials

Worldwide, non-wood sources make up about six percent of the total fiber supply for papermaking. Non-wood fibers are derived from agricultural fibers such as straw and other plant fibers such as bamboo, bagasse (residual of sugarcane refining), and annual fiber crops such as kenaf. In general, non-wood plant fibers are more costly to collect and process than wood fiber in regions of the world where wood supplies are adequate, and

thus pulp is produced almost exclusively from wood fiber in most regions of the world. However, substantial quantities of non-wood pulp are produced, especially in regions of Asia and Africa where wood fiber is relatively less abundant and non-wood fibers are available.

Bagasse, Straw, Reeds, etc.

Most non-wood fibers are relatively short, similar to fibers derived from hardwood, and therefore are suited to similar applications, such as writing paper. However, non-wood fibers are often used for other grades as well, such as newsprint and corrugated board, simply because local wood is not available for pulping.

Non-wood species normally cook more readily than wood chips. Thus, Kraft cooking is normally replaced with soda cooking (sodium hydroxide only), and the charge is usually less. The spent liquors usually have lower concentrations of dissolved organics and process chemicals compared with chemical pulping of wood, thus increasing the cost of chemical recovery. In addition, non-wood pulping plants are normally small, typically producing less than 100,000 t/yr of pulp, and therefore lack the economies of scale that make environmental investments economical at larger facilities. As a result, many non-wood mills have limited or no recovery of chemicals and have substantially higher waste emissions per ton of product than modern Kraft mills.

Non-wood plants normally contain higher amounts of silica than wood. Silica causes problems in chemical recovery and also adversely affects paper quality. In particular, silica increases scaling in the liquor evaporators and reduces the efficiency of both the causticizing operation and conversion of lime mud (calcium carbonate) to calcium oxide (burnt lime) in the lime kiln. To counter these effects, non-wood pulping facilities generally

discharge higher proportions of lime mud and purchase higher amounts of lime or limestone as make-up.

Cotton and Other Long Fibers

Certain non-wood fibers have special and valuable properties for specialty products. For example, cotton linters, hemp, flax, and abaca fibers are long and useful for products such as document papers with water marks, security papers, banknote paper, tea bags, etc. The production of these specialty products is small and, therefore, is of limited concern in terms of potential environmental impact.

Bleaching

Bleaching is any process that chemically alters pulp to increase its brightness. Bleached pulps create papers that are whiter, brighter, softer, and more absorbent than unbleached pulps. Bleached pulps are used for products where high purity is required and yellowing is not desired (e.g. printing and writing papers). Unbleached pulp is typically used to produce boxboard, linerboard, and grocery bags.

Any type of pulp may be bleached, but the type(s) of fiber and pulping processes used, as well as the desired qualities and end use of the final product, greatly affect the type and degree of pulp bleaching possible. The lignin content of a pulp is the major determinant of its bleaching potential. Pulps with high lignin content (e.g., mechanical or semi-chemical) are difficult to bleach fully and require heavy chemical inputs. Excessive bleaching of mechanical and semi-chemical pulps results in loss of pulp yield due to fiber destruction. Chemical pulps can be bleached to a greater extent due to their low (10 percent) lignin content.

Whereas delignification can be carried out within closed water systems, bleach plants tend to discharge effluent to external

treatment. Effluents from the bleach plant cannot easily be recirculated into the chemicals recovery mainly because they would increase the build-up of chlorides and other unwanted inorganic elements in the chemical recovery system, which can cause corrosion, scaling, and other problems.

Chemical Pulp

The chemicals most commonly used in chemical pulp bleaching plants are sodium hydroxide, chlorine dioxide, oxygen, ozone, and hydrogen peroxide. Peracetic acid has recently become commercially available as a bleaching chemical. Chlorine and hypochlorite have largely been phased out as primary bleaching chemicals over recent years. Small amounts of chlorine are formed as a by-product in most of the chlorine dioxide generation systems, and at least part of this chlorine will be present when chlorine dioxide is used in bleaching. Chlorine dioxide and ozone have to be produced on site. Peroxide, oxygen, and alkali can be delivered to the mills. Ozone is a very reactive bleaching agent, while chlorine dioxide, oxygen, and hydrogen peroxide are less reactive.

The introduction of extended cooking and oxygen delignification have resulted in more efficient recovery of organic substances and allowed development of and use of chemicals other than chlorine in bleaching, thereby significantly reducing the total amount of organic compounds and total amount of chlorinated organic compounds generated during bleaching. Enzyme treatment before bleaching can also enhance the effectiveness of the bleaching chemicals used but typically results in a small loss of yield.

A bleach plant consists of a sequence of typically four to five separate bleaching stages. Different chemicals are added at each stage, and acid and alkali stages are usually alternated. Each bleaching stage consists of devices for mixing the

chemicals and the pulp, a bleaching reactor designed with a suitable residence time for chemical reactions, and washing equipment for separation of used chemicals and removal of lignin and other dissolved materials from the pulp.

The two main types of bleaching methods in use are ECF (Elemental Chlorine Free--no molecular or gaseous chlorine is dosed in the bleaching) and TCF (Totally Chlorine Free) bleaching. ECF bleaching uses chlorine dioxide, alkali for the extraction of dissolved lignin, and peroxide and oxygen for the reinforcement of the extraction stages. TCF bleaching uses oxygen, ozone or peracetic acid, and peroxide with alkali for lignin extraction. Both ECF and TCF bleaching are used at Kraft mills, although ECF is the more common.

Mechanical Pulp

Bleaching of mechanical pulp is based on lignin-saving methods and is fundamentally different from bleaching of chemical pulps, which is based on removal of lignin. The bleaching of mechanical pulp changes chromophoric groups of lignin polymers into a colorless form. Thus, the bleaching of mechanical pulp increases primarily the brightness of the pulp with minimum losses of dry solids and overall yield. The effect is not permanent, and the paper yellows with time. As it does not result in permanent brightness gain, bleached mechanical pulp is more suitable for newsprint and magazine paper than for books or archive papers.

The lignin-saving bleaching is carried out in one to two stages, depending on the final brightness requirements of the pulp. The bleaching stages are distinguished according to the bleaching agent applied.

Reductive bleaching uses sodium dithionite ($\text{Na}_2\text{S}_2\text{O}_3$), which does not dissolve organic material from the pulp, and therefore

results in only a minimal reduction in yield. Residual dithionite in the pulp can cause corrosion of metallic components downstream in the process. In most mills a metal chelating agent (e.g. EDTA, DTPA) is used to prevent degradation of the dithionite.

Oxidative bleaching uses hydrogen peroxide (H_2O_2). Peroxide bleaching results in an approximately 2 percent reduction in yield, mainly due to the alkalinity during the bleaching that results in some dissolution of organic substances in the wood (and in an increase of pollution load). Peroxide bleaching also improves the strength and water uptake capacity of the pulp. The bleaching process results in lower brightness in the presence of heavy metal ions; therefore, chelating agents (e.g. EDTA, DTPA) are usually added before bleaching to form complexes with heavy metals (e.g., Fe, Mn, Cu, Cr), which prevents the pulp from discoloring and the peroxide from decomposing. EDTA and DTPA contain nitrogen, which enters the wastewater. Introduction of a washing stage between pulping and bleaching is effective in reducing the problematic metals and can thus reduce the amount of chelating agent needed and improve the effectiveness of the applied peroxide. The bleached pulp is acidified with sulfuric acid or sulfur dioxide to a pH of 5 - 6.

Papermaking

After pulping (and bleaching, if applicable), the finished pulp is processed into the stock used for paper manufacture. Market pulp, which is to be shipped off-site to paper or paperboard mills, is simply dried and baled during this step. Processing of pulp in integrated mills includes pulp blending specific to the desired paper product desired, dispersion in water, beating and refining to add density and strength, and addition of any necessary wet additives. Wet additives are used to create

paper products with special properties or to facilitate the papermaking process. Wet additives include resins and waxes for water repellency; fillers such as clays, silicas, and talc; inorganic and organic dyes for coloring; and certain inorganic chemicals (e.g., calcium sulfate, zinc sulfide, and titanium dioxide) for improved texture, print quality, opacity, and brightness.

The processed pulp is converted into a paper product via a paper production machine, traditionally a Fourdrinier type machine, but increasingly using proprietary twin-wire systems. In paper machines, the fiber slurry is deposited on a moving wire belt that carries it through the first stages of the process. Water is removed by gravity, vacuum chambers, and vacuum rolls. This excess water is recycled to the fiber recovery step of the process due to its high fiber content. The continuous sheet is then pressed between a series of cylinders to remove more water and compress the fibers.

After pressing, the sheet enters a drying section, where the paper fibers begin to bond together as steam heated cylinders compress the sheets. In the calender process, the sheet is pressed between heavy rolls to reduce paper thickness and produce a smooth surface. Coatings can be applied to the paper at this point to improve gloss, color, printing detail, and brilliance. Lighter coatings are applied on-machine, while heavy coatings are performed off-machine. The paper product is then spooled for storage.

Annex B - Effluents and Emissions Guidelines / Resource Use Benchmarks

Table 1 (a)—Effluent Guidelines for Pulp and Paper Facilities--Bleached Kraft Pulp, Integrated

Parameter	Units	Guideline
Flow ^a	m ³ /ADt	50
pH		6 – 9
TSS	kg/ADt	1.5
COD	kg/ADt	20
BOD ₅	kg/ADt	1
AOX	kg/ADt	0.25
Total N	kg/ADt	0.2 ^b
Total P	kg/ADt	0.03

Table 1 (b)—Effluent Guidelines for Pulp and Paper Facilities--Unbleached Kraft Pulp, Integrated

Parameter	Units	Guideline
Flow ^a	m ³ /ADt	25
pH		6 – 9
TSS	kg/ADt	1.0
COD	kg/ADt	10
BOD ₅	kg/ADt	0.7
Total N	kg/ADt	0.2
Total P	kg/ADt	0.02

Table 1 (c)—Effluent Guidelines for Sulfite Pulp and Paper Facilities—Sulfite Pulp, Integrated and Non-Integrated

Parameter	Units	Guideline
Flow ^a	m ³ /ADt	55 ^d
pH		6 – 9
TSS	kg/ADt	2.0
COD	kg/ADt	30 ^e
BOD ₅	kg/ADt	2.0
AOX	kg/ADt	0.005
Total N	kg/ADt	0.5
Total P	kg/ADt	0.05

Table 1 (d)—Effluent Guidelines for CTMP Facilities

Parameter	Units	Guideline
Flow ^a	m ³ /ADt	20
pH		6 – 9
TSS	kg/ADt	1.0
COD	kg/ADt	5
BOD ₅	kg/ADt	1.0
Total N	kg/ADt	0.2
Total P	kg/ADt	0.01

Table 1 (e)—Effluent Guidelines for Pulp and Paper Facilities—Mechanical Pulping, Integrated

Parameter	Units	Guideline
Flow ^a	m ³ /ADt	20
pH		6 – 9
TSS	kg/ADt	0.5
COD	kg/ADt	5.0
BOD ₅	kg/ADt	0.5
AOX	kg/ADt	0.01
Total N	kg/ADt	0.1
Total P	kg/ADt	0.01

Table 1(f)—Effluent Guidelines for Pulp and Paper Facilities—Recycled Fiber, Without Deinking, Integrated

Parameter	Units	Guideline
Flow ^a	m ³ /ADt	10
pH		6 – 9
TSS	kg/ADt	0.15
COD	kg/ADt	1.5
BOD ₅	kg/ADt	0.15
AOX	kg/ADt	0.005
Total N	kg/ADt	0.05
Total P	kg/ADt	0.005

Table 1(g)—Effluent Guidelines for Pulp and Paper Facilities—Recycled Fiber, With Deinking, Integrated

Parameter	Units	Guideline
Flow ^a	m ³ /ADt	15
pH		6 – 9
TSS	kg/ADt	0.3
COD	kg/ADt	4.0
BOD ₅	kg/ADt	0.2
AOX	kg/ADt	0.005
Total N	kg/ADt	0.1
Total P	kg/ADt	0.01

Table 1 (h)—Effluent Guidelines for Pulp and Paper Facilities—Recycled Fiber Tissue Mills

Parameter	Units	Guideline
Flow ^a	m ³ /ADt	25
pH		6 – 9
TSS	kg/ADt	0.4
COD	kg/ADt	4.0
BOD ₅	kg/ADt	0.5
AOX	kg/ADt	0.005
Total N	kg/ADt	0.25
Total P	kg/ADt	0.015

Table 1 (i)—Effluent Guidelines for Pulp and Paper Facilities—Uncoated Fine Paper Mills

Parameter	Units	Guideline
Flow ^a	m ³ /ADt	15
pH		6 – 9
TSS	kg/ADt	0.4
COD	kg/ADt	2.0
BOD ₅	kg/ADt	0.25
AOX	kg/ADt	0.005
Total N	kg/ADt	0.2
Total P	kg/ADt	0.01

Table 1 (j)—Effluent Guidelines for Pulp and Paper Facilities—Coated Fine Paper Mills

Parameter	Units	Guideline
Flow ^a	m ³ /ADt	15
pH		6 – 9
TSS	kg/ADt	0.4
COD	kg/ADt	1.5
BOD ₅	kg/ADt	0.25
AOX	kg/ADt	0.005
Total N	kg/ADt	0.2
Total P	kg/ADt	0.01

Table 1 (k)—Effluent Guidelines for Pulp and Paper Facilities—Tissue Mills

Parameter	Units	Guideline
Flow ^a	m ³ /ADt	25 k
pH		6 – 9
TSS	kg/ADt	0.4
COD	kg/ADt	1.5
BOD ₅	kg/ADt	0.4
AOX	kg/ADt	0.01
Total N	kg/ADt	0.25
Total P	kg/ADt	0.015

Table 1 (l)—Effluent Guidelines for Pulp and Paper Facilities—Fiber Preparation, Non-Wood

Parameter	Units	Guideline
Flow ^a	m ³ /ADt	50
pH		6 – 9
TSS	kg/ADt	2.0
COD	kg/ADt	30
BOD ₅	kg/ADt	2.0
Total N	kg/ADt	0.5
Total P	kg/ADt	0.05

Sources: European Commission. 2001. *Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques in the Pulp and Paper Industry*. December 2001; and U.S. EPA Effluent Guidelines for the Pulp, Paper, and Paperboard Point Source Category, 40 CFR Part 430.

Notes:

kg/ADt = kilograms of pollutant per 1,000 kg of air dry pulp

- a Cooling water and other clean water are discharged separately and are not included.*
- b Any nitrogen discharge associated with the use of complexing agents should be added to the figure of tot-N.*
- c Because of higher kappa number after cooking for magnefite process the BAT associated level is 35 kg COD/ADt.*
- d Does not include process water from the paper mill in integrated sulfite pulp mills.*

Table 2—Emission Guidelines for Pulp and Paper Facilities

Parameter	Type of Mill	Units	Guideline Value
TSP	Kraft, bleached	kg/ADt	0.5
	Kraft, unbleached—Integrated	kg/ADt	0.5
	Sulfite, integrated and non-integrated	kg/ADt	0.15
SO ₂ as S	Kraft, bleached	kg/ADt	0.4
	Kraft, unbleached—Integrated	kg/ADt	0.4
	Sulfite, integrated and non-integrated	kg/ADt	1.0
NO _x as NO ₂	Kraft, bleached	kg/ADt	1.5 for hardwood pulp 2.0 for softwood pulp
	Kraft, unbleached—Integrated		1.5 for hardwood pulp 2.0 for softwood pulp
	Sulfite, integrated and non-integrated		2.0
TRS as S	Kraft, bleached	kg/ADt	0.2
	Kraft, unbleached—Integrated	kg/ADt	0.2

Sources: European Commission. 2001. *Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques in the Pulp and Paper Industry*. December 2001; and U.S. EPA National Emission Standards for Hazardous Air Pollutants For Source Categories, 40 CFR Part 63. Notes:

TSP= total suspended particulates

SO₂ = sulfur dioxide

S = sulfur

NO₂ = nitrogen dioxide

N = nitrogen

TRS = total reduced sulfur compounds

Kg/ADt = kilograms of pollutant per 1,000 kg of air dry pulp

Table 3—Energy and Water Consumption

Mill Type	Reported Ranges		
	Water Consumption (m ³ /t) ^a	Heat Energy (GJ/t)	Electrical Energy (kWh/t)
Kraft Pulping, bleached	20 – 100 ^b	10 - 14	600 – 1200 ⁱ
Sulfite Pulping (magnesium base)	40 - 100		
Mechanical Pulping--Groundwood	5 – 15		1100 – 2200 ^c
Mechanical Pulping--TMP	4 – 10		1800 – 3600 ^d
Mechanical Pulping—CTMP	15 - 50		1000 – 4300 ^e
Recovered Paper Mill—Uncoated Folding Boxboard	2 – 10		
Recovered Paper Mill—Coated Folding Boxboard	7 – 15		
Recovered Paper Mill—Corrugated Medium and Packaging Paper	1.5 – 10		
Recovered Paper Mill—Newsprint	10 – 20		
Recovered Paper Mill—Tissue	5 – 100 ^c		
Recovered Paper Mill—Writing and Printing Paper	7 - 20		
Paper Mill—Tissue	10 – 50 ^f		500 – 3000
Paper Mill—Printing and Writing Paper, Uncoated	5 – 40 ^g		500 – 650
Paper Mill—Printing and Writing Paper, Coated	5 – 50 ^g		650 - 900
Paper Mill—Paper Board	0 – 20 ^h		-550 - 680
Paper Mill—Specialty Paper	10 - 300		

Source: European Commission. 2001. *Integrated Pollution Prevention and Control (IPPC) Reference Document on Best Available Techniques in the Pulp and Paper Industry*. December 2001

Notes:

- a. Clean cooling water is generally not reported as part of the water consumption.
- b. Reported quantities greater than about 50 m³/t probably include cooling water.
- c. Approximately 20% of energy is recoverable as hot water.
- d. Approximately 20% of energy is recoverable as hot water, and about 40 – 45% of energy is recoverable as steam.
- e. Water consumption in tissue mills is highly dependent of the process conditions (e.g., machine speed) and product (e.g., basis weight). Because of the low basis weight of the product, water consumption per ton of product can be higher than for other types of paper mills.
- f. For RCF based tissue; includes RCF processing
- g. May include water used in pulp processing
- h. Includes water used in pulp processing.
- i. Modern bleached kraft mills are net exporters of electricity typically generating about 30% more than they consume by burning black liquor and bark.