NAICS Code: 322120 - Paper mills (Sulfite variation)

SUMMARY INFO: Sulfite paper manufacturing dominated U.S. paper production in the 19th and early 20th century, bleaching sulfite pulp to produce soft, bright paper. It has since gradually declined in use, overtaken by Kraft paper production, which more efficiently produces paper for commercial use.[1] Sulfite plants no longer produce large-scale commodity paper, though existing small-scale production supports employment in timber-rich areas. These facilities produce bright, durable sulfite papers used in specialty paper products, tissue, and food-grade paper packaging like bakery bags.[2]

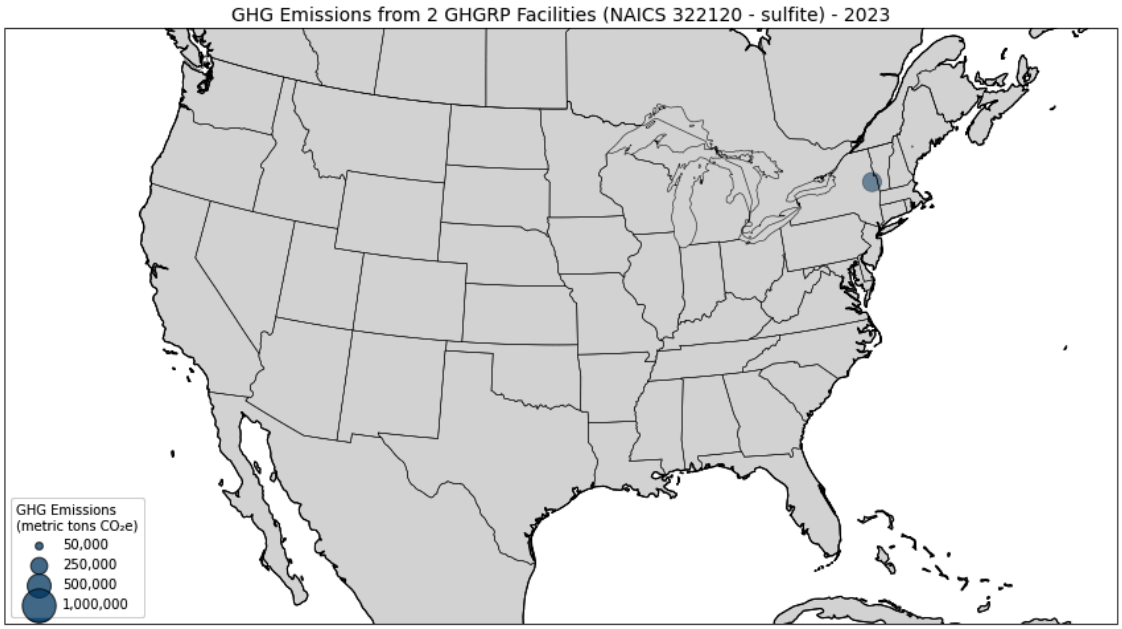
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Link to archetype code:
https://github.com/ISALGroup/archetypes/blob/main/archetypes_list/sulfite_paper_mill.py

Archetype Name: Pulp mill Sulfite

Emissions and facility overview: According to the United States Census Bureau, there are 159 establishments associated with NAICS 322120 in the United States in 2023, 90 of which are plants that report annual GHG emissions in the GHGRP.[3] According to the criteria outlined in the Technical Appendix (i.e. presence of a recovery boiler and no lime kiln onsite in the GHGRP dataset), two of the 90 paper mills have been classified as mills using a Sulfite process. Reported emissions from GHGRP amounted to 47.2 Mt CO_2e in 2023 for all plants with the 322120 NAICS code, including biogenic emissions. The two plants classified as Sulfite mills account for 0.3 Mt CO_2e, or 0.7% of the emissions reported in the GHGRP. The plants are located in the Northeastern U.S., as summarized in the map below.



[1] David McKeever. The United States Woodpulp Industry. USDA. 1987.
[2] Oumar Fofana. Sulphite paper in modern packaging. October 2025.
[3] U.S. Census Bureau. 2023: ECNSVY Business Patterns County Business Patterns CB2300CBP. 2023; U.S. Environmental Protection Agency. Greenhouse Gas Reporting Program (GHGRP). 2025.

Sector outputs: Paper mills manufacture paper as a final product and exclude paperboard products

Process pathways: Paper manufacturing consists of extracting cellulose fibers to make pulp and then processing that pulp by aligning fibers, pressing them, and drying the sheet to transform it into market-ready products. These fibers come from two main sources:

- Recovered paper
- Virgin fibers

Recovered fibers come from used paper that gets treated to be cleaned, de-inked and re-pulped and dried to make market pulp. The U.S. has a fairly high rate of recovered paper of 65.8% in 2017,[4] and this means that recycling of pulp cannot be ignored and will be included in the presented models.

When fibers come from virgin sources (i.e., wood cut for the express purpose of manufacturing paper products), there are several pathways available to recover cellulose from the wood matrix, which contains cellulose, lignin, and hemicellulose. These pathways are typically classified into mechanical processes, which rely on grinding wood to release the fibers, and chemical processes, which rely on chemical reactions to dissolve lignin to free the fibers. According to FAO,[5] the sulfite process is responsible for 0.5% of the production capacity of paper pulp in the U.S. and 47.2% of pulp is bleached. As such, bleaching of pulp cannot be ignored and will be included in the models. Furthermore, according to Ek et al.[6], the majority (75%) of virgin paper produced worldwide is obtained through chemical processes, while the mechanical and semi-chemical (which includes both chemical separation and mechanical grinding) methods are responsible for around 20% and 5% of global production respectively. Among the chemical methods, the Kraft process is responsible for the vast majority of the production (~90%), while the main other production route is the sulfite method. Tran and Vakkilainnen[7] also support that assessment, stating that ⅔ of the global virgin fiber production comes from the Kraft process among all processes, and 90% of the chemical processes. In addition, that pulp can then be made into different products, like paper, paperboard or specialized paper products. This specific document focuses on the sulfite process for paper production.

Process overview: Figure 1 represents the process flow diagram of a pulp production mill that uses the sulfite process. A large part of the process overview section is based on the "Pulp and Paper Chemistry and Technology" series.[8]

The Sulfite pulping process can be broadly separated into 6 distinct phases: wood handling, digestion/cooking, chemical recovery, bleaching and finishing for the main production line, and a paper recycling phase for recovering waste paper.

[4] James L. Howard and Shaobo Lang. U.S. Timber Production, Trade, Consumption, and Price Statistics, 1965-2017. USDA. 2019.
[5] Food and Agriculture Organization of the United Nations. Pulp and Paper Capacities Survey 2023-2025. 2024.
[6] Monica Ek et al. Pulp and Paper Chemistry and Technology Volume 2: Pulping Chemistry and Technology. 2009.
[7] Honghi Tran and Esa K. Vakkilainnen. The Kraft Chemical Recovery Process. 2008.
[8] Monica Ek et al. Pulp and Paper Chemistry and Technology Volume 1: Wood Chemistry and Wood Biotechnology. 2009; Monica Ek et al. Pulp and Paper Chemistry and Technology Volume 2: Pulping Chemistry and Technology. 2009; Monica Ek et al. Pulp and Paper Chemistry and Technology Volume 3: Paper Chemistry and Technology. 2009; Monica Ek et al. Pulp and Paper Chemistry and Technology Volume 4: Paper Products Physics and Technology. 2009.

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Wood Handling Production Line: This first phase consists of cutting logs to get wood chips that can be treated in the digesters and impregnated in chemicals. There are four process units in that phase: debarking, bark press, chipping, and screening.

Debarking (sometimes also called "barking") consists of removing the bark from the other wood material. In general, bark refers to the outer layer of the tree, but can refer to a large variety of cells considered as bark. Some of them have a morphology similar to the rest of the wood and similar composition in terms of cellulose, hemicellulose, and lignin, but other cells are mostly composed of extractives and minerals. While bark does contain cellulose that could be used to produce paper pulp, it is typically not used for making pulp and is discarded to be burned instead. The reasons for not using bark in pulp making are numerous: the fiber content of bark is fairly low (~20%),[9] making it relatively unprofitable to recover that low quantity of fibers. Bark can also contain a variety of impurities, like grains of sand that would induce heavy wear in the chipper. Some of those impurities, if undegraded in the digestion and bleaching steps, could also be left in the fibers and stain pulp or paper. The proportion of bark can vary depending on a wide variety of factors, like the tree's species, its size and age, or even climate factors. According to the USDA Forest Service,[10] a typical range would be between 13 and 21% of bark proportion by dry weight. Barking is typically done in rotary drum barkers, in which logs rub against each other to create friction to remove the bark. As bark gets separated from the logs, it gets collected for further processing. Note that debarking does not remove all bark, and some remains after treatment. An estimated 1% of bark by dry weight remains in debarked logs, but this can vary.[11]

The removed bark can then be used as hog fuel burned in Stoker (solid fuel) boilers. Bark contains a lot of moisture (55%-60% for birch, pine, and spruce),[12] and high moisture contents make bark burning difficult. To that end, a bark press is typically used to remove moisture from the detached bark.

The debarked logs are then processed into smaller pieces of wood – chips – in a chipper unit. Making smaller pieces is a necessary step in chemical processes to ensure optimal chemical and heat distribution. The most common chippers are disk chippers, which consist of radially arranged blades, toward which logs are fed, often either through feeders that use gravity or horizontal conveyor belts. Chips are typically 20-30 mm in length, 3-8 mm in thickness, and 15-30 mm in width.[13]

The last step of wood handling consists of screening the wood chips to have a uniform chip size to ensure a uniform digestion process. Depending on chipper blade wear or log type, larger chips (overthick) or larger pieces of wood may be present in the chipper outlet. Similarly, thinner chips and fines like sawdust may appear in the chipper outlet. Screening is necessary to recirculate larger chips and wood pieces back to the chippers to achieve the right thickness, while finer chips and sawdust are filtered out to be burned or processed out of the facility. Screens or disks can be used to sieve the different chip sizes. The proportion of fines in the processed wood varies depending on wood type and screening technology. Some sources[14] estimate 90% accepted chips, and thus 10% fines and thinner chips.

The moisture content of wood can vary widely depending on weather, wood type, and storage

[9] Monica Ek et al. Pulp and Paper Chemistry and Technology Volume 2: Pulping Chemistry and Technology. 2009.
[10] John M. Harkin and John W. Rowe. Bark and its Possible Uses. USDA. 1971.
[11] Johan Gullichsen et al. Papermaking Science and Technology, Book 6B. Chemical Pulping. 2000; Jyrki Laitinen. Determination of residual bark in debarked pulpwood using image analysis. January 2001.
[12] Johan Gullichsen et al. Papermaking Science and Technology, Book 6B. Chemical Pulping. 2000.
[13] Monica Ek et al. Pulp and Paper Chemistry and Technology Volume 2: Pulping Chemistry and Technology. 2009.
[14] Desmond E. Smith and Shannon R. Javid. New approaches to fines and pins screening. January 1992.

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conditions. Larger ranges of wood moisture content in the USDA report[15] are 25.9-75.1%.

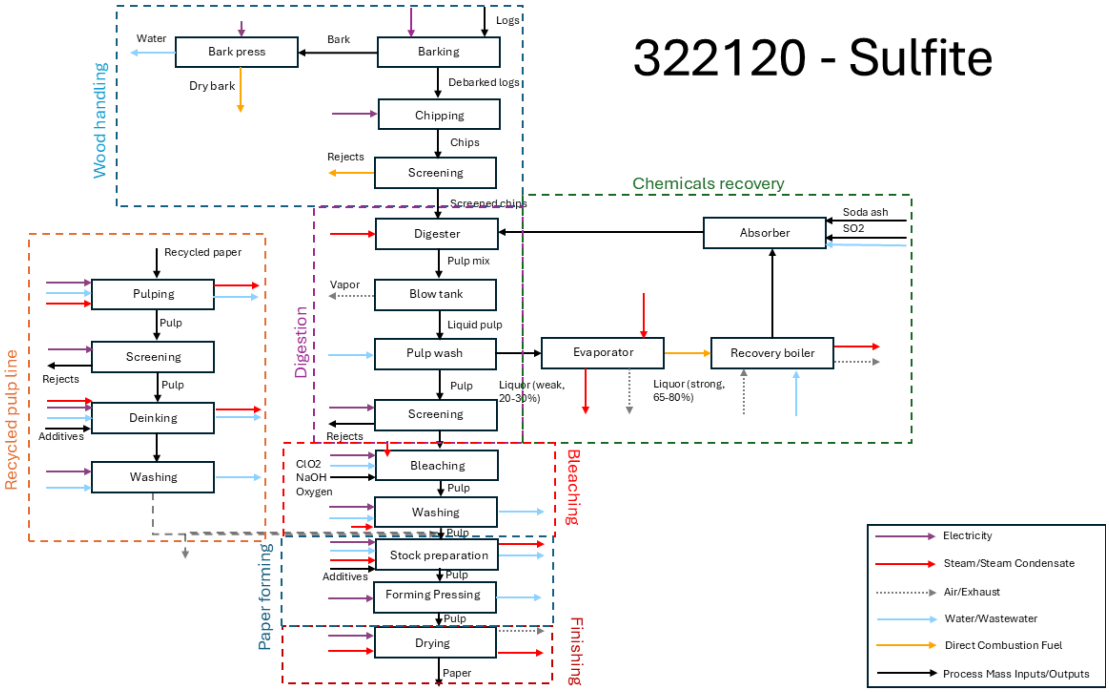


Figure 1: Sulfite Integrated Paper Mills Archetype Process Flow Diagram

Once properly-sized chips are obtained, they are sent to the digester to begin chemical delignification of the wood. In the sulfite process, most chemicals used in digestion are recovered and reused. The sulfite process line is then separated into 2 parts for this description: the digestion and the recovery of chemicals.

Digestion Production Line: The lignin that holds the cellulose fibers together is made water-soluble by the action of hydroxide and hydrosulfide ions. Digestion involves mixing wood chips with a cooking liquor typically made of a solution of water, sulfur dioxide (SO_2) and calcium, sodium, magnesium or ammonium bisulfite (NH_4HSO_3) and saturated steam in a pressurized vessel.[16] For the representative model chosen in this archetype, a magnesium base is assumed. Digesters can come in a variety of configurations, typically separated into batch digesters, which typically consist of a vertical cylinder filled with chips, cooking liquor and steam and closed, and continuous process digesters, which rely on continuous screw feeders for the cooking process. Cooking temperature typically ranges from 160-180°C.[17] The cooking liquor is recovered in a separate line and reused for digestion.

The pressurized pulp mixture is sent to a blow tank to separate the liquid pulp and steam to send the liquid pulp for washing and treatment. The blow tank operates at atmospheric pressure and separates the two phases. The quantity of steam and the composition of liquid pulp is determined through an energy balance.

[15] John R. Erickson. The Moisture Content and Specific Gravity of the Bark and Wood of Northern Pulpwood Species. USDA. 1972.
[16] Drake Mboowa. A review of the traditional pulping methods and the recent improvements in the pulping process. January 2021.
[17] Ibid.

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Liquid pulp is sent for washing, which separates the cellulose fibers and the dissolved lignin. Water is circulated through the pulp to extract non-cellulose materials. The washing water takes away the now water-soluble dissolved lignin and other wood carbohydrates, and that mixture of water, dissolved solids, and chemicals is known as brown liquor. The fibers are extracted at another end of the washer thanks to filters. Part of the wood is digested and ends up as dry solids in brown liquor; however, the sulfite process boasts a 5% higher yield compared to the kraft process.[18] Brown liquor is sent to the chemical recovery loop, while pulp is sent for screening. Screened pulp is then sent for bleaching.

Chemical Recovery Production Line: The chemical recovery loop consists of concentrating brown liquor to an acceptable level, burning it in recovery boilers to recover heat from the dissolved solids, and then regenerating the chemicals from the smelt and flue gas generated in the recovery boilers. Brown liquor after washing has a low dry content of less than 20%, which makes it highly unsuitable for combustion. The concentration in the models is calculated according to the parameters of the washing step.

The first step treats brown liquor by concentrating the dry solids. Dry solids are concentrated to 70% dry content, which is the lower bound of Ek et al.[19] and the upper bound of Biermann.[20] To reduce energy demand during brown liquor concentration, multiple-effect evaporators are used. These are evaporation units arranged in series, which separate the incoming mixture into a concentrated fraction and remove moisture as steam. Steam from each evaporation unit heats the next unit, with each unit at higher pressure than the next to lower the boiling point. This means the first unit receives live steam, and its heat is reused by using its steam in the next unit, and so on. In modern plants, a counter-current configuration is typically used, where the input weak brown liquor with the highest moisture content is placed last in line, while the evaporation unit producing strong brown liquor for combustion receives live steam. A single-effect evaporator would evaporate less than 1 ton of water from the product for every ton of live steam fed into the unit, while multiple-effect evaporators can evaporate multiple tons of water for every ton of steam fed. This ratio of water evaporated to input steam is called steam economy. This ratio is dependent on several factors, the most important of which is the amount of evaporation units used. To keep a general approach that includes older and smaller plants, a conservative estimate is kept, but can be modified in the models to suit modern processes.

After evaporation, strong brown liquor is sent to the recovery boilers for combustion. This combustion serves two purposes:

- It valorizes the undigested wood by producing a large amount of heat in the form of steam that can be used for the other process units, like the digester or the evaporators, but also to produce electricity that can power the process or be sold to utilities
- The combustion products contain the reacted chemicals from the cooking liquor that can be recovered to be reinjected into the digester through a recovery loop

Strong brown liquor is combusted in the recovery boilers. It has an energy content similar to typical woody fuels, and combustion releases energy and is valorized in the form of steam. Flue gases (composed of magnesium oxide (MgO) particulates and SO_2) are recovered. MgO is recovered via cyclones and slaked with water to produce magnesium hydroxide. Gases are cooled, and SO_2 reacts with magnesium hydroxide to produce a magnesium bisulfite solution used for the cooking liquor, along with make up SO_2.

[18] Lawrence Berkeley National Laboratory. Opportunities to Improve Energy Efficiency and Reduce Greenhouse Gas Emissions in the U.S. Pulp and Paper Industry. July 2000; Christopher J. Biermann. Handbook of Pulping and Papermaking. 1996.
[19] Ibid.
[20] Christopher J. Biermann. Handbook of Pulping and Papermaking. 1996

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Bleaching Production Line: Bleaching is not always necessary, but a brighter pulp or paper may be desired. In this case, pulp is sent for bleaching to remove the darker color from residual lignin after cooking. This is included as most chemically produced pulp is bleached to obtain brighter pulp and paper. Bleaching stages typically use different chemicals in sequence, although several chemicals can sometimes be used simultaneously in one stage. Various chemicals can be used for bleaching, including acid treatment, chlorine, chlorine dioxide, oxygen, hydrogen peroxide, and ozone, with no standard for chemical application, allowing flexibility in this step. After the bleaching stages, bleached pulp is washed to remove bleached material and chemicals.

Recycling Production Line: Pulp can also be sourced from recycled paper at end-of-life by re-pulping waste paper and treating it to remove impurities. This is broadly divided into four steps: pulping, screening, de-inking, and washing.

Pulping typically takes place in drum pulpers or high-consistency batch pulpers with a consistency of 12%-18%.[21] Conventional pulpers are assumed to run at 80°C. It is assumed to take between 16 and 39 kWh per ton of pulp, with a baseline at 28 kWh.

Then, a screening step takes place and is assumed to be in the same condition as the main kraft line. De-inking is a flotation process that usually takes place between 1% and 2% consistency with a baseline at 1.5% and at temperatures between 40°C and 45°C.[22]

Then, a screening step takes place and is assumed to be in the same condition as the main sulfite line. De-inking is a flotation process assumed to take place between 1% and 2% consistency with a baseline at 1.5% and to be staying at a temperature between 40°C and 45°C.
Finally, a washing step takes place in the same conditions as the washing in the main sulfite line.

Paper Forming Production Line: Finally, pulp is sent to be formed into paper. This step consists of preparing the pulp to be formed into a net of fibers, then sending it into a Fourdrinier machine, which allows the continuous production of paper. This machine consists of several sections; three are modeled in this work: forming, pressing, and drying. Stock preparation occurs at 40-45°C,[23] at around 4% consistency as well as requiring around 10 m^3 of effluent per ton of paper.[24] Forming and pressing paper consistencies are 20% and 40% after the wire section and after the press section, respectively.[25]
Paper is then assumed to be sent to multi-cylinder dryers. Typical moisture content in paper is around 5%.[26]

Archetype Unit Process Assumptions:

In this work, we assume that wood and bark have moisture contents of 55% in weight. The model used is depicted in Figure 1, and Table 1 contains the assumptions made in each process unit of the model.

Limitations and future work: Generic units were modeled for dryers and evaporators. Additives use modeling lacks some details, but these would have a low impact on overall process heat demand. At the time of report production, numbers from DOE were used in order to supplement energy demand per process unit as the recycled paper line was not yet included in the models. Paper treatment is also

[21] Pratima Bajpai. Recycling and Deinking of Recovered Paper. 2024.
[22] Pratima Bajpai. Recycling and Deinking of Recovered Paper. 2024.
[23] Pratima Bajpai. Pulp and Paper Industry: Energy Conservation. 2016.
[24] Monica Ek et al. Pulp and Paper Chemistry and Technology Volume 3: Paper Chemistry and Technology. 2009.
[25] Ibid.
[26] Monica Ek et al. Pulp and Paper Chemistry and Technology Volume 3: Paper Chemistry and Technology. 2009.

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assumed to be done in cylinder dryers.

Table 1: Sulfite Paper Mill Archetype Unit Process Assumptions

Unit Process Name	Assumptions	Parameter Basis	Source
Barking	Bark : 15.0% of dry weight	Literature-derived	Johan Gullichsen et al. Papermaking Science and Technology, Book 6B. Chemical Pulping. 2000; Jyrki Laitinen. Determination of residual bark in debarked pulpwood using image analysis. January 2001.
Bark press	Bark moisture drop: 15%	Literature-derived	André Holmberg and Stig Stenström. Dewatering and Drying of Bark. 2014.
	Bark heating value: 5900 kJ/kg	Literature-derived	Dan Gavrilescu. Energy from biomass in pulp and paper mills. 2008.
Chippers	Chippers electricity use: 30.3 kWh/ton	Literature-derived	Lawrence Berkeley National Laboratory. Opportunities to Improve Energy Efficiency and Reduce Greenhouse Gas Emissions in the U.S. Pulp and Paper Industry. July 2000.
Screening	Rejects ratio: 5%	Engineering judgment	Monica Ek et al. Pulp and Paper Chemistry and Technology Volume 2: Pulping Chemistry and Technology. 2009.
Digester	Steam temperature: 170 ℃	Engineering judgment	
	Recycled digestion liquor temperature: 45 ℃	Engineering judgment	
	Digestion liquor/chips ratio: 1.0	Literature-derived	Harry L. Brown et al. Energy Analysis of 108 Industrial Processes. 1996. Monica Ek et al. Pulp and Paper Chemistry and Technology Volume 2: Pulping Chemistry and Technology. 2009.
	Digestion liquor composition: SO2: 4.5% MgO: 1.45%	Literature-derived	Tomlinson G.H.Sulphite Pulping Patent. June 4, 1963.
	Yield: 55%	Literature-derived	Lawrence Berkeley National Laboratory. Opportunities to Improve Energy Efficiency and Reduce Greenhouse Gas Emissions in the U.S. Pulp and Paper Industry. July 2000; Christopher J. Biermann. Handbook of Pulping and Papermaking. 1996.

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Pulp wash	Electricity:3 kWh/ ton liquid pulp	Literature-derived	Monica Ek et al. Pulp and Paper Chemistry and Technology Volume 2: Pulping Chemistry and Technology. 2009.
	Water-to-pulp ratio: 1.0	Literature-derived	Monica Ek et al. Pulp and Paper Chemistry and Technology Volume 2: Pulping Chemistry and Technology. 2009.
Evaporators	Steam economy: 4	Literature-derived	David T. Clay. Evaporation Principles & Black Liquor Properties. 2008.
Recovery boilers	Dry brown liquor energy content: 15MJ/kg	Literature-derived	Honghi Tran and Esa K. Vakkilainnen. The Kraft Chemical Recovery Process. 2008; International Flame Research Foundation. What is black liquor? April 2003.
	Brown liquor elemental carbon content: 35%	Literature-derived	David T. Clay. Evaporation Principles & Black Liquor Properties. 2008.
	Dry solids content: 5%	Engineering judgment	
Bleaching	Number of steps: 3	Engineering judgment	
	Chemicals used in each step: NaOH, O_2, ClO_2	Literature-derived	European Commission. Best Available Techniques (BAT) Reference Document for the Production of Pulp, Paper and Board. 2015.
	Chemicals amount per stage: ClO_2: 1.5% pulp mass O_2: 10 kg/ton of pulp NaOH: 20 kg/ton of pulp	Literature-derived	Harry L. Brown et al. Energy Analysis of 108 Industrial Processes. 1996. Confederation of European Paper Industries. Best Available Technology in the Manufacturing of Pulp. 1997
	Dry content: 10%	Literature-derived	Monica Ek et al. Pulp and Paper Chemistry and Technology Volume 2: Pulping Chemistry and Technology. 2009.
	Bleaching losses: 10%	Literature-derived	Harry L. Brown et al. Energy Analysis of 108 Industrial Processes. 1996.
	Bleaching temperature: 100 ℃	Literature-derived	Monica Ek et al. Pulp and Paper Chemistry and Technology Volume 2: Pulping Chemistry and Technology. 2009.
Stock preparation	Electricity: 274 kWh/ton paper	Literature-derived	Lawrence Berkeley National Laboratory. Opportunities to Improve Energy Efficiency and Reduce Greenhouse Gas Emissions in the U.S. Pulp and Paper Industry. July 2000.
Forming pressing	Electricity: 238 kWh/ton paper	Literature-derived	Lawrence Berkeley National Laboratory. Opportunities to Improve Energy Efficiency and Reduce Greenhouse Gas

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			Emissions in the U.S. Pulp and Paper Industry. July 2000.
Paper dryer	Market paper moisture content: 5%	Engineering judgment	
	Air temperature: 110℃	Engineering judgment	
	Exhaust temperature: 100℃	Engineering judgment	
Recycling line pulper	Temperature: 80℃	Literature-derived	Jerry Aue et al. Fiber Recovery from Waste Paper: A Breakthrough in Re-Pulping Technology. 2004.
	Electricity: 28 kWh/ton pulp	Literature-derived	Pratima Bajpai. Pulp and Paper Industry: Energy Conservation. 2016.

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