An Update on Biopulping Commericialization

Gary M. Scott, Ph.D.
Associate Professor
Faculty of Paper Science and Engineering
State University of New York, College of Environmental Science and Forestry
One Forestry Drive, Syracuse, NY 13224

Masood Akhtar, Ph.D.
President
Biopulping International, Inc.
P.O. Box 5463
Madison, WI, 53705

T. Kent Kirk, Ph.D.
Professor
Department of Bacteriology
University of Wisconsin
E.B. Fred Hall, 1550 Linden Drive
Madison, WI 53706

ABSTRACT
Biopulping is defined as the treatment of wood or other lignocellulosics with a natural lignin-degrading fungus prior to pulping. Research consortia made up of the USDA Forest Service, Forest Products Laboratory in Madison and the Universities of Wisconsin and Minnesota have evaluated biopulping from a small laboratory scale to a 50-ton semi-commercial scale over the past 12 years. The investigations were supported in part by 23 pulp and paper and related companies and the Energy Center of Wisconsin. The State University of New York, College of Environmental Science and Forestry has also joined as a partner in this research. The research established that biopulping substantially lowers the electrical energy required for mechanical pulping (or increases mill throughput), improves certain strength properties (reducing the need to augment with chemical pulps), and reduces environmental impact. Biopulping also reduces the pitch content of the pulp.

At a pilot scale, we have developed methods for decontamination of wood chips, cooling, and fungal inoculation sequentially in screw conveyers, and controlling temperature and moisture throughout the chip pile. Mill-scale refining of fungus-treated chips gave results similar to those obtained using the laboratory-scale bioreactors. With this information, a complete process flowsheet has been established for the commercial operation of the process. Based on the electrical energy savings and the strength improvements, the process economics looks very attractive. Several independent economic evaluations of biopulping have now been completed by both university and industry economists and engineers and are in agreement. Based on 33% energy savings and a 5% reduction in kraft pulp in the final product, a savings of about $ 5 million each year can be realized. The additional benefits of increased throughput, and reduced pitch content and environmental impact improve the economic picture for this technology even further. It has now passed through the science and the engineering evaluation phases, and is in the realm of business.

One of the chemical companies has already agreed to produce and supply fungal inoculum on a commercial scale. No adverse effects of lignin-degrading fungi on humans have been reported in the literature. These fungi are natural wood decayers. However, a biopulping operation would entail producing substantial amounts of fungus in a pile on a routine basis. For that reason, the best biopulping fungus, Ceriporiopsis subvermisprora, was tested by professionals for adverse effects on humans. It was concluded that the fungus is safe for use on a commercial scale. One of the paper companies has hired a professional company to look into the effects of the technology on the environment. The company is currently analyzing VOC's given off during biopulping and comparing them with those from a standard chip pile storage. This paper will summarize biopulping process development and commercialization.

INTRODUCTION

Mechanical pulping accounts for about 25% of the wood pulp production in the world today. This volume is expected to increase in the future as raw materials become more difficult to obtain. Mechanical pulping, with its high yield, is viewed as a way to extend these resources. However, mechanical pulping is electrical energy-intensive and yields paper with lower strength than chemical pulps. Kraft pulp is often added to mechanical pulps to impart strength, but it is much more expensive than mechanical pulps. These disadvantages limit the use of mechanical pulps in many grades of paper. Biomechanical pulping, defined as the treatment of lignocellulosic materials with a natural lignin-degrading fungus prior to mechanical pulping, has the potential to ameliorate some of these problems. The reader is referred to several much more comprehensive summaries of the research and development leading to the current status of biomechanical pulping [1-5]. Citations to the original papers and patents can be traced through these summaries.

BIOLOGICAL CHALLENGES

Biopulping is a simple concept, but harnessing lignin-degrading fungi in a commercially attractive process has not been simple. Many biological variables had first to be examined and optimized; major ones included fungus species and strains, inoculum form and size, wood species, chip pretreatments, incubation time, aeration, and nutrients. Each variable had to be examined independently of the others, using the tedious "assay" of making pulp (with energy measurements), making replicated paper handsheets, and measuring several paper properties, including burst-, tear- and tensile strengths, brightness, etc. Thus thousands of time-consuming "runs" had to be completed and the data analyzed to get to the current process. Of the many biological variables, three were paramount: fungus selection, chip surface decontamination, and inoculum.

Fungi. Two fungi were selected from over 600 species: Ceriporiopsis subvermispora and Phlebia subserialis. These are effective with all major pulping woods used in the U. S., as well as eucalyptus species, which are important in other parts of the world. Neither of these fungi sporulates asexually, making spore aerosols a non-issue, but also meaning the inoculum must consist of hyphal fragments. Almost all R and D has been done with C. subvermispora, the efficacy of which was discovered first.

Chip Surface Decontamination. Wood chip surfaces normally are contaminated with cells and spores of many fungi and bacteria. These unwanted microorganisms can hamper biopulping, making decontamination desirable. We discovered that a brief atmospheric steaming of chips (as short as 15 seconds) effectively decontaminates the chip surfaces.

Inoculum. We reduced the required amount of inoculum (macerated mycelial mats from liquid surface cultures) from 3 kg to 5 g or less per ton of wood, which is well within a commercially attractive range. This was achieved by adding an inexpensive and commercially available nutrient source, unsterilized corn (maize) steep liquor, to the inoculum suspension. This additive stimulates fungal growth, making it possible to use a much lower amount of inoculum. Corn steep liquor is produced widely in the United States and other countries where corn is processed.

ENGINEERING AND SCALE-UP CHALLENGES

Once the biological variables were optimized, we turned to engineering process development and scale-up, focusing mainly on chip pretreatment, incubation conditions, and economics. On a laboratory scale (usually 1.5 kg), steaming, cooling, and inoculation were performed in a batchwise fashion. The first challenge was to carry out these three steps continuously on a much larger scale. As previously mentioned, a brief steaming of the chips allows C. subvermispora to colonize and become established on the chips. After steaming, the chips are near 100oC surface temperature. Thus, the chips need to be cooled sufficiently prior to fungal application. The next step in the process is chip inoculation with a suspension containing the fungus, corn steep liquor, and dilution water. Challenges involved in this step included metering the inoculum mixture to give the proper amount of fungus and obtaining the correct moisture content for the chips. An additional challenge was the even distribution of the inoculum over the chips.

The second engineering challenge was maintaining the proper conditions in the chip pile to promote fungus growth. The key variables were the temperature and humidity of the aeration air and the chip moisture content. The fungus has an optimum growth range for each of these variables. Furthermore, the fungus is not self-regulating in respect to any of them. For example, when biopulping was performed in a 1-ton chip pile without forced ventilation, the pile center reached about 42oC within 48 h after inoculation as a result of metabolic heat, the fungus ceased to grow, and no biopulping action occurred in that region of the pile. The use of forced air was explored for controlling temperature and moisture throughout the pile. This required an understanding of the air flow through the chip pile, the heat generation of the fungus, and the changes in the chip structure caused by the fungus (allowing compression and reduced air flow).

Commercial biopulping will involve treatment of about 200 to 2,000 tons of wood chips per day. The gap between laboratory scale and the much larger commercial scale was bridged through a series of experiments, culminating in two 50-ton trials. The scale-up studies demonstrated that: (a) chips can be decontaminated and inoculated on a continuous basis rather than a batch process as was done on the laboratory scale and (b) the process can be scaled as expected from an engineering standpoint.

A treatment system was built based on two screw conveyers that transported the chips and acted as treatment chambers (Figure 1). Steam was injected into the first screw conveyer, which heated and decontaminated the wood chip surfaces. A surge bin was located between the two screw conveyers to act as a buffer. From the bottom of the surge bin, a second screw conveyer removed the chips, which were subsequently cooled with filtered air blown into the second conveyer. In the second half of the second conveyer, the inoculum suspension was applied and mixed thoroughly with the chips through the tumbling action in the screw conveyer. From the screw conveyer, the chips fell into a pile for the 2-week incubation. Equipment of this design was used to treat 50 tons of spruce chips (dry weight basis) with C. subvermispora at FPL at a throughput of 2 tons per hour (dry weight basis). During the subsequent 2-week incubation, the chip pile was ventilated with conditioned air to maintain the proper growth temperature (27-32oC) and chip moisture (50-60% on a wet weight basis) throughout the pile. Figure 2 is a photo of one of the 50-ton trials with the equipment beside it.

Findings from two 50-ton trials and the numerous laboratory and pilot-scale experiments were in agreement: biopulping reduces refiner energy consumption by about 30% and improves strength properties. The resulting biomechanical pulp is darker than pulp made from non-treated control chips, but is readily bleached to a satisfactory brightness using hydrogen peroxide.

Figure 1. Overview of a continuous treatment process for decontaminating, cooling, and inoculating wood chips. The system is based on two screw conveyers with a surge bin between them.

Figure 2. Overview of a 50-ton trial held at the Forest Products Laboratory in Madison, Wisconsin. To the left of the pile are the aeration units, and to the right is the treatment apparatues.

Figure 3. Energy required, for the control and fungus-treated chips from a 50-ton trial, during thermomechanical pulping to produce pulps at about 50 Canadian Standard Freeness.

MILL-SCALE EVALUATION OF FUNGUS-TREATED CHIPS

Control and fungus-treated chips (from one of the 50-ton trials) were refined through a commercial TMP mill producing lightweight coated paper. The fungal pretreatment saved 33% electrical energy (Figure 3) and improved paper strength properties significantly compared to the control. Since biomechanical pulp fibers were stronger than the conventional TMP fibers, we were able to reduce the amount of bleached softwood kraft pulp in the final product (Table 1).

Table 1. Strength and other physical properties comparison

Parameters	Control (50%TMP + 50% kraft)	Treatment (55%TMP + 45% kraft)	
Burst index (kN/g)	2.29	2.39	
Tear index (mNm2/kg)	9.92	10.0	
Tensile index (Nm/g)	38.9	41.2	
Brightness (%)	73.0	69.8a	73.0b
Opacity (%)	85.2	86.4	
Light scattering coefficient (m2/kg)	46.2	47.7	
Drainage time (sec)	8.5	9.9	
Density (kg/m3)	689	610	

aSame amount of hydrogen peroxide was applied in the control and treatment.
bSixty percent more hydrogen peroxide was applied on the treatment. Strength and optical properties were not affected by the use of additional hydrogen peroxide (data not shown).

INDUSTRIAL-SCALE PROCESS FLOWSHEET

The fungal treatment process can fit well into a mill's woodyard operations. Wood is debarked, chipped, and screened according to normal mill operation. The chips are then briefly steamed to eliminate natural chip microorganisms, cooled with forced air, and inoculated with the biopulping fungus. The inoculated chips are piled and ventilated with filtered and humidified air for 1-4 weeks prior to processing (Figure 4).

Figure 4. Overview of the biopulping process showing how the biotreatment process fits into an existing mill's wood handling system.

PROCESS ECONOMICS

The economics of biomechanical pulping look attractive. A preliminary economic evaluation was performed for a 250 ton/day TMP mill. The fungus treatment time was two weeks in a flat-pile geometry. Capital costs to incorporate biopulping technology into this mill are estimated to be $6 to $ 8 million. This preliminary analysis is subject to appropriate qualifications. Capital costs are subject to some variability, in particular the cost associated with integrating a new facility into an existing site. Too, much of the cost basis will be site-specific, depending on the operating conditions at a particular mill. Based on 33% energy savings and a 5% reduction in kraft pulp in the final product, in our analysis, a savings of about $5 million each year can be realized. The cost of additional bleach chemicals was quantified and included in the analysis. The additional advantages of biopulping, such as environmental benefits and pitch reduction, have yet to be quantified [6].

COMMERCIAL VIABILITY ISSUES

Several issues need to be considered in making the final scale-up to the industrial levels. A larger scale operation with a 2-week treatment time would require the routine storage of 14,000 tons of wood for a 1,000 ton per day plant, which is a pile 160,000 m3 in volume. To put that amount of chips in perspective, it would be a pile of chips 100 m long, 40 m wide, and 20 m high. Although some mills do store and manage inventories in these ranges, others may need to make significant changes in their yard operations to take advantage of this technology. As is the case with most new technology, incorporating it into new construction would be much easier than retrofitting. However, the first large-scale operation will probably be a retrofit. Chip rotation has to be controlled with a first-in, first-out policy to maintain a consistent furnish to the pulp mill. However, this would not be seen as a great difficulty for most mills because this strategy is currently used in inventory maintenance.

As the scale of the project increases, the construction of needed equipment will probably become much easier, and will improve greatly with time and experience. However, industrial scale equipment is already available in the required capacity ranges that will suit the purposes of this technology for its initial utilization.

Indoor storage should also be considered as an option for incorporating a biopulping operation into a mill. Enclosing the chip storage/treatment operation will significantly reduce blowing dust, contamination by unwanted microorganisms, and other environmental concerns. Furthermore, better control of the environment for the growth of the fungus would be maintained throughout the year. Enclosing the chip storage would also allow the recovery of the heat produced by the fungus for use in conditioning the incoming air. The geometry of the enclosed storage would also tend to reduce the blower costs. These factors could result in substantial energy savings, especially during the winter months in northern climates.

No adverse effects of lignin-degrading fungi on humans have been reported in the literature. These fungi are natural wood decayers. However, a biopulping operation would entail producing substantial amounts of fungus in a pile on a routine basis. For that reason, C. subvermispora was tested by professionals for toxicity, allergenicity, etc. It was concluded that the fungus is safe for use on a commercial scale. One of the paper companies in the U.S. has hired a professional company to look into the effects of the technology on the environment. The company is currently analyzing VOC's given off during biopulping and comparing them with those from a standard chip pile storage. Runoff water from the pile during mill-scale trials will be tested by professionals. We did not see any leachates coming out of our 50-ton pile, perhaps because of forced aeration used in the trial. It is notable that closely related fungi are actually being used commercially to clean up chemically-contaminated soils.

BIOPULPING OF NONWOODY PLANTS

The preservation of forests and increasing environmental awareness have focused research on exploration of agro-based resources for papermaking [7]. A rapid increase in the use of such resources for value-added products is already occurring in developing countries; with growing environmental and other pressures in the United States, these resources will become increasingly important. Currently the use of agricultural plants for pulp and paper in the United States is almost negligible, although several hundred millions of tons are apparently available [7]. Research done in other laboratories and ours has shown that the fungal pretreatment is very effective on kenaf for both mechanical and chemical pulping processes.

We determined the efficacy of the best biopulping fungus, C. subvermispora, on different non-woody plant materials utilizing different pulping methods. Six different materials were investigated: kenaf, bagasse, corn stalk, wheat straw, rice straw, and flax. Of these, kenaf seems to be the most promising fibrous material. Our results with mechanical pulping of whole kenaf indicated that the fungal pretreatment saved 36% electrical energy and improved paper strength properties significantly compared to the control. During kraft pulping, the fungal pretreatment had a profound positive effect on the resulting brightness; for both whole and bast kenaf biokraft pulps, brightness ranged from 86%-88% compared to 78% to 81% for similarly bleached controls. The mechanical properties of bast kenaf biofibers were close to those of softwood kraft pulp and far superior to those of hardwood kraft pulp [8]. Current research is focused on process optimization, engineering/scale-up, and process economics.

CONCLUSIONS

After 12 years of research, we have established the commercial and economic feasibility of biomechanical pulping. At a pilot scale, we have developed methods for decontamination of wood chips, cooling, and fungal inoculation sequentially in screw conveyers, and controlling temperature and moisture throughout the chip pile. Mill-scale refining of fungus-treated chips from this trial gave results similar to those obtained using the laboratory-scale bioreactors. With this information, a complete process flowsheet has been established for the commercial operation of the process. Based on the electrical energy savings and the strength improvements, the process appears to be economically feasible. The additional benefits of increased throughput, and reduced pitch content and environmental impact improve the economic picture for this technology even further. (Based on the promising results and attractive economics, pulp mills from the U. S., Brazil, Europe and India have made commitments to conduct mill-scale trials at their sites, in the coming months.)

The technology has been exclusively licensed to a U.S. company, Biopulping International, Inc, (BII). The principals of BII are offering mills a "technological package", which includes the patent license, the supply of fungal inoculum, equipment design and construction of the facility, and most importantly, the technical know-how so that interested mills would have to deal with only one company, BII. One of the chemical companies from North America has already agreed to produce and supply fungal inoculum on a commercial scale. An engineering and construction company from Europe has also agreed to provide engineering and construction services, performance guarantees on the equipment, and the capital needed for full-scale implementation of the technology.

It is worth noting that biopulping studies with the non-woody lignocellulosic kenaf have given even more promising results that those with wood.

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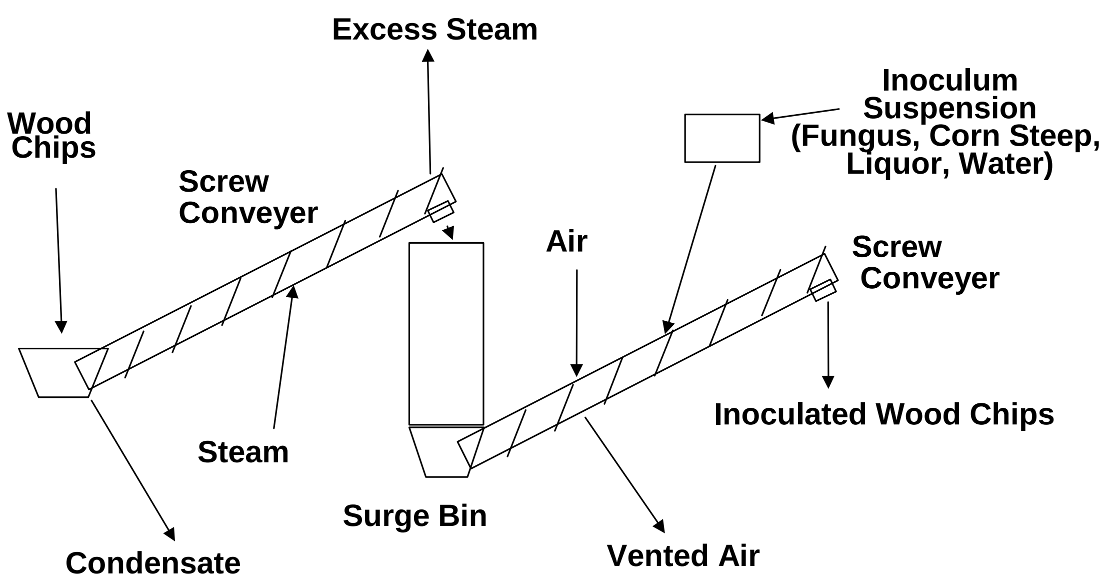

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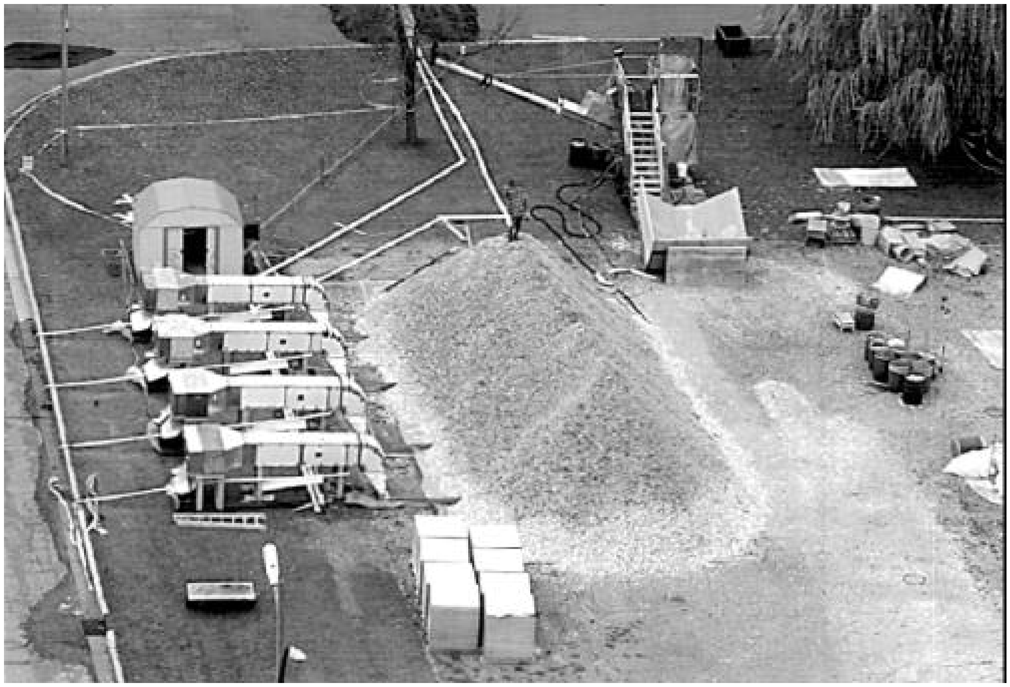

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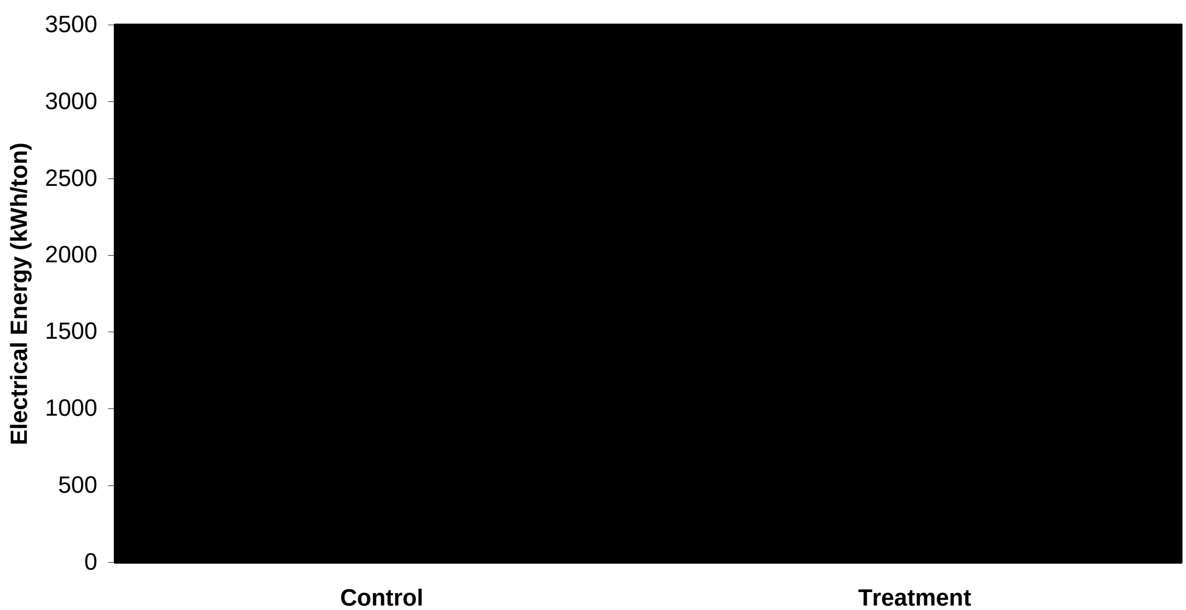

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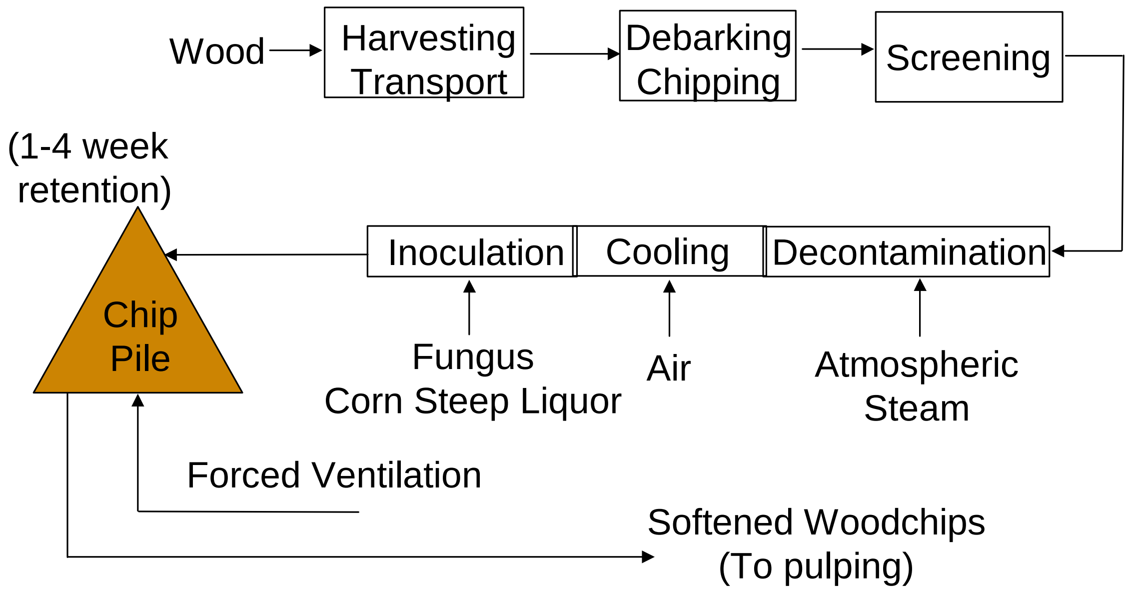

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