***Eucalyptus* Wood Quality Requirements for Pulp and Paper, Charcoal and Biomasss Fuel End-Uses**

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1. Introduction

The wood of the *Eucalyptus* has gained a respectable position as raw material for several utilizations. Thanks to an excellent forestry technology, which was developed in countries like Brazil, Portugal, South Africa, Spain, Chile, Uruguay, Australia, and others, the *Eucalyptus* have reached the status of "super-trees". In a historical first moment, the efforts coming from tree breeding and silvicultural techniques were directed to the production of volume and/or weight in the trees. The acquired productivity would provide the desired competitiveness to the wood-based businesses. Wood specific unit costs and forest operations costs were dramatically reduced by this developed technology. Thanks to the high productivity at the planted forests and to the low production costs, the wood of *Eucalyptus* soon gained importance to several industries, as pulp and paper, charcoal for steel manufacturing, lumber, furniture, and others. This raw material could easily supply fibers and biomass fuel, in unbeatable conditions. In a short period of time, the world quickly became surprised and enchanted with the *Eucalyptus* fast growth rates and wood quality. The quality targets are becoming more and more sophisticated for each of the wood utilizations. In the beginning of this history, the selection of the raw materials was based in productivity (volume or dry weight), yields in the manufacturing conversion processes, and low wood costs. Today, the needs for product differentiation and for adding value in the production chain have oriented the woods and trees to new requirements. Besides the traditional needs for productivity, yields and costs, there are immediately two new and important requirements to the wood: tree and wood uniformities. The control of the forest variability may be seen as a simple task, but it is tremendously difficult. The anticipation to the cloning techniques was very high to the aim for controlling variability. However, the dream for having trees very alike has not been materialized. Although a lot more uniform, the cloned trees show an important level of variability. This happens in the trees and in the wood quality (anatomical, physical and chemical properties).

Today, the foresters have placed attention in the production of trees having good shape, straight trunks, higher shape factors, and low percentage of bark. Additionally, the foresters also consider the resistance of the trees to pests and diseases, and the tolerance to unfair weather conditions (frost, winds, water deficits in the soil, flooding, etc). All these issues are demanding a lot of attention and research. The target for high quality *Eucalyptus* planted forests are not that simple. Even being healthy, with good shape, and fast growth, the trees may not be suitable to some end-uses. For example, marvelous *Eucalyptus grandis* trees, with fantastic growth rates, and tree shapes, may not be well suitable to the production of charcoal. The wood density may be too low for this purpose, the logs very cracked when dried, and the charcoal would be poorer in density, in calorific value per volume, very bulky, and with more generation of fines during manufacturing and handling. On the other hand, wonderful trees of *Eucalyptus robusta* may give low pulp yield in the conversion to kraft pulp due to the excess of extractives and/or lignin.

In short, now it is just the right time not only to have wonderful forests and trees, but also with qualities oriented to the end-uses. A very good forest oriented to the production of charcoal surely will not be so desirable for kraft pulping, since both utilization have opposite requirements in terms of wood lignin content. Whereas for charcoal, the best wood quality is the one with very high lignin content and wood density; for kraft pulping, the lower the lignin the best the wood. The wood density for pulping cannot be very high due to the problems with liquor impregnation.

Although the knowledge for the required wood characteristics are well understood by most researchers, the truth is that we are still finding many mistakes being performed in breeding programs. The major of all these mistakes is the precarious sampling procedure being used in the majority of the tree and wood quality improvement programs. As far as the variability remains high for many qualitative parameters, even for cloned forests, the size of sampling should be larger than it is being used. Additionally to this, the sampling should be more representative, collecting samples from all segments of the population according to their frequency. Today, there is a trend to take few trees with the average volume. Average sized trees are not synonymous of trees with average basic density, or average lignin content, etc., etc. In case a first recommendation has to be made right away, it is related to trees and woods sampling. Definitively, the size and the representativeness of these samples need to be improved. The second recommendation is to increase the number of analyses, the number of repetitions for each of the required quality parameters being evaluated. In general, the analyses are made with a single repetition and the mean value is used in the tree and wood improvement program. Depending on the statistical error that the forest breeder is willing to have as maximum, these numbers of repetitions have to be considerably higher. I dare to assure that there are many analyses being made only to have numbers or to prove that there are things being done. However, the conclusions may be far from the right ones. There are many chances that the breeder is accepting as good a genome that definitively is not for a given property of the tree or wood. This is something that needs to be reevaluated immediately. Until now, these mistakes or statistical errors are not appearing with intensity because they are being hidden by the impact of the cloning, replacing the old stands of forests, with poorer and more variable genomes. In the previous era of the *Eucalyptus* genetic improvement, the variability was a lot more important. Anything that could be done to reduce it, as the cloning technique for multiplication of trees, would show a considerable and visible result. However, we are now funneling the tree and wood breeding, the perspectives of gains are not so impressive, and they are being considered as continuous improvements. In these cases, the analytical evaluations must be a lot more reliable and with better level of confidence.

2. *Eucalyptus* wood quality requirements for the production of kraft pulp

Independently in which pulp mill we are, the pulp sector has as fundamental issues the high productivity, the high operational efficiency (no losses, no problems, no breaks, no stops), the low production costs and the uniform quality of the process and products. For achieving these targets, the raw material must be as uniform as possible, with characteristics in a narrow variation in order not to cause strong impacts in the pulping process and pulp qualities. To tame this variability, the pulp mill engineers are used to blend woods. They don't care to blend very different woods, as far as the result may have a reasonable average quality, in the minimum acceptable. This is not the ideal situation, but it is the most usual.

When the pulp maker ask for uniform wood he is not making a request only for wood basic density. He includes here a number of wood quality parameters that are very important to its conversion process: proportion of bark in the wood chips, wood chip dimensions, decay level of the wood, moisture of the wood, wood chip bulk density, etc., etc. His objective is to have a cooking and bleaching operation with the minimum variability, without undesirable surprises. The final quality must be uniform and within the specification limits, and the losses along the process should be as minimum as possible. When a standardization in the wood intake is searched by the mill manager, he is first trying to guarantee an appropriate quantity of dry wood being fed to the digesters. Since chips are fed by volume to the digesters, it is important to keep chip bulk density as uniform as possible for continuous addition of the same dry weight of wood. The mill manager is making what I call the "management of the wood dry quantity intake to the mill". He is very concerned about this. When an uniform flow of wood dry weight is guaranteed; the liquor, steam, and chemical flows do not sharply change and the process runs evenly. The process and product quality is more easily achieved. For controlling the dry quantity of wood chips, the mill managers do accept blends of woods with different qualities. The first and important goal is not to vary the dry wood feeding flow to the digester.

The second type of management that the mill manager wishes is the variability control. The "management of wood variability" tries to guarantee a narrow variability in the wood and its consequences, as measured by characteristics such as: wood basic density, lignin content, extractives content, active alkali consumption during kraft cooking, bleaching chemical consumption's, yields in the conversion of the wood to bleached pulp, etc. There are other associated goals, as to minimize the overload of dry solids to the recovery boiler, to reduce the specific wood consumption in cubic meters of wood by air-dry metric tons of pulp, to guarantee stable quality and to reduce the production costs.

Management of dry quantities and management of wood variability are really basic physiological requirements in any pulp mill. The mill manager needs to have these needs fulfilled to go further in the next type of management: the "management for product differentiation", or "tailor making orientation in the manufacture of products". This type of management requires substantial changes and offers important challenges to the mill personnel. The changes may happen in wood quality (for example: low and high basic density woods), process conditions (for example: ECF or ECF-Light bleaching sequences), or even others recently added qualities (certified or non-certified wood). Differentiation of products is more easily achieved in mills with more than one fiberline. This means that the mill may run each fiberline with a differentiated product, without experiencing the usual troubles with transitions from one product to another using a single fiberline. Anyhow, the tailor making concept only will be winner when the pulp maker has guaranteed the two first mentioned types of management: dry quantity and variability. It is very simple to say, but very difficult to understand and to implement. For this reason, many conflicts and misunderstandings are frequent between the commercial, production and product innovation areas in a pulp mill. Each of these areas has their own needs and dreams about product uniformity, product uniqueness, and product differentiation. In most of the cases, each area has difficulties to understand the other side's position. As a result, few *Eucalyptus* pulp mills have products that may be said completely differentiated in their products portfolio. Most of the market pulp manufacturer aims to have a single product, as uniform as possible, with the minimum cost, and maximum in productivity and in operational efficiency. Having in mind that the behaviors, needs, commitments and purposes are different, what is really important to promote a culture for tailor making in market pulp mills? What is important to be managed? How to do this? What properties in the wood may be successfully controlled to offer differentiation in products? What are the most important wood parameters that the mill manager should care about? And the commercial director? What about the R&D manager?

It is relatively difficult to say what is the single most important wood characteristic for a given pulp mill. The reason is that there is not a universal wood property to be managed. Depending on the pulp mill bottleneck, the wood quality is defined to guarantee the maximum performance to this mill The most common bottlenecks are the capacities of digester, recovery boiler, drying machine, lime kiln and causticising, pulp washing, pulp bleaching chemicals. As a conclusion, it may be said that the type of mill bottlenecks will define the most desirable wood quality. This is the case for existing mills. For new greenfiend mills, the quality may be previously built at the forest. However, soon the mill starts up, and the bottlenecks will appear to define the new wood quality standards. This is the reality, no doubt about. This is also the cause of domestic conflicts within the company.

A list of important properties of the *Eucalyptus* wood that may impact the kraft pulp production process is now referred, with some comments for each of the properties:

- <u>Wood cleanliness</u>

This is an item not very clear to many forest managers, who try to mechanize their operations to reduce costs and do not realize the impacts on wood cleanliness. It is very important to pulp mill that the wood be as clean as possible in terms of bark, soil, leaves, stones, decayed wood, etc.

- <u>Wood basic density</u>

To the pulp maker, the uniformity on wood density is very important. More uniform is the wood in this respect, better and simple is the management of the quantity and of the variability. In case the mill has a design capacity that allows to use light woods, the mill manager even like this, because lighter woods are easier to be impregnated with cooking liquor, and demand lower alkali charge. However, when the digester is bottlenecked, the mill manager wants a denser wood to be managed to raise mill production in the digester. Again, the kind of bottleneck is the source of specifications for the wood quality. When the mill solves the bottleneck, the search for new wood quality specifications restarts again. Something that upsets the forest breeders, who many times do not understand the reasons for these changes on wood quality specifications. Pulp mills are short-term oriented and forest breeders are long-term. The conclusions and behaviors are very different in both cases. It is mainly due to a bottleneck effect that some mills prefer to use low density wood (0.40-0.45 g/cm³), other medium (0.50 – 0.55 g/cm³) and other love high density (0.55 – 0.60 g/cm³). And it is also for this reason that *Eucalyptus* pulps from different suppliers are not alike. Some are more recommended to an end-use better than others.

- <u>Active alkali consumption and pulp yield</u>

These variables are vital. They are consequence of many wood characteristics as lignin, extractives, ash, density, *Eucalyptus* species, tree age, etc. The pulp maker wants to manufacture more and better, without overload its production process. For this reason, the wood quality improvement needs to be oriented to these process qualities in pulp manufacturing.

- <u>Specific wood consumption</u> (m³/adt = cubic meters of wood by air dry ton of pulp)

This consumption is the result of many inter-connected wood and kraft process variables: wood basic density, pulp yield, decay of wood, process losses of fibers, wood chipping operations, etc. The specific consumption of the wood is responsible for important fraction of the pulp cost, Wood is the main component on pulp production cost, even in low-cost wood countries. For this reason, this is one of the most vital indicators to the mill manager. All qualitative wood characteristics that may impact the wood specific consumption are welcome to be optimized.

- <u>Lignin content and lignin type</u>

Lignin is abundant in *Eucalyptus* wood, mainly in those planted in Brazil. The total lignin content in the Brazilian *Eucalyptus* varies from 24 to 32%, relatively high for hardwoods. This affects the pulp yield in the conversion to kraft pulp, as well as the consumption of active alkali and the generation of dry solids to the recovery boiler. There are *Eucalyptus* species with lower lignin contents, and the wood in this respect is more appropriate in pulping operations. *Eucalyptus globulus* and *Eucalyptus dunnii* are well known for this. In comparison to *E.urograndis*, *E.urophylla*, *E.grandis* and *E.saligna*, they offer woods with 2 to 8% lower in total lignin based on dry wood. For this reason, the tree breeders in the world are trying to combine in hybrids for cloning these wood characteristics in association to the fast growth rates of the other species. Gains in wood specific consumption, alkali charges and pulp yield are significant. As a rule, for 1.2 - 1.5% in lignin reduction in the wood, the kraft pulp yield increases 1% based on dry wood. The active alkali consumption reduces around 0.2 - 0.3% for the same lignin reduction. This is definitively a new road for hybridization and cloning, without any need for genetic modification to insert genes for low lignin in the wood. At the same time, in Portugal, the purpose is to keep the purity of *E.globulus*, and to improve the forest productivity in volume as much as possible through genetic and silviculture. With this in mind, the Portuguese foresters are willing to improve the productivity of *E.globulus* in equivalent tons of pulp per hectare.year. In Brazil, this quality indicator shows *Eucalyptus* commercial planted forests with 9 to 15 adt/ha.year, while in Portugal the *E.globulus* forests have 6 to 8 adt/ha.year. Even with growth rates not very high, the *E.globulus* trees are offering a competitive raw material thanks to the wood basic density, lignin content and pulp yield. On the other hand, not only the quantity of lignin in the wood is important, but also its quality. The lignin with high syringyl/guaiacyl ratio offers easy cooking and pulp bleaching. Guaiacyl type lignin is more difficult to be removed by the chemical reactions. This ratio in Brazilian *Eucalyptus* varies from 2 to 3, and in Portuguese *E.globulus* it may go from 2.5 to 6.

- <u>Extractives content</u>

The extractives are undesirable in the pulping process because they impact on pulp yield and in contamination of pitch to the process and in the final product. The total extractives content in the *Eucalyptus* woods varies as a function of species, age, silvicultural stresses, pests and diseases, etc. Values are variable as much from 1.5 to 6%. There are several ways to express extractives since the methodology implies to extract them with a solvent (water, caustic soda, ethanol, toluene, dichlormethane, etc). In all cases, lower the extractives, better it is to the pulping, bleaching and cleanliness of the final product.

- <u>Ash content</u>

The woods are rich on mineral elements. These minerals are absorbed by the trees as nutrients. When the wood is harvested, the minerals are exported from the soil to the mills. Minerals are measured in the wood as ash content, after burning the sampled wood as sawdust. Ash content in *Eucalyptus* wood varies from 0.3 to 1.0%, being the most important minerals the calcium, potassium and magnesium. With the trend to close the water cycles in the pulp mills, these minerals are able to build up in the systems, bringing enormous problems with incrustations, pitch formation, formation of "stones" in the recovery boiler, etc. Ash content is very variable among the *Eucalyptus* species. For this reason, it is an important parameter for tree breeding. When low ash content woods are selected, the exportation of nutrients from the soil is minimized. The trees are more efficient to form wood using or immobilizing less minerals in their tissues. These minerals, also known as non-process elements, leave the pulp mills as pollution (solid residues, air pollution particulate or dust, and dissolved ions in liquid effluents). This means that a fantastic natural resource is transformed into pollution, in mills not oriented to prevent or to develop clean production techniques for controlling and recycling these minerals. For this reason, the emphasis today is to prevent the intake of minerals into the mils, both those in the wood composition, or as contaminants (soil, stones, etc). Bark is also very rich in ash (about 5 to 10 times richer in ash content than wood). The contamination of logs and chips with bark brings additional amounts of minerals to the mill process, what it is a real problem to the pulp making.

3. *Eucalyptus* wood quality requirements for the production of paper

All these wood characteristics and related consequences mentioned till now they favor the pulp mills in their targets for productivity, costs and efficiency. However, they are only part of the wood features to be evaluated. *Eucalyptus* pulp is a raw material for the manufacture of several grades of papers. For each paper grade, and for each paper mill design, different are the wood and pulp quality requirements.

It is important to mention that, independently of the type of the manufactured paper, all the papermakers have what are know as basic physiological needs. These needs are similar to those from the pulp manufacturer. The targets are alike in both cases: productivity, operational efficiency, quality, and costs; no matter the paper is being made or the paper-machine is being used.

Productivity requires fast speed in the paper machine, fast drainage in the wet end, high consistency after wet presses, and minimum number of paper sheet breaks along the machine. Quality implies in maximum percentage of paper in the specification range and minimum generation of broke. Machine operation efficiency is the dream of any paper manufacturer. He wants his machine working smoothly, at the maximum speed as possible, no breaks, and achieving the required quality in the manufactured products. The consequence of all this is that the specific unit cost is also here optimized. No doubt that a good pulp is the one able to provide good paper-machine runnability and appropriate quality in the end product.

Some of the pulp properties are very much related to these performances. For this reason, the papermaker keeps an eye on them. Some of these properties are result of the wood quality, other depend on the conversion of wood to pulp (cooking, bleaching), and many are a combination of these two factors influencing the pulp quality. For example, some properties that are related to pulping and bleaching are: viscosity and degradation of cellulose chains, fiber deformations and individual fiber strengths, surface charges in fibers, etc. One very important pulp property that is related to wood quality and pulp conversion is the hemicellulose content in the pulp. This content depends on how high is the content in the wood and in the ability of the pulping process to preserve them in the fibers.

There are many pulp properties that are dependent both on wood quality and on pulping/bleaching processes. There are also many cases where the exigencies are placed a lot on the wood quality, when the wood is not the only factor to determine the pulp quality for paper. It is the case of properties as: WRV – water retention value, WWS – wet web strength, fiber bonding and individual fiber strength. There are many other properties related not only to the wood quality. For example, the fine content of the pulp. Fines in the wood are mainly parenchyma cells, but in the pulp they are also fiber fragments that are generated in operations such as wood chipping, pulp pumping, pulp dynamic mixers, pulp dewatering presses, etc.

As a rule, there are some physiological properties that any pulp has to fulfill to be loved by papermakers. They are related to the following:

- <u>Drainage in the wet end section in the paper-machine</u>

  This behavior is very much affected by the fiber population (number of fibers per gram of pulp), by the initial or refined pulp freeness (drainability of the pulp measured as Canadian Standard Freeness or Schopper Riegler degree), by the Water Retention Value (hydration and swelling ability of the pulp furnish), and by the fine content in the pulp furnish.

- <u>Paper sheet strength along the paper-machine, mainly at the wet end and press section</u>

  This sheet behavior is very much dependent on the individual fiber strength, fiber bonding, furnish contaminants (shives, sand, solid debris, etc), and consolidation of the paper web. Individual fiber strength is related to fiber wall thickness, fibril angle, fiber deformations and micro-fractures, and *Eucalyptus* species.

As far as the physiological needs are achieved, the papermaker feels enthusiasm to work for differentiation of products. Differentiation implies in different products to be supplied to different markets or customers. One of the most important ways to reach differentiated products is through the control of the wood quality. The genetic improvements on the wood quality may, not only help to reach the physiological needs in the pulp and paper manufacturing, but also to provide very different pulp fibers to be supplied to the manufacture of different products. This is what is known as to tailor making the wood to the end product. The following wood and pulp quality parameters are important drivers in the differentiation of paper products:

- <u>Fiber population or the number of fiber per gram of pulp</u>

The fiber population is related to the weight of each individual fiber, and by extension to the fiber coarseness and to the percentage of fiber wall in the fiber volume. There is a number of fiber properties associated to fiber population and fiber coarseness: fiber wall fraction (ratio between cell wall thickness and fiber ray), Runkel index, fiber flexibility index (ratio between the lumen diameter and fiber diameter), index of fiber collapsibility, ratio fiber wall thickness and fiber perimeter, wood basic density, and fiber length.

It may be shortly said that pulps with lower fiber population show better drainage in the wet end, and the paper sheets are more porous, bulkier, more permeable and absorbent. They are very much appreciated by papermakers because they allow faster machine speeds, as far as the furnish may impart enough strengths to the wet paper sheet.

- <u>Individual fiber strength</u>

This fiber characteristic is very difficult to be measured in short fibers as those from *Eucalyptus*. There are tests correlated to this strength, as the zero span, very useful for predicting pulp quality and behavior at the pulp-machines.

- <u>Fiber bonding ability</u>

This test is measured by the wet/dry zero span technique or by other equipment for bonding tests, as the Scott bond tester. It is also related to the hemicellulose content of fibers, fiber population, fiber drainability (CSF or SR), fiber fines content and fiber collapsibility.

- <u>Fiber swelling</u>

This fiber property is very affected by the pulping and bleaching operations during pulp manufacture, and by the pulp hemicellulose content. Several properties are associated to the swelling of fibers:

water retention value, fiber charges, fiber wall micro-porosity, fiber wall micro-fractures.

- Fiber deformations

The deformations in the fibers are measured as curl index, fiber kinks, fiber latency, and fiber micro-fractures in the cell wall. They affect the fiber strengths, but they provide substantial improvements in the paper sheet porosity, bulk, smoothness and water absorption.

Finally, after providing the right furnishes to the paper manufacturer, he is able to add runnability to his machine and to go sleeping without any nightmare. However, according to the grades of paper he is manufacturing, he is demanded to have differentiated properties in the final product. *Eucalyptus* pulps are special products to the manufacture of bulky and/or opaque papers. Today, *Eucalyptus* pulps are preferred raw materials in the manufacture of tissue, printing and writing, carton-boards, industrial filter, impregnation based, cigarette and many other papers. *Eucalyptus* fibers may be the sole fiber in the pulp furnish or to be part of a blend with other short and/or long fibers.

Tissue papers demand softness, smoothness, absorption, bulk and the exact strength to provide machine runnability and very fast drainage in the wet end. Bonding is a poison up to a certain extent. The fibers cannot collapse because this will flat the paper surface, the paper becomes stronger in tensile, but all the tactile properties are lost. Pulp fines are also undesirable for two reasons: fiber bonding and building up in the paper-machine white water system, reflecting in losses of drainability. The most indicated *Eucalyptus* fibers for tissue manufacture are those showing: low fiber population and consequently high coarseness, low fine content, low bonding ability, low hemicellulose content, high bulk and water absorption in the paper manufactured sheets. Fiber deformations are also important, since these deformations improve the bulk, porosity and absorption of these papers. An important issue to remember is that fiber deformations may be artificially created in the pulp mills. The manufacture of industrial filter papers, and impregnation-based papers are demanding the same properties, but in a higher level. This means, to go to these specialty paper markets, the differentiation must be even more pronounced. The simplest way to work in differentiated pulps to these very specialty markets is to work towards very high coarseness (low fiber population, what means high wood basic density), low hemicellulose content, and to intensify fiber deformations (by high consistency presses, fiber shredding, or pulp flash drying).

For printing and writing papers, the desirable paper properties are: formation, paper strength, porosity, dimensional stability and opacity. At the same time, the papermaker wants to keep the machine runnability. We should never forget about the physiology of the papermaking. A higher fiber population is welcome for improved opacity, associated to a lower fiber coarseness. Also, fiber bonding is important to improve strength. Hemicellulose and pulp fine contents do help in this task. However, there are limits to all this and the limits depend on each paper-machine system and operation. A very high fiber population may be wonderful to improve opacity and formation, but drainage in the wet end and consistency after wet presses may be deteriorated, and machine speed reduced. The papermaker is to refuse this pulp. He wants quality and runnability both aligned, remember this. Fiber deformation here may not be so important, but they may help to balance the pulp properties, since it may be created by machines. Higher contents of hemicelluloses are welcome because they favor refining, bonding, consolidation of the paper web, and strength properties (tensile, burst, tear, folding). An ideal pulp should have high strengths at the low levels of refining. This indicates the possibility to have strengths and bulk / porosity at the same time in the paper sheet. The papermaker don't like to refine a pulp very hardly: he is raising energy costs, reducing the life of refiner discs, and deteriorating machine drainage, machine speed, steam consumption and a very important paper property that is dimensional stability. Definitively, the best pulps are those showing good strengths at low levels of refining. Papermaker is very sensitive to this. Having this, he is also optimizing paper bulk and porosity. Besides these properties, there is another wood anatomical characteristic very important to the printing grade papers: vessel elements content and vessel dimensions (specially the diameter). Large, wide and numerous vessels are undesirable for P&W papers. They are responsible for a printing defect known as vessel picking. The papermaker needs to have special conditions to combat the vessel-picking tendency in the paper. For these reasons, a wood with smaller vessels and not so abundant is preferred. The same for the corresponding pulps.

There are many other grades of papers manufactured with *Eucalyptus* pulps. In most of the cases, the *Eucalyptus* fibers are used to improve paper formation, opacity, smoothness, dimensional stability, bulk and porosity. The *Eucalyptus* fiber population in the pulps, and their rigid and difficult to be collapsed fibers are important properties loved by the papermakers. There is another key driver to papermakers for using *Eucalyptus* fibers: the market pulp prices of this fiber. Thanks to the low production costs, high pulping yield and lower chemical and wood consumption, these pulps are in general less expensive than softwood pulps. No doubt that production costs are also key issues for papermakers. The same to the entire *Eucalyptus* pulp and paper production chain.

Eucalyptus pulps have today gained the status of the most admired fiber supply. They are growing in an unbeatable rate in the paper world business. They may be used as the single fiber in the furnish or blended with others, such hardwoods, softwoods or recycled fibers. Wood and fiber quality improvements due to genetics, silvicultural operations and conversion process optimization may contribute to even further worldwide appreciation of the *Eucalyptus*.

4. *Eucalyptus* wood quality requirements for wood charcoal manufacturing and biomass fuel

Brazil has had enormous success in the utilization of *Eucalyptus* biomass as firewood and to the wood charcoal production. The first biomass fuel-oriented forest plantations were based on high wood density *Eucalyptus* species, as *E.paniculata*, *E.camaldulensis*, *E.tereticornis*, *Corymbia citriodora* and *C.maculata*. Wood basic density is a fundamental wood characteristic because it leads to better quality charcoal, and more calorific value per volume of wood or charcoal. However, as important as the wood density, the goal is to reach the maximum possible production of dry biomass (trunk, branches and bark) per hectare, as forest growth rate. In case an *Eucalyptus* species leads to high-density wood, but its growth rate is poor, the production of total biomass may not be attractive. For this reason, the wood biomass segment has directed its efforts to the diversification of species, and hybridization. Today, there are more species involved and being used in the forest breeding: *E.cloeziana*, *E.pellita*, *E.urophylla*, and hybrids, as the *Eucalyptus urograndis*. These species are adapted to grow in tropical regions of Brazil, where the pests and diseases attacks are more frequent, due to higher temperature and humidity. In case the wood charcoal production would migrate to temperate regions, there are other species very suitable as: *E.dunnii, E.viminalis, E.benthamii, E.saligna, E.globulus,* and hybrids.

It is important to mention that wood density is a key property, but there are other wood characteristics that are important to the destination of a wood for fuel purposes. The trees should be as straight as possible to favor the feeding of the charcoal ovens or biomass furnaces or chippers. The bark content is required to be as minimum as possible, since the wood for energy is not debarked. The *Eucalyptus* bark, comparatively to the corresponding wood, has as a rule a higher percentage of minerals, and lower carbon content, basic density and calorific value. Furthermore, the high phosphorous content in the bark may disturb the utilization of this material to the manufacture of some grades of charcoal.

Complementing what has been said, the following wood properties are welcome to be included in a forest breeding program for biomass fuel wood and charcoal manufacture:

- <u>Wood basic density and forest growth rate</u>

  It is essential the optimization of these two key parameters at once. Faster growth and higher wood density are welcome, and the goal is the maximization of dry biomass production per hectare.

- <u>Lignin content, lignin composition and carbon content</u>

  The lignin calorific value is higher than the obtained from the cellulose and hemicelluloses carbohydrates. The carbon content in lignin is somewhat higher than in the wood carbohydrates. For this reason, higher the lignin content, higher the carbon content, and better is the wood for fuel. The ratio syringyl/guaiacyl is another point to be worked. Guaiacyl lignin is richer on carbon content than syringyl. This means that, contrarily to the wood for pulping, the wood for energy needs the syringyl/guaiacyl ratio as lower as possible.

- <u>Ash content</u>

  Wood minerals do not generate heat, by contrary; they consume the heat during combustion for increasing their temperature for nothing. They also reduce the carbon content of the wood and bark based on dry weight content. Both wood and bark are requested to have as minimum as possible their ash content.

- <u>Volatile extractives</u>

  The charcoal production implies in substantial dry weight losses. The usual yields when manufacturing charcoal with *Eucalyptus* wood varies from 30 to 40%. Many types of wood extractives are very volatile and they are lost in the exhaust flue gases from the controlled combustion. Depending on the manufacturing process, the extractive content of wood and bark may be important to the charcoal yield.

- <u>Wood moisture</u>

  High-density woods have lower moisture due to the fact that they have less open spaces or porosity to hold water. For this reason, they are easily dried to become ready for consumption as fuel raw material. Fast speed drying is a good quality parameter for wood selection. In any case, lower the wood and bark moisture, better is the raw material suitability as biomass fuel.

- <u>Anatomical composition of the wood</u>

  It has been proved that the woods that are rich on vessel elements and parenchyma cells are less recommended for charcoal manufacturing. They are in general lower in density, and these anatomical elements are responsible for giving origin to more friable and poor quality charcoal.

- Fissured and cracked logs

It is very important that the logs have good dimensional stability, with the minimum cracks and fissures. These wood defects give origin to higher fine content in the charcoal, and lower yield as consequence, since fines have to be screened out from the charcoal to improve its quality.

5. Final conclusions

Woods may be engineered and improved by selection, genetics, and silvicultural operations. For maximization of results, it is important to know and to understand the parameters that are important to be improved. They need to show good heritability and to add value to the conversion processes and to the end-use products. Sound planning, representative sampling, high quality evaluation and data interpretation are vital to the success of any wood quality improvement program. A lot of the today's success may be attributed to the excellent opportunities offered by the hybridization and cloning techniques. Wood basic density has been the most important quality parameter being used to predict wood quality. However, wood density is not the unique wood characteristic. There are many others. Another point to remember is that wood basic density is a very good parameter to compare only the woods that are alike, from the same species, or with similar behavior for a given utilization. For example, even with the same wood density, two very different species of *Eucalyptus* may show very different behavior in the pulping and papermaking ability. An *Eucalyptus saligna* wood with 0.5 g/cm³ usually shows a completely different performance than an *Eucalyptus robusta* wood with exactly the same wood basic density.

As a final remark, it should be interesting to try to find reasonable answers to some of the questions:

"What procedures and cares does the tree breeder need to have to avoid errors and misinterpretation of his data?"

"What are the roads for a continuous success in the future, based on new technological jumps and continuous improvements?"

"How to combine the demands arising from the forester, the pulp maker, the paper maker, the end-product consumers and the users of biomass fuel?"

Definitively, there are many roads to walk in the direction to the future. We need to be efficient and efficacious in the guidance of the improvement programs. These programs are supposed to be the key to the continuous competitiveness of the *Eucalyptus* as source of raw materials to the industry. Although we may feel we are doing a nice job today, we need to do a lot more, now combining not only economic and quality issues, but also environmental and social performances. These new roads are demanding new additional challenges, and because of this, science, technology, knowledge and goodwill are to be soundly matched.

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